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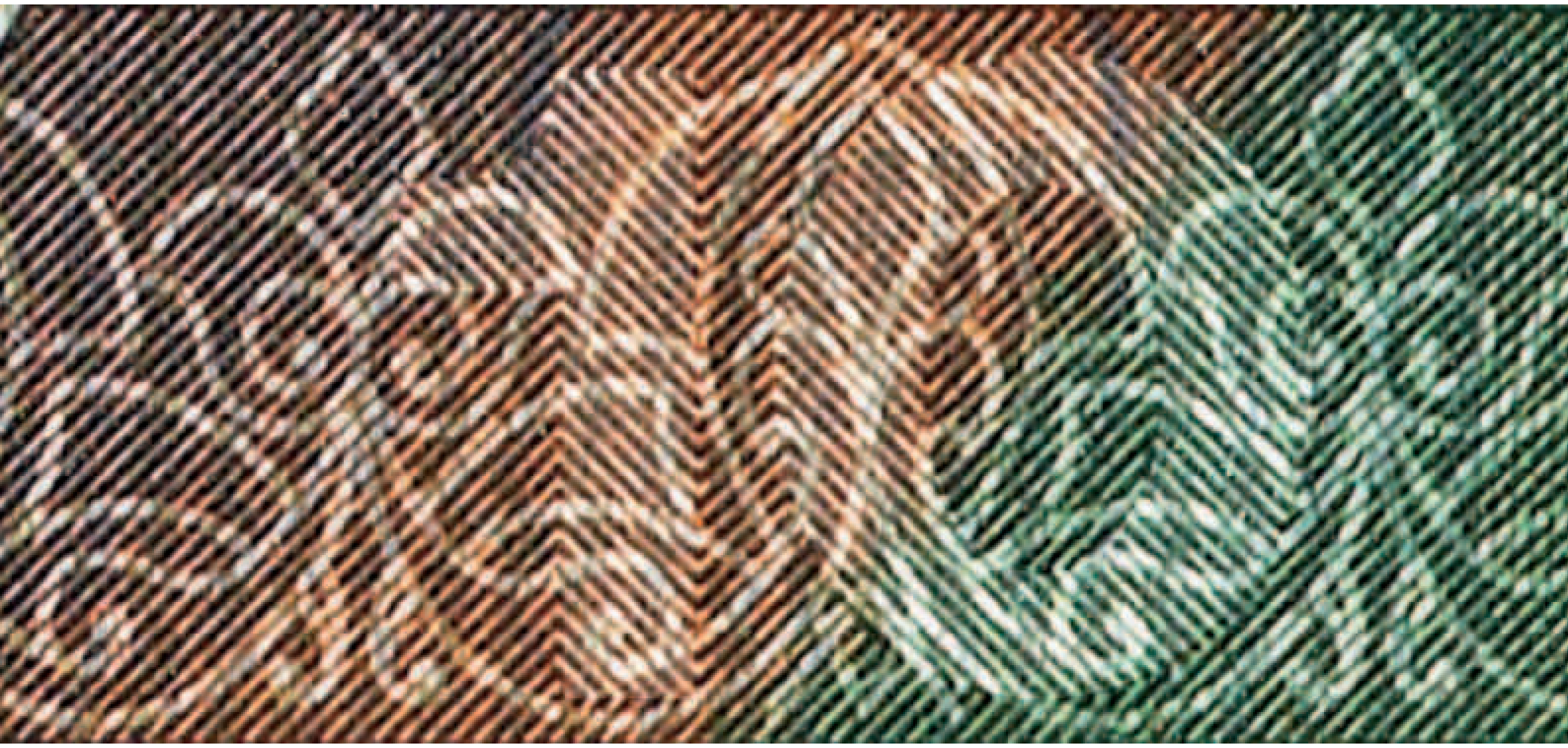

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Abstract

This study presents estimates of the optimal level of aggregate Tier 1 capital ratio in the Polish banking sector. The analysis takes into account macroeconomic benefits of raising Tier 1 capital ratio and macroeconomic costs related to it. The main macroeconomic benefit from a higher capital captured in the study is a higher resilience of the banking sector and consequently a reduction in the likelihood of a banking crisis. The benefit of higher capital ratios is expressed as the product of a decrease in the likelihood of a crisis and the expected cost of a crisis. The latter was calibrated based on the literature review. The probabilities of crisis for different levels of capital were calculated based on probit models estimated on macro data and a simulation model reflecting some of the main features of the banking sector in Poland. The SVAR model estimated on data for the Polish economy was used to assess the scale of the slowdown in GDP growth due to a rise of capital ratios. The net effect of an increase of capital ratios, expressed as a percentage of GDP, reflects the difference between their expected benefits due to the reduction in the probability of a crisis and their economic costs in the form of a decrease in the expected GDP growth rate. The level of Tier 1 ratio, at which the net effect, i.e. the difference between benefits and costs of raising capital ratios, is the largest, is called optimal from a macroeconomic perspective. The results indicate that the optimal level of aggregate Tier 1 ratio is in the range of 11%-23% with the expected value derived from this analysis and the literature at the level of 18%.

Keywords: financial crisis, macroprudential policy, bank capital, banking sector regulation

JEL: G01, C25

1 Introduction

The study presents estimates of the optimal level of Tier 1 capital ratio in the Polish banking sector. The study takes into account the macroeconomic benefits of increasing the aggregate Tier 1 capital ratio and costs associated with it. The net effect of an increase of the capital ratio is calculated as the difference between those benefits and costs. The value of Tier 1 ratio, at which the difference between the benefit of increasing the capital ratio to this level and costs associated with it is the biggest (the largest net effect), is called optimal from a macroeconomic perspective.

The main macroeconomic benefit of an increase in the banking sector's Tier 1 ratio is better resilience of the financial system to negative shocks and the probability of a banking crisis, which has a negative impact on the growth rate and level of GDP, is reduced.[1] Estimates of the costs of banking crises are subject to considerable uncertainty – they range from about 20% of pre-crisis GDP to over 150% – but even with optimistic calculations they remain high. Consequently, even a small reduction in the likelihood of crisis entails relatively large benefits. On the cost side of higher capital levels, the literature indicates possibility of an increase in the cost of financing for banks, which leads to an increase in interest rates on loans and a slowdown in lending, which in turn slows down GDP growth.[2]

The net effect of higher capital ratios depends on which factor prevails – the benefits of increasing the system's resilience and reducing the likelihood of a crisis, or costs in the form of increased costs of credit and other banking services and, consequently, slowdown of economic growth.

To make judgement about the benefits and costs of increasing Tier 1 capital requirements, it would be necessary to take into account changes in the aggregate surplus of Tier 1 capital in the banking sector over the level of requirements. If we assume that the voluntary buffer (in percentage terms, i.e. in percentage of risk-weighted assets) will not change, the results of this

[1] BIS (2010), Yan et al. (2012), Brooke et al. (2015).
[2] BIS (2010), Miles et al. (2013), Yan et al. (2012), Noss and Toffano (2016), Meeks (2017).

study (regarding the aggregate Tier 1 ratio maintained by the banking sector) could easily be translated into the level of Tier 1 / RWA capital requirements.

The research methodology is the following – benefits and costs are analyzed in different classes of models and then the net effect is calculated. Details of the approaches used, and results of the study are presented in the next chapters of the document. Chapter 2 outlines the methodology of the study, Chapter 3 describes the benefits of higher capital ratios, Chapter 4 their possible costs, Chapter 5 presents the net effect of an increase of capital ratios, and Chapter 6 answers the question about the optimal level of Tier 1 ratio in the Polish banking sector. The last part summarizes the study. The methodological appendix contains technical details regarding the models.

2 Methodology

When analyzing the benefits and costs of higher Tier 1 ratios, the starting point was the level of Tier 1 capital to the risk-weighted assets (RWA) equal to 8.5%.[3] The costs and benefits related to an increase of this ratio by 0.5 p.p., 1.5 p.p., 2.5 p.p. etc. up to 30%, were estimated. Estimates were made on the aggregate level, not for individual banks.[4]

The net effect of increasing the aggregate Tier 1 capital ratio by x p.p. was calculated as follows:

$$\boldsymbol{Net\ effect} = Expected\{\boldsymbol{Benefits} - \boldsymbol{Costs}\} =$$

$$\left\{\begin{matrix} [Probability\ of\ a\ crisis\ when\ Tier\ 1\ ratio\ is\ equal\ to\ 8.5\% \times Cost\ of\ a\ crisis\ (in\ \%\ of\ GDP)] - \\ [Probability\ of\ a\ crisis\ when\ Tier\ 1\ ratio\ is\ equal\ to\ (8.5+x)\% \times Cost\ of\ a\ crisis\ (in\ \%\ of\ GDP)] \end{matrix}\right\}$$

$$-\ \{Cumulated\ \Delta\ GDP\ due\ to\ an\ increase\ of\ Tier\ 1\ ratio\ by\ x\ p.p.\ (in\ \%\ of\ GDP)\}$$

The macroeconomic benefit from reducing the risk of a crisis is due to the fact that banking crises are very expensive - on average, the cost of a banking crisis is (according to the median from the world's research) about 63% of pre-crisis GDP. As an example, if an increase in the Tier 1 capital ratio from 8.5% to 9% means a 2 p.p. reduction in the likelihood of a crisis, then the macroeconomic benefit amounts to at least 1.3% of GDP (0.02 x 63% of GDP) per year. For ten years and with a discount rate of 3%, this gives a total benefit of around 8% of current GDP. If the cost of a crisis was further reduced, e.g. thanks to the reduction of the government's contribution to the possible recapitalization of the banking sector and the reduction in moral hazard in the financial sector, the benefits would be even greater. At the same time, banks' increase of capital may lead to temporary restraints in lending and a decline in GDP growth. The difference between the above-mentioned benefits and estimated costs is equal to the expected net effect of an increase in capital ratios over a specified time horizon.

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[3] According to the CRR and CRD IV, the minimum requirement for Tier 1 capital is 6% of risk-weighted assets. It was augmented with a mandatory conservation buffer of 2.5% RWA, which must be met with Common Equity Tier 1 capital (CET 1). Therefore, the net effect of an increase of capital ratios was calculated against the initial level of 8.5% Tier 1/RWA. The same starting level was adopted in the study of Brooke et al. (2015).

[4] It means that the initial level of Tier 1 ratio equal to 8.5% should be treated as an aggregate level of Tier 1 capital to RWA in the entire banking system.

In this study, the level of aggregate Tier 1 ratio that was consider optimal is the one for which the excess of benefits over the costs associated with an increase of Tier 1 ratio to this level, is the largest. The most important assumptions made for the purpose of calculating the net effect of an increase of Tier 1 ratio are related to the impact of higher capital ratios on:

- **the scale of reduction in the probability of a banking crisis** – economic research indicates that there is a drop in the risk of the financial crisis associated with an increase in capital ratios (BIS (2010), Barrel et al. (2009), Kato et al. (2010), Yan et el. (2012), Brooke et al. (2015)). The more pronounced this effect is, the greater are the benefits associated with it. In this study when calculating change in the likelihood of a crisis, the fact that each bank maintains Tier 1 ratio at a slightly different level was not taken into account. Estimates were made for the aggregate capital ratio.
- **the scale of reduction in the cost of a banking crisis** – the greater the decrease of the cost of a crisis associated with higher capital ratios is, the greater are the benefits of stronger capital position of banks. No matter whether this effect is included or not, the assumptions related to the banking crises temporarily affecting or permanently lowering GDP trend, are extremely important. The magnitudes of crisis cost estimates in these two cases differ significantly. The greater the cost of a crisis is, the greater are the benefits of increasing the capital ratio. In this study, the baseline scenario did not take into account the effect of the reduced cost of a crisis due to the better capitalization of a banking sector. However, the impact of the assumption regarding crisis cost on the sensitivity of the results was examined and the details are presented in the appendix.
- **the scale of an increase in the cost of financing in the economy, reduction in loan availability and ultimately GDP growth slowdown** – strengthening banks' capital position may lead to an increase in their financing costs and, consequently, to credit and GDP growth slowdown (BIS (2010), Brooke et al (2015), Miles et al (2013), Angelini et al. (2011), Barrel et al. (2009), Berrospide and Edge (2010), Yan et al. (2012)). The more pronounced this effect is, the greater are the macroeconomic costs of increasing capital ratios. In this analysis, the impact of banks' heterogeneity on financing the economy was not taken into account and the banking sector was analyzed at an aggregate level.

Assumptions related to the time horizon in which benefits, and costs are analyzed are also important. If the benefits from the reduction in the expected costs of crises are permanent and the costs in the form GDP growth slowdown are temporary, extending time horizon of the analysis increases the benefits associated with an increase of Tier 1 capital ratio. Discount rate is the factor influencing the relationship between short – and long-term effects – the higher the discount rate is, the less important long-term effects will be.

An important modelling assumption is that macroeconomic costs related to an increase of capital ratios are linear in relation to the scale of this increase. It is also assumed that the costs are the same regardless of which level of Tier 1 ratio is treated as the starting one, e.g. costs in the form of a GDP growth slowdown related to an increase of the aggregate Tier 1 ratio from 8.5% to 10.5% are the same as if the increase was from 16%[5] to 18%.

Reduction in the likelihood of a systemic banking crisis

There are theoretical and empirical reasons to argue that increasing banks' capital ratios decreases the likelihood of a banking crisis. The study takes into account the possibility of a non-linear relationship between the change of capital ratios and the probability of a crisis. Two complementary approaches were used for this purpose - probit models with random effects estimated for a large group of countries and then applied to Poland and a simulation approach calibrated for the Polish banking sector. Details are described in the first part of Chapter 3.

Reduction in the cost of a banking crisis

There are also strong premises to recognize that increasing the resilience of banks not only reduces the likelihood of a crisis, but also crisis costs. The BIS study (2015) indicates that, firstly, greater resilience of banks reduces the pressure on an increase of government spending during the crisis due to a smaller scale of bail-out needed. Secondly, along with a decrease in expectations regarding the fiscal costs of future crises, the yield on government bonds may decline, which directly or indirectly affects the cost of loans granted to the private sector.

[5] The aggregate Tier 1 to risk-weighted assets ratio of the Polish banking sector (excluding Bank Gospodarstwa Krajowego) in the 4th quarter of 2017 was equal to 16.23%, and this value inspired the choice of a number in the example.

Following BIS (2010), this study assumes that an increase of capital ratios will not affect the cost of a crisis, but only its probability. Such assumption reduces the expected benefits from an increase of capital ratios and thus, from the point of view of a question about the appropriateness of increasing capital ratios, it should be treated as conservative. As part of the sensitivity analysis, the impact of introducing the assumption of lower costs of a crisis was examined. Details on the assumptions regarding the cost of a crisis are described in Chapter 3.

Time horizon of the analysis

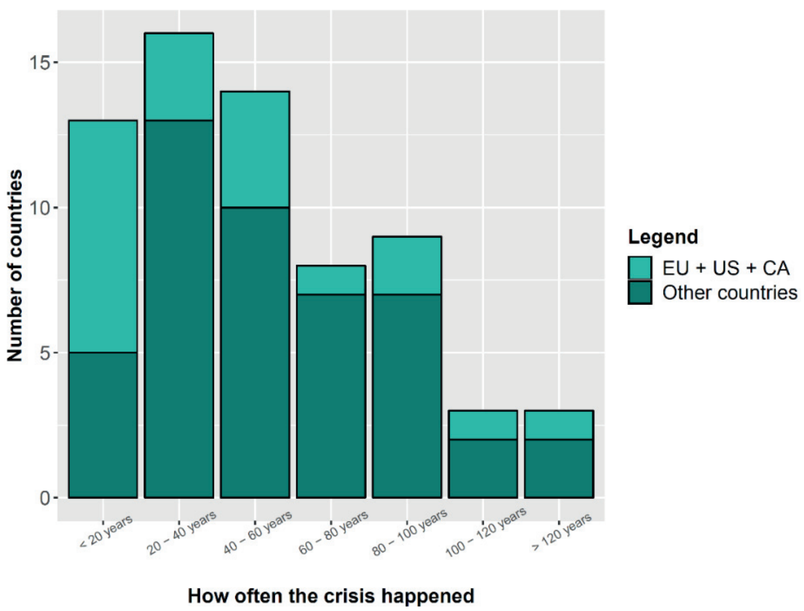
Since in this analysis the benefits related to a reduction in the probability of a crisis are permanent, while the costs in the form of a GDP growth slowdown are temporary, extending the time horizon of the analysis increases the positive net effect of raising Tier 1 ratios. However, along with an extension of the time horizon, the scale of uncertainty around results increases in a way that is difficult to quantify. Making an assumption, that economic relations estimated on the basis of historical data and a simulation taking as a starting point the current structure of the banking sector in Poland and the current macroeconomic situation will be preserved not only over the next several years but also decades, is difficult to defend. Therefore, it seems reasonable to adopt a time horizon coherent with the one of macro-prudential policy. The time horizon of 10 years, which is in line with the estimated length of the financial cycle in Poland, has been adopted for this study. In the first three years, the value of the discount rate is equal to the growth rate of potential GDP from the NBP inflation projection from March 2018, and beyond that time horizon, the value from the last year of the projection.

3 Benefits from an increase of capital ratios

As mentioned earlier, expected benefits from an increase of capital ratios can be expressed as a product of the scale of a reduction in the probability of a systemic banking crisis due to stronger capital position of banks and the cost of a systemic banking crisis expressed as a percentage of GDP.

According to historical data collected by Reinhart and Rogoff (2009), a banking crisis occurred on average (according to the median) every 44 years (among 66 developed and developing countries). For European countries, Canada and the United States, the median frequency was 26 years (Figure 1). This number indicates that in European and developed countries crises were not rare events - the probability of a banking crisis was on average around 4% per annum.

Figure 1. Number of countries according to the frequency of banking crises.



Source: Own estimates based on Reinhart and Rogoff (2009).

Notes: the analysis was carried out for 66 countries (including 18 European countries). Horizontal axis illustrates the historical frequency of banking crises in this sample of countries. Frequency of crises for a given country was obtained by dividing the number of banking crises that have occurred since the country was established (or since 1800, if it existed before) by the number of years until 2008.

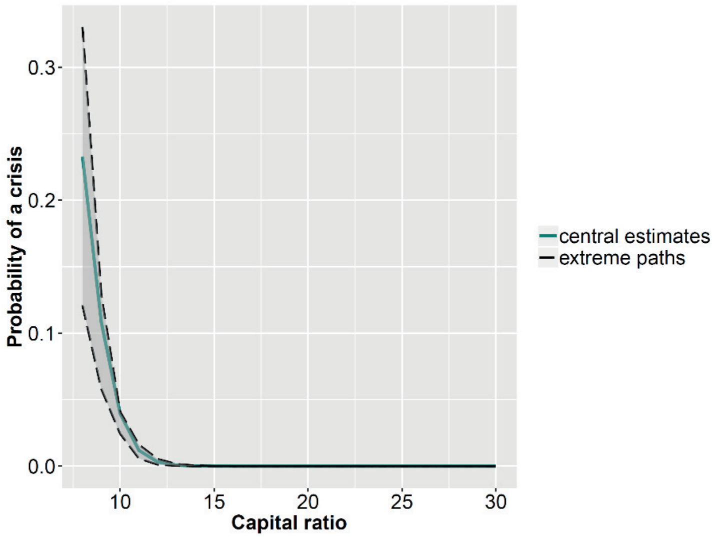
Changes in the likelihood of a crisis for different levels of capital ratios in the banking system were estimated based on two complementary approaches: a macroeconomic model and a simulation that uses bank level data from several dozen countries. Conclusions from each approach were analyzed in separation, as well as in the form of an average of the two. Decision to employ different models was aimed at reducing the impact of assumptions on the final results and thus increasing the reliability of estimates.

In the first approach over 3,000 probit random effects models were estimated for quarterly data. Each of them was intended to explain the binary variable describing the occurrence of systemic banking crises in 45 economies[6] in the period 1970Q1-2017Q4. The set of variables with a data source list, is presented in Table 2 in Appendix I. Random effects probit models were estimated using the data for all countries in the sample (including those which have never experienced a crisis). The advantage of models of this class is the fact that they allow for the inclusion of factors that are time-invariant and specific to a given country, i.e. individual effects. Technical aspects of model class selection, as well as the process of testing the models and narrowing their number to 8 models, are described in Appendix II.

Tier 1 capital ratio (level of Tier 1 capital to risk-weighted assets) was in the set of explanatory variables in all the models that were tested. Bayesian Model Averaging showed that aggregate Tier 1 capital expressed as a percentage of risk-weighted assets is an important variable influencing the likelihood of a crisis. Limiting ourselves to models that contain the Tier 1 capital ratio among regressors was therefore proven to be justified. Due to the short time series for the variable Tier 1/RWA, in the models containing this variable, only the recent global financial crisis was effectively taken into account. The probability of a systemic banking crisis for various Tier 1/RWA levels for the baseline model specification, together with extreme scenarios, is presented in Figure 2. The remaining variables were left at the level of those for Poland in the third quarter of 2017.[7]

[6] European Union and OECD countries (apart from Chile, Israel and New Zealand) as well as Brazil, China, Indonesia, India, Malesia, Russia and Thailand were included in the sample.
[7] Due to delays in the publication of data for most variables at the time of making calculations the most recent observations were the ones from the third quarter of 2017.

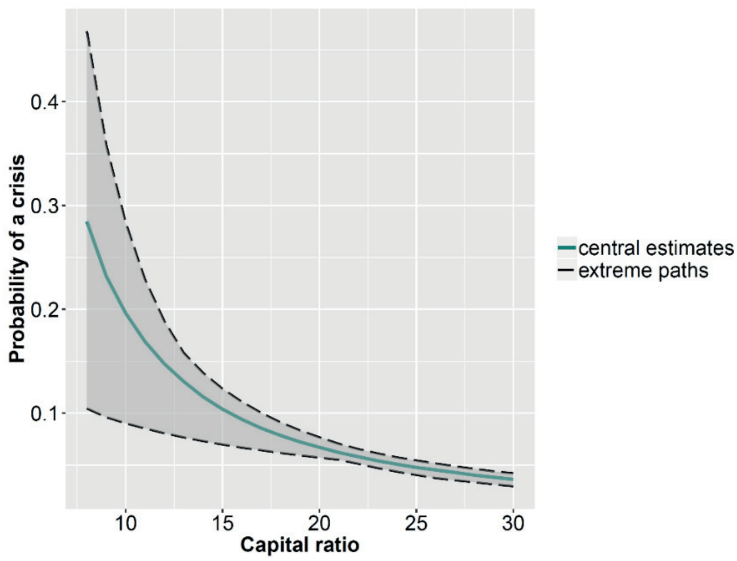
Figure 2. Probability of a systemic banking crisis for various levels of Tier 1 capital in relation to RWA. Probit models.



The limitation of probit models is the low percentage of countries in the sample for which capital ratios before the crisis exceeded 15%. As a result, model uncertainty associated with the probability of a crisis for these values of capital ratios is greater. The simulation approach described below allows to partially overcome this limitation.

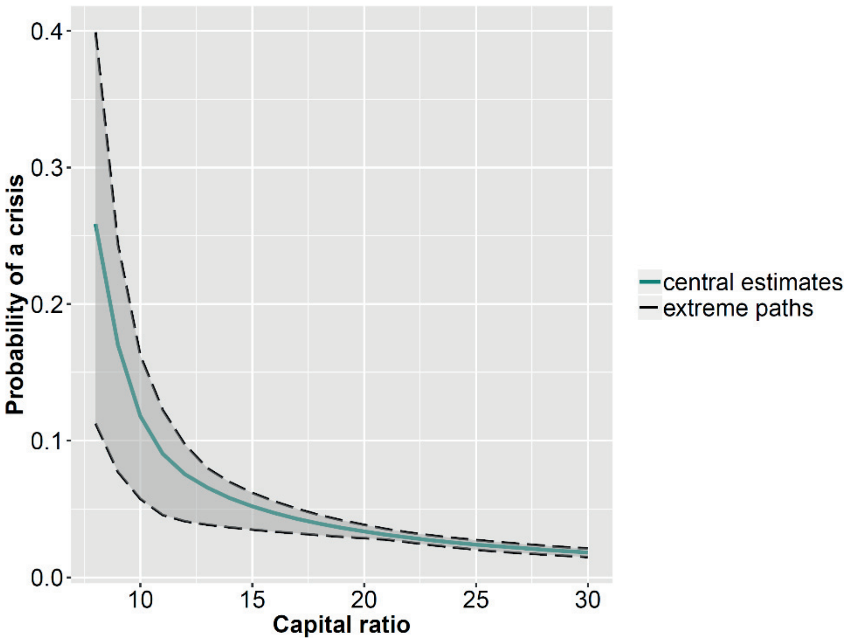
The second approach simulated the probability of a systemic banking crisis based on data for individual banks from OECD countries and the European Union. Those banks have been selected whose business profile is similar to the ones operating in Poland (e.g. investment banks were excluded from the sample). The empirical distribution of profits and losses expressed in relation to risk-weighted assets was determined for the set of available banks. It was assumed that this distribution represents the distribution of profits and losses for each bank in Poland. Values for profits and losses for all banks in Poland (i.e. the entire banking sector as an aggregate) were simulated by drawing repeatedly from this distribution and allowing different structures of dependencies between the incomes of individual banks - from weak dependencies to strong ones, including the possibility of strong dependencies in the tails of the distribution or lack of it. For this purpose, Gaussian copula and t-copulas with different degrees of freedom and correlation coefficients were used. Details of the procedure are described in Appendix III. After repeating draws for various hypothetical capital ratios of the banking sector (from 8.5% to 30% Tier 1/RWA), the frequency with which the systemic crisis occurred (the ratio of the number of crises generated and the number of draws) was calculated. The systemic crisis was defined as a loss of excess capital over the regulatory minimum equal to at least 8% of this surplus for the entire banking sector. This threshold was set based on a logit model estimated on a sample of 45 economies (the same countries as in the approach based on macroeconomic data), where the dependent variable was the banking crisis, and the explanatory variable was the excess of Tier 1 capital over the regulatory minimum. The probability of a systemic banking crisis for various Tier 1/RWA levels, along with extreme scenarios reflecting different dependency structures, is presented in Figure 3.

Figure 3. The probability of a systemic banking crisis for various levels of Tier 1 capital in relation to RWA. Simulation approach.



Figures 2 and 3 illustrate that the probabilities of a systemic banking crisis calculated in the simulation approach are higher than probabilities estimated using probit models. Judging by the number of assumptions adopted in the construction of the simulation model, it seems reasonable to be cautious when approaching the results regarding the optimal level of capital, in which the part concerning the probability of a crisis is based only on simulation. For this reason, averaging results from both approaches, i.e. from probit models and the simulation, seems to be the right solution that at least partially reduces the modeling risk. The average probability[8] of a systemic banking crisis for various Tier 1/RWA levels along with extreme scenarios is presented in Figure 4.

Figure 4. Probability of a systemic banking crisis for various levels of Tier 1 capital in relation to RWA. The arithmetic average of the probabilities from the approach based on macroeconomic data and from the simulation.



Costs of crises

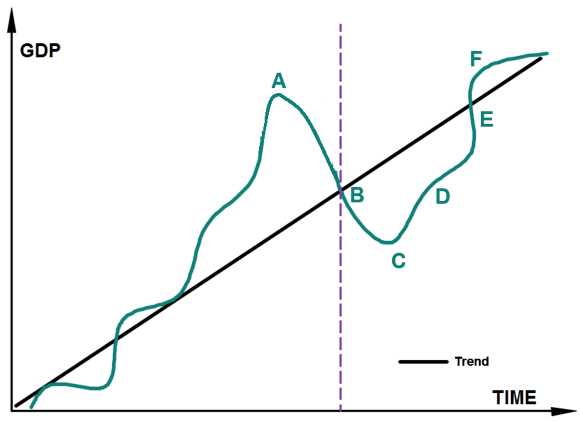
Estimates of the costs of banking crises were adopted from the literature (BIS, 2010). Those studies were considered, whose authors calculated the cumulative loss of GDP due to the crisis (or for which it is possible to calculate cumulative losses). Following the BIS study (2010), two approaches to calculating crises costs that can be found in the literature were adopted. In the first one GDP losses during the crisis[9] are estimated, while in the second one it is assumed that

[8] Probit models potentially underestimate the probability of a crisis for high capital ratios (values higher than 18 were very few in the sample). On the other hand, the simulation is based on a larger number of empirically unverified assumptions. Having no reason to consider one of the approaches as better, probabilities from both approaches were averaged with weights equal to ½.

[9] The method for dating crisis periods varies depending on the study. Laeven and Valencia (2008, 2010, 2012) focus on the level of GDP in the first four years of a crisis. Hoggarth et al. (2002) rely on expert judgement when dating the beginning and end of a crisis. Cecchetti et al. (2009) mark the end of a crisis as a moment when GDP level returns to the one from before the crisis, while Haugh et al. (2009) assume that a crisis ends when GDP returns to its pre-crisis trend.

the crisis lowers the GDP trend. In the latter case it means that infinite time horizon should be considered. These two alternative hypotheses regarding the behavior of GDP during and after the banking crisis are illustrated in Figures 5 and 6. There is no clear consensus in the literature as to which hypothesis is correct. As a result, it was decided to be neutral in this respect and in the baseline analysis the median of all studies was adopted for the calculations (median of the crisis costs equals to 63% of current GDP). The studies in question are presented in Table 4 in Appendix IV. Additionally, in the sensitivity analysis, medians from the studies presenting the two approaches (median of crisis costs equal to 19.5% assuming the transitional effects of a crisis and 158% when considering the infinite horizon) were considered. Like in the case of estimating the likelihood of a crisis, the adoption of different scenarios, as well as the median of them, aims to reduce the impact of individual assumptions on the results and thus increase the reliability of the final estimates. The results of the sensitivity analysis are presented in Appendix VIII.

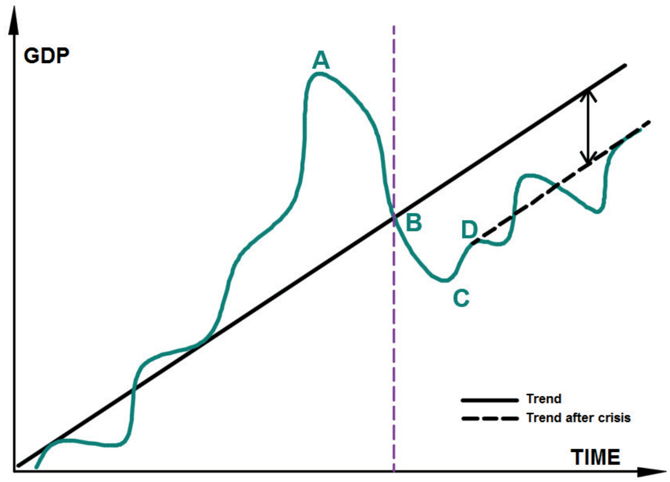
Figure 5. The GDP path resulting from a crisis, assuming that the crisis does not affect the GDP trend.



Source: adopted from Brooke et al. (2015)

Notes: point A in the graph corresponds to the peak of the business cycle before the crisis, point B - the beginning of the crisis, point C - the crisis through, point D - the moment in which the GDP growth rate equals the trend GDP growth rate, point E - GDP returning to the level corresponding to the pre-crisis peak of the business cycle, point F - the return of GDP to the pre-crisis growth path.

Figure 6. The GDP path resulting from a crisis, assuming that the crisis affects the GDP trend.



Source: adopted from Brooke et al. (2015)

Notes: point A in the graph corresponds to the peak of the business cycle before the crisis, point B - the beginning of the crisis, point C - the crisis through, point D - the moment in which the GDP growth rate equals the trend GDP growth rate.

Since the same variables, including banks' capital, may affect both the probability and the cost of the crisis, separate estimation of these effects may lead to their overestimation. For this reason, in the baseline scenario the entire effect of an increase in capital ratios is recognized in the changed probability of a crisis.

A possible extension of this study is to take into account the impact of an increase of capital ratios on the expected cost of a crisis, i.e. together on the probability and cost of the crisis. In the current study the baseline scenario, in which the cost of the crisis is not reduced, should be treated as conservative. It probably underestimates the benefits associated with an increase of capital ratios. However, in the sensitivity analysis, optimal level of capital ratio was determined assuming different costs of a crisis (Chapter 6 and Appendix VIII).

4 Costs related to higher capital ratios

In addition to the potential benefits of increasing capital ratios in the form of a limited probability of a systemic banking crisis, improving capital position by banks may also generate costs. Literature indicates that it may lead to an increase in banks financing costs, and consequently, to limited lending and slowdown of the GDP growth.[10]

A structural model of vector autoregression (SVAR) estimated on quarterly data for Poland from 2004Q1-2016Q4 was used to express the potential costs related to an increase of capital ratios as a percentage of Poland's current GDP. Reaction of model variables to the shock in the form of an increase of the aggregate Tier 1/RWA ratio of 1 p.p. was examined. Since the shock response is linear with respect to the shock scale, the estimate of the drop in the annual real GDP growth rate resulting from an increase of Tier 1/RWA ratio by any value can be obtained by multiplying the central path of the GDP response to a standard shock of 1 p.p. by this value (scale of change of the capital ratio). In the pessimistic scenario (high costs), the lower bound of the confidence interval (95%) of the impulse response function was taken instead of the central path.

Changes in the real GDP growth rate corresponding to the rescaled impulse response function over the three-year horizon were referenced to the projected real GDP growth rate for 2018-2020 from the NECMOD model. For the horizon of 4 to 10 years (inclusive), a constant growth rate of real potential GDP from the last available projection period (2020Q4) and a fixed value of the rescaled impulse response function from the 12th quarter were taken. The GDP loss over the three-year horizon obtained in this way was discounted by the rate of real GDP growth from the NECMOD model and in the next years by the growth rate from the last available quarter of the GDP projection. Subsequently, the discounted loss was expressed as a fraction of the real potential GDP from 2017. In this way, the cumulative macroeconomic cost resulting

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[10] BIS (2010), Brooke et al. (2015), Miles et al. (2013), Angelini et al. (2011), Barrel et al. (2009), Berrospide and Edge (2010), Yan et al. (2012). At the same time, forces acting in the opposite direction can occur. One of them may be the reduction of contributions to the Bank Guarantee Fund (BGF) due to a better capitalization of banks. It may have a positive impact on lending. It is worth noting, however, that in 2017 the total contribution to the BGF slightly exceeded 2 billion PLN, which is a relatively small amount in comparison to the value of banking sector assets in Poland. In addition, the weight of Tier 1 capital in the calculation of the contribution to the BGF is only 9%, which significantly limits this effect. Therefore, it was not included in the study.

from an increase of the aggregate capital ratio, expressed as a percentage of the current real GDP, was obtained.

Alternatively, it was assumed that after three years, the costs associated with an increase of Tier 1 capital ratio would be zero. Adopting such an assumption is justified by the fact that the time horizon of GDP projection from the NECMOD model is three years and that, with time, the uncertainty around the estimates of the impulse response function increases. Analyzing the 3 and 10-years scenarios should address two issues. On the one hand, the adoption of a short time horizon for costs (i.e. 3 years) is more model-based but leads to a potential overestimation of the net effect in the next years. Extending the time horizon of the analysis to 10 years is more difficult to justify when SVAR model is employed, but on the other hand it allows symmetric treatment of costs and benefits. Consideration of those two scenarios allows to determine the impact of the time horizon for cost analysis on the overall results and the optimal level of capital.

Technical aspects of the SVAR model estimation and the results obtained from it were included in in Appendix V *Impact assessment of higher capital requirements on economic growth*.

5 Net effect of an increase of capital ratios

The net effect of an increase of capital ratios was calculated according to the formula presented in Chapter 2. It comes down to the difference between the expected benefits, which are the greater the more severe the banking crisis is and the more the probability of its occurrence decreases, and the expected costs, in the form of a transitional slowdown in GDP growth due to increased costs of financing in the economy.

$$\text{Net effect} = \text{Expected benefits} - \text{Expected costs}$$

It was assumed that the benefits resulting from higher capital ratios will have a lasting impact on the distribution of GDP in the future, i.e. they will affect GDP in each of the years in the time horizon of the analysis. On the other hand, costs are assumed to be short-term. Extending the time horizon increases uncertainty about benefits in a manner that is difficult to quantify, as structural and macroeconomic changes that will likely take place in the next several or several dozen years are not taken into account. Therefore, it seems reasonable to limit the time horizon, which in this study remains consistent with the time horizon of macro-prudential policy. It was assumed that the macroprudential policymaker's perspective extends 10 years into the future, which corresponds to the upper bound of the estimated length of the financial cycle in Poland.

In the baseline scenario it is assumed that the cost of a crisis is equal to 63% of current GDP,[11] and the probabilities of a crisis at different capital ratios of the banking system correspond to the average of central scenarios from probit models based on macroeconomic data and from the simulation (see footnote 8).

The technical aspects of calculating the net effect of an increase of capital ratios are presented in Appendix VI.

[11] Median value from studies that assume transitional impact of a crisis on GDP and studies, which assume that the crisis lowers the GDP trend.

6 Optimal Tier 1 capital ratio of the Polish banking sector

The level of the Tier 1/RWA, at which the surpluss of the expected benefits from an increase of this ratio to this level over costs (i.e. the net effect) is the greatest, we call *optimal* from a macroeconomic point of view. Following the employed methodology, it is possible to calculate the net effect of raising capital ratios from any starting level by any value. According to the CRR and CRD IV, the minimum requirement for Tier 1 capital ratio is 6%. It has been topped up by a mandatory conservation buffer of 2.5% of risk-weighted assets and it must be covered by Common Equity Tier 1 capital (CET 1). Therefore, the net effect of an increase of capital ratios was calculated against the initial level of Tier 1/RWA equal to 8.5%. The same starting level was adopted in Brooke et al. (2015).

Figure 7 shows the net effect of a capital ratio increase in an approach, in which the probability of a crisis is the average of probabilities from the probit models and the simulation. This effect corresponds to a gradual increase of the aggregate Tier 1 capital ratio from 8.5% to 9%, 10%, 11%,... up to 30%. Figures 16 and 17 in Appendix VII present the results for probit models and simulation separately.

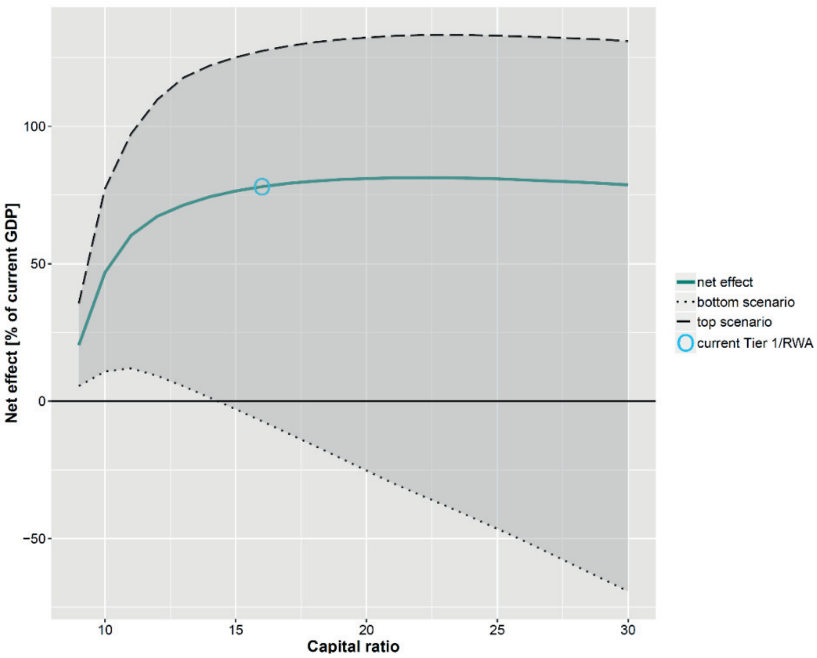
Lines depicting central estimates and extreme scenarios for the net effect were obtained under the following assumptions: cost of a crisis equal to 63% of pre-crisis GDP, [12] time horizon of the analysis equal to 10 years, costs of increasing capital ratios non-zero over the entire ten-year period and discount rate equal to GDP growth rate projected from the NECMOD model.[13] The scenario marked with a green line was obtained using the baseline estimates of the likelihood of a crisis and the central path of the impulse response function from the SVAR model. The scenario depicted with a dotted line (low probabilities of a crisis) was constructed using lower path for probabilities of a crisis from probit models and the lower bound of the

[12] As in the baseline scenario BIS (2010), it is is equal to the median of results from studies assuming a temporary impact of the crisis on GDP and studies, which assume that the crisis lowers the GDP trend.
[13] In periods exceeding the time horizon of the projection, discount rate is equal to the last available GDP growth rate from the projection.

confidence interval of the impulse response function from the SVAR model (high costs of raising capital ratios). The scenario marked with a dashed line was created using crisis probabilities at the higher end of the spectrum considered (high probabilities of a crisis) and the central path of the impulse response function from the SVAR model.

In Figures 7, 16 and 17 the level of Tier 1/RWA corresponding to the aggregate capital ratio of the Polish banking sector at the end of 2017 is marked with a blue circle. Capital ratio for which the parabola achieves its maximum corresponds to the level of the aggregate capital ratio, at which the net effect of increasing it from 8.5% to this value, is the largest. Increasing the capital ratio further is associated with the benefits that grow more slowly than costs.

Figure 7. Net effect of increasing Tier 1/RWA from 8.5% taking the average from probit models and simulation as the probability of a crisis.



Notes: the value of the net effect, expressed in % of the current real GDP of Poland, illustrated on the vertical axis is relative to the reference point for the capital ratio, which in this study is equal to 8.5%. Due to reference point being arbitrary, one should rather look at a change in the net effect between two points on the graph, measured by the difference in their y-axis values, rather than on their absolute values from the vertical axis.

Using the average of probabilities from probit models and simulation, the largest net effect from an increase of Tier 1 ratio is achieved with values of Tier 1/RWA being between 11% and 23%. This range is determined by the vertices of parabolas illustrated in Figure 7 (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of an increase of capital ratio. If for calculating the probability of a systemic banking crisis the results of only probit models are taken into account, the optimal level of Tier 1/RWA ratio in none of the scenarios exceeds 13% (see Figure 16 in Appendix VII). Using only probabilities obtained from the simulation it can be as high as 29% (see Figure 17 in Appendix VII).

As described in Chapter 4, the adoption of a 10-year time horizon for costs allows symmetrical treatment of costs and benefits from an increase of capital ratios, but it is difficult to justify for the class of SVAR models. Therefore, in an alternative variant of the analysis, it was assumed that costs expire after three years. Figures 18-20 in Appendix VII illustrate the net effect when taking the likelihood of a crisis as an average of the results from probit models and simulation, probabilities only from probit models and only from simulation respectively. In comparison to the base variants only one assumption was changed: costs of increasing capital ratios expire after three years. In this case, the limits of the range for the optimal capital ratio (x-axis values of the parabola vertices in Figures 18-20) are shifted to the right in comparison with the base variants. In the approach with the average probability of a crisis the interval lies between 12% and 31%.

In the simulation approach in the scenario, where the costs of increasing capital ratios are non-zero over the entire ten-year horizon, net benefits from raising capital ratios are nondecreasing in almost the entire spectrum of analyzed ratios (8.5% - 30% Tier 1/RWA). One might be tempted to say that based on this approach, it might be reasonable to set minimum capital requirement for Tier 1/RWA at the level close to 30%. However, there are costs of raising capital requirements that for technical or natural reasons could not be taken into account in this study. The main one seems to be regulatory arbitrage, which may result in an outflow of capital to countries where regulations are less severe. Banks whose parent companies are foreign entities may change the legal form of their subsidiaries (so-called *branchification*), which will make them subject to capital requirements set in the country of their parent company.

However, it is extremely difficult to determine the level of the requirement, above which such effects can take place.

What is more, the research method used to analyze the costs of increasing capital ratios implies a short-term nature of costs.[14] However, there are reasons to believe that following changes in capital ratios, in the long run the economy will reach a new steady-state that is different from the previous one. The analysis of long-term adjustments would require the employment of a different class of models, e.g. DSGE (dynamic stochastic general equilibrium) models. Due to the importance of the assumptions related to the model selection, the results obtained for the Polish banking sector were combined with the results of studies, which used various model assumptions, for other countries.

Comparison with other studies

For the ease of comparison of the results with the literature, Table 1 provides estimates of the optimal capital ratio obtained in other studies. Some of them are country specific, some other like the BIS report (2010) and the postulates of Admati and Hellwig (2013) are more universal. It should be noted that in various studies results can be expressed in different capital measures (CET 1, TCE etc.), hence they are not always directly comparable. To ensure their comparability, they were converted into a common measure - Tier 1/RWA[15] (see the last column of Table 1). Almost all studies referred to in Table 1 indicate the range, in which the optimal capital ratio is located. According to some studies it is quite a wide range.

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[14] Vector autoregression models are used for medium-term analyzes. In the long run the impulse response functions come back to zero. In the baseline scenario of this study, to mitigate the effect of the model assumptions on the results, it was assumed that costs of increasing capital ratios will be non-zero over the entire ten-year period. For years from 4 to 10, the value of the scaled impulse response function from the 12th quarter from the SVAR model was adopted. Alternatively, it was assumed that after 12 quarters costs are equal to zero.

[15] To bring various capital ratio measures (CET 1/RWA, TCE/RWA, capital/assets) to a common Tier 1/RWA measure, the approach adopted in BIS (2010) was followed. For banks from each country or group of countries (depending on the sample used in a study), regression was run, in which the dependent variable was Tier 1/RWA of the given institution and the independent variable was the capital ratio used in the study. Quarterly bank level data from the S&P Global Market Intelligence database from the period 2002Q1-2018Q1 was used, after removing outliers. Outliers were defined as those for which Tier 1/RWA was higher than CET 1/RWA or TCE/RWA or for which the value of the dependent or independent variable was below the 1th percentile or above the 99th percentile of its distribution. Following BIS (2010), pooled regression (and without a constant) weighted by values of bank assets was used. The estimated coefficient next to the explanatory variable was adopted as a scaling factor to rescale original results reported in Table 1. Since scaling factors were obtained from a simple pooled regression with time invariant coefficients and without taking into account individual effects for banks, results of the rescaling should be treated with caution.

Table 1. Results of research on the optimal level of capital in the banking sector.

Author	Country, on which the study is focused	Capital ratio measure	Optimal level of capital ratio	Optimal level of capital ratio (expressed as Tier1/RWA - see footnote 15)
BIS (2010)	Universal	Tier 1/RWA (conversion rate for euro area)	14%-20%+	14%-20%+
de Ramon et al. (2012)	United Kingdom	Tier1/RWA	Tier 1/RWA corresponding to the Basel III minimum could be increased to 28% before the positive net effects were exhausted	Tier 1/RWA corresponding to the Basel III minimum could be increased to 28% before the positive net effects were exhausted
Yan et al. (2012)	United Kingdom	CET1/RWA	10%	11%
Miles et al. (2013)	United Kingdom	CET1/RWA	16%-20%	19%-24%
Brooke et al. (2015)	United Kingdom	Tier1/RWA	10%-14%	10%-14%
Sveriges Riksbank (2011)	Sweden	CET1/RWA	10%-17%	11%-19%
Sveriges Riksbank (2017)	Sweden	Capital/assets	5%-12%	19%-46%
Krag-Sorensen (2012)	Norway	CET1/RWA	13%-23%	14%-24%
Clerc et al. (2015)	Calibration partly for euro area	CET1/RWA	10.5% for corporate loans and 5.25% for mortgage loans	11.7% for corporate loans and 5.8% for mortgage loans
Admati, Hellwig (2013)	Universal	Capital/assets	20%-30%	32%-48%
Firestone et al. (2017)	United States	Tier1/RWA	from 13% to more than 26%	from 13% to more than 26%
Federal Reserve Bank of Minneapolis (2016), so-called Minneapolis Plan	13 TBTF banks in the United States	CET1/RWA	At the beginning 23.5% and after 5 years an increase of 1 p.p. annually up to 38%	At the beginning 27% and after 5 years an increase of 1 p.p. annually up to 43%

In the face of high uncertainty regarding the optimal level of capital, both in this study[16] and in the literature, it was decided to use a probabilistic measure to approximate the probability of individual capital ratios being optimal in the range obtained in the baseline scenario and in the ranges from country studies. When choosing the appropriate distribution, it was taken into account that the probability distribution of the optimal capital ratio is not uniform but concentrates around central estimates (given in Table 1), and that it is positively skewed (long right tail). The second assumption comes from the fact that while it is very unlikely that the optimal Tier 1/RWA ratio is lower than 8.5%, it cannot be ruled out that from the macroprudential point of view it may be desirable to maintain Tier 1 capital at the level of 35% - 40% of risk-weighted assets, as some of the studies indicate. The lognormal distribution meets both of these requirements. Therefore, it was used to generalize the baseline results (presented in Figure 7) and results from the literature.

Figure 8 presents distributions fitted to the ranges, in which the optimal capital ratio is located, according to this study and studies cited to in Table 1 (along with an average of the latter ones). Each of the distributions is lognormal with parameters selected in such a way that the value of the cumulative distribution for the lower limit of the interval for optimal capital ratio is 0.05 and for the upper limit of the interval it is equal to 0.95. To construct the distributions for studies that used other measures of capital ratio, the results converted into Tier 1/RWA were used.

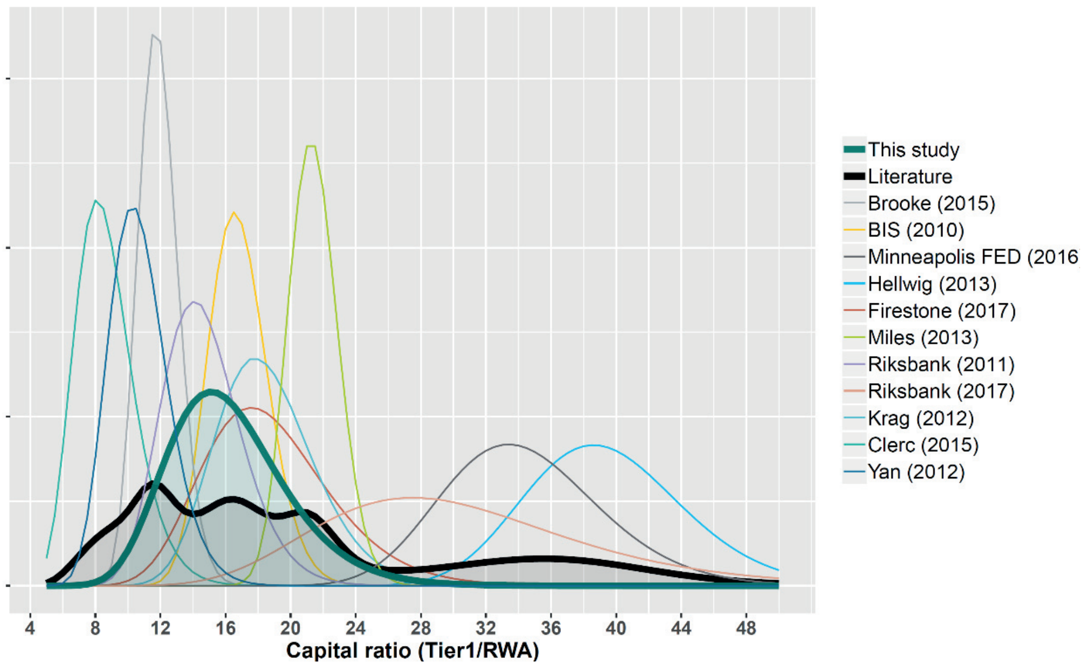
Comparing the results for Poland, with the results of other studies (all expressed in Tier 1 capital to risk-weighted assets), it is visible that they are similar. Taking into account the results obtained in this study and international experience, the optimal level of Tier 1 capital to risk-weighted assets is around 18%.[17]

It should be noted that the optimal level of Tier 1/RWA obtained in the study for Poland should not be treated as an optimal level of the regulatory minimum. If, as it is currently the case, after the regulatory minimum is raised, banks want to keep a buffer above it, the regulatory

[16] Under the basic assumptions and in the sensitivity analysis discussed later in the paper wide ranges for the optimal Tier 1/RWA ratio were obtained.
[17] The average of the expected value from the study for Poland (for the baseline scenario) and the average of the expected values from other studies is around 18%.

requirement should be lower than the determined optimal level of the capital ratio by the value of the voluntary buffer expected to be maintained.

Figure 8. Density of distributions for the optimal capital ratio according to this study and selected studies for different countries.



Sources: own study based on S&P Global Market Intelligence, BIS (2010), Yan et al. (2012), Miles et al. (2013), Brooke et al. (2015), Sveriges Riksbank (2011), Sveriges Riksbank (2017), Krag-Sorensen (2012), Clerc et al. (2015), Admati and Hellwig (2013), Firestone et al. (2017), Minneapolis FED (2016).

Notes: The green line labeled as "This study" was created to generalize the results presented in Figure 7. It is a density of a lognormal distribution fitted to the range of optimal capital ratios under the following baseline assumptions: cost of crisis equal to 63% of GDP, discount rate equal to GDP growth rate projected from the NECMOD model, time horizon of the analysis equal to 10 years and non-zero costs of increasing capital ratios for the entire time horizon. The probability of a crisis is the average of probabilities from probit models and simulation with a systemic loss threshold equal to approx. 8% of the capital surplus over the regulatory minimum. The black line marked as "Literature" represents the arithmetic mean of the values of the density functions from all cited studies.

This study, like other studies on the optimal level of capital, is subject to uncertainty due to the number of assumptions. To verify the importance of individual assumptions, the results regarding the optimal level of capital were subject to the sensitivity analysis. The following assumptions were considered: the cost of a banking crisis (crisis costs equal to 10% of GDP, 20% of GDP, ..., 160% of GDP), discount rates (1%, 2%, ..., 6%) of future costs and benefits from an increase of capital ratios, adoption of an alternative time horizon for the analysis (5, 10, 15 years). For each set of assumptions, the net effect was calculated according to the same methodology as the baseline results presented in Figure 7[18]. The limits of the range for the optimal Tier 1/RWA were determined by the vertices of the parabolas (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of increasing the capital ratio, similarly as in the baseline scenario.

Like in the baseline scenario, lognormal distributions were fitted to the ranges for the optimal capital ratio, obtained under different assumptions regarding the costs of a crisis, discount rates and the time horizon of the analysis. Details of the sensitivity analysis are described in Appendix VIII.

Analysis of Figures 22-23 in Appendix VIII reveals that the cost of a crisis is a factor having a large impact on the determination of the optimal capital level. However, this is not true for the approach that uses probabilities of crisis from probit models only. In this approach similar results were obtained independently of the adopted assumptions. The most sensitive to changes in the assumption regarding the cost of a crisis is the approach that uses probabilities from simulation with a baseline systemic loss threshold of around 8%. In this approach the sensitivity to assumptions regarding the discount rate and the time horizon of the analysis is noticeably higher for medium and high costs of the crisis (63% and 158%). Sensitivity analysis of the approach that uses the average probability from probit models and simulation with the baseline systemic loss threshold (Figure 21 in Appendix VIII) indicates that the optimal Tier 1 ratio is approx. 18% (like in the baseline scenario). This result derived from the sensitivity

[18] The other assumptions adopted in the construction of Figure 7 and in the determination of the range, in which the optimal Tier 1/RWA ratio is located, remained unchanged.

analysis considers also the average from other studies. The sensitivity analysis itself indicates that the optimal level of capital may be slightly lower and amount to around 16%, which still falls within the range of 11-23% which was obtained in the baseline scenario.

7 Conclusions

The level of Tier 1 ratio, for which the macroeconomic net effect is positive and the highest, is called the optimal capital level in the Polish banking sector. The more severe the banking crises are, and the more their probability of occurrence is going to fall with higher capital ratios, the higher are the benefits. The costs are related to temporary slowdown of GDP growth due to higher financing costs for banks and the whole economy. The net effect is equal to the difference between the expected benefits and costs.

The results indicate that the optimal Tier 1 capital ratio is in the range of 11%-23% with the expected value from this study and the literature at around 18%. The sensitivity of results to changes in assumptions is often high and the results should be treated with caution. In some scenarios of the analysis, the optimal capital ratio may approach or exceed 30%.

The obtained optimal level of capital is not a regulatory minimum, as it also includes voluntary buffers that banks usually maintain above the regulatory minimum. The level of capital ratio that is justified from a regulatory perspective is therefore lower than the optimal one presented here.

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Technical Appendix

Appendix I Variables used in probit models

Tabele 2. Independent variables used in probit models.

Variable	Transformation	Sign of the parameter estimate in line with economic intuition	Description	Source
CreditBroad	growth rate YoY	+	Market value of loans granted to the private non-financial sector	BIS total credit statistics
CreditNarrow	growth rate YoY	+	Market value of loans granted by the banking sector to the private non-financial sector	BIS total credit statistics
TotCHH	growth rate YoY	+	Market value of loans granted to households and non-profit institutions serving households	BIS total credit statistics
TotCNFC	growth rate YoY	+	Market value of loans granted to non-financial corporations	BIS total credit statistics
REER	growth rate QoQ	+ or -	Real effective exchange rate (2010=100, deflator: CPI, 42 trading partners)	Eurostat Exchange Rates
DSRBIS	growth rate YoY	+	Ratio of debt-service costs to income of private non-financial sector	BIS debt service ratios statistics
RePPRindex	growth rate YoY	+	Real index of residential real estate prices (2010=100)	BIS Residential Property Price database: selected series
PublicDebtToGDP	level	+	General government debt in % of GDP	Eurostat Government Finance Statistics

VAfinancialGDP	level	+	Seasonally and calendar adjusted value added of financial and insurance sector in % of GDP	Eurostat Quarterly National Accounts
CAToGDP	level	-	Seasonally adjusted current account in % of GDP	OECD Key Short Term Economic Indicators
CapitalRatio	level	-	Tier 1 capital to risk-weighted assets (in %)	IMF Financial Soundness Indicators: Core FSIs for Deposit Takers; Bankscope[19]
LiquidityRatio	level	+	Ratio of liquid assets to short-term liabilities (in %)	Financial Soundness Indicators: Core FSIs for Deposit Takers
CreditBroadToGDP	deviation from trend	+	Deviation from trend of market value of loans granted to private non-financial sector expressed in % of GDP, trend calculated with HP filter (lambda = 400 000)	BIS total credit statistics
CreditNarrowToGDP	deviation from trend	+	Deviation from trend of market value of loans granted by banks to private non-financial sector expressed in % of GDP, trend calculated with HP filter (lambda = 400 000)	BIS total credit statistics
VIX	level	+ or -	Volatility implied by S&P500 index options, calculated by *Chicago Board Options Exchange*	FRED

[19] Due to the short time series for the Tier 1/RWA in the *IMF Financial Soundness Indicators*, the IMF data series were extended backwards with the data from *Bankscope* database. Annual data for individual banks from *Bankscope* database were aggregated at the national level and then approximated to the quarterly frequency by means of interpolation (cubic spline interpolation). Nevertheless, the time series obtained, were still quite short, which means that in the models that include CapitalRatio variable only the last global financial crisis was captured.

Data on crises in EU countries and Norway were taken from the ECB/ESRB database "A new database for financial crises in European countries". Those systemic crises were considered, the element of which was materialization of risk in the banking sector.[20] It was assumed that the date of the end of a crisis corresponds to the quarter in which crisis management ended. For other countries in the sample, the dating of crises was adopted in accordance with the Laeven and Valencia (2012) database. The main advantage of the ECB/ESRB database is the fact that it is more up-to-date and, secondly, that for each crisis, the start and end dates are given in months. In case of Laeven and Valencia (2012), the start of only some crises is reported in months, and the end is always reported on an annual basis.

[20] 66% of systemic crises included in the ECB/ESRB database are complex crises, in which the materialization of various types of risk took place simultaneously: banking sector risk, the risk of asset prices correction, currency risk and sovereign debt risk. 4% of the total number of systemic crises are those related only to the banking sector. For the purposes of this study systemic crises that included materialization of banking risk were selected. Transition crises were excluded from the sample. In total 33 crises were considered.

Appendix II Technical aspects of the approach based on macroeconomic data employed to Determine the benefits of higher capital ratios

Probit models

To calculate the probability of a crisis at different levels of capital ratios, in the first approach binary choice models were used. They were estimated on quarterly macroeconomic data from 45[21] economies in the period 1970Q1-2017Q4. In each model there were 5 regressors from a selected set of 15 variables presented in Table 2 in Annex I. Due to the panel imbalances and the different length of time series for each variable, the effective number of observations on which each model was estimated, was different.

The first class of models used were pooled probit models, which abstract from the panel nature of the data, i.e. they do not include country individual effects. As an alternative, probit models with random effects were estimated. For most models the hypothesis of zero variance of individual effects was rejected based on the Breusch-Pagan test for their significance. This result indicates the low usefulness of pooled regression models. Further analysis was therefore limited to random effects probit models that went through the Breusch-Pagan test successfully. At the stage of choosing the type of model, logit models with fixed effects were rejected because during the analyzed period Poland did not experience a systemic banking crisis other than the one associated with transition of the economy.[22] In the case of fixed effects logit models, the estimation method that uses a conditional likelihood function would disregard the data for countries that did not experience a systemic banking crisis, so among others data for Poland.

[21] European Union and OECD countries (apart from Chile, Israel and New Zealand) as well as Brazil, China, Indonesia, India, Malesia, Russia and Thailand were included in the sample.
[22] Transition crises were excluded from the sample (see footnote 20).

What could potentially undermine the unbiasedness and consistency of estimators in random effects models is lack of independence of individual effects from explanatory variables in each period. For some models this possibility was excluded using the Mundlak version of the Hausman test (1978). Models that passed the Hausman test were qualified for further analysis. In addition to testing the independence of individual effects from explanatory variables, all models were verified for collinearity of regressors. Due to the potential for collinearity, models with more than one variable associated with the level or dynamics of credit in the economy were excluded. The presence of an aggregate capital ratio of the banking sector variable in the models was checked and the estimated parameter next to it was tested for significance. The models in which the mentioned variable did not occur, or its coefficient was insignificant at the 0.05 significance level, were disregarded, because the previously performed Bayesian model averaging procedure proved that this variable has a high informational value in explaining the probability of a crisis (high posterior inclusion probability). The focus of this study was limited to models in which coefficient estimates had signs in accordance with the economic theory.[23] To avoid bias of estimates due to too small number of observations in the sample (in the basic specification the explained variable takes a value of 1 for crisis periods and a value of 0 for other periods), it was assumed that for each model the number of ones[24] for the explained variable must be greater than ten times the number of estimated parameters.[25]

[23] It was decided that the variables whose model coefficients should have a positive sign in accordance with the economic theory are the following: CreditBroad, CreditNarrow, TotCHH, TotCNFC, DSRBIS, RePPRindex, PublicDebtToGDP, VAfinancialGDP, LiquidityRatio, CreditNarrowToGDP, CreditBroadToGDP. Variables whose coefficients should have a negative sign according to the economic intuition, are: CAToGDP and CapitalRatio. Depending on the assumed number of lags for independent variables in the model, the signs of parameter estimates next to REER and VIX may be different according to the economic theory. Therefore, they were not specified *a priori*. It is difficult to state unambiguously how the VIX index behaves before the crisis. The sign of the parameter estimate standing next to VIX should depend on the time remaining until the crisis. It may happen that 4 quarters before the crisis the value of the index falls, because most investors are optimistic, while in the first quarter before the crisis, its symptoms are already visible and reflected also in the sharp increase in the volatility of option prices. Equally volatile behavior depending on the time remaining until the beginning of a crisis one can expect of real effective exchange rate.

[24] Due to the panel imbalance and the different length of the time series for individual variables, the number of ones in the sample is different for each model.

[25] The condition for the minimum number of ones per each estimated parameter was taken from Peduzzi et al. (1996), who analyzed this problem in logistic regression.

For each model that passed the tests mentioned, the conditional probability of a crisis was calculated (conditional on the realization of the random effect for Poland) for different Tier 1/RWA levels, with the remaining independent variables held constant at the levels corresponding to observations for Poland for the third quarter of 2017. Predictions from models in each approach were weighted according to their prognostic quality. Weights were calculated based on the absolute usefulness of the models.[26] Following Sarlin and Holopainen (2016) it was assumed that the absolute usefulness of the model is defined as:

$$U_a(\mu) = \min(\mu P_1, (1-\mu)P_2) - L(\mu)\,, \qquad (1)$$

where the loss function L (μ) is calculated according to the following formula:

$$L(\mu) = \mu T_1 P_1 + (1-\mu) T_2\, P_2. \qquad (2)$$

In the equations (1) and (2) μ and (1 - μ), contained in the range (0, 1), describe the relative preferences of the decision maker between missing the signal of a crisis that will happen and receiving a false signal of a crisis that will not actually take place. T_1 is the probability of making the type I error (number of missed crises to the total number of crises in the sample), T_2 is the probability of making the type II error (number of false alarms divided by the number of non-crisis periods in the sample). The decision maker's preferences regarding the subjective ratio of the cost of type I and type II errors were set at 3:1 (which corresponds to $\mu = 0.75$). This is in line with the approach taken in similar studies, where from policy maker's perspective failure to identify crisis ex ante is assumed to be more costly than sounding a false alarm (Behn et al. 2013). P_1 and P_2 is the percentage of crises and non-crisis observations in the sample, respectively. The limits of confidence intervals for the weighted probability from the models were set to be equal to the minimum and maximum values of predictions obtained from all models that underwent the described procedures, after rejecting the extreme values.

Change in the likelihood of a crisis as a result of raising capital ratios by x p.p. was calculated as the difference in the likelihood of a crisis for Poland with a banking sector capital ratio equal

[26] Models whose absolute usefulness was negative or equal to zero were excluded from the analysis.

to 8.5% and other explanatory variables corresponding to data for Poland for the third quarter of 2017,[27] and the probability of a crisis with a capital ratio equal to (8.5 + x)% *ceteris paribus*.

Discrete choice models explaining the occurrence of banking crises are prone to adverse causality problem. If the explained variable has a value of 1 in crisis periods and 0 in others, and explanatory variables are not lagged, then both explanatory variables affect the crisis, as well as the crisis affects the values of explanatory variables. It is therefore justified to introduce lags of explanatory variables. If for any crisis the number of lags for explanatory variables is lower than the number of crisis periods, then the estimated parameters reflect not only the influence of explanatory variables before the crisis on the likelihood of a crisis occurring in several periods, but also the influence of explanatory variables during the crisis on the probability of the crisis lasting longer according to the formula:

$$\Pr\left(Y_{i,t}=1 \,\middle|\, X_{i,t-k}\right)=\Pr\left(Y_{i,t}=1\,, Y_{i,t-k}=0 \,\middle|\, X_{i,t-k}\right)+\Pr\left(Y_{i,t}=1\,, Y_{i,t-k}=1 \,\middle|\, X_{i,t-k}\right), \quad (3)$$

where k=1, 2, …, K denotes the number of lags for explanatory variables.

Two elements of the above sum can be treated as two situations that cannot occur simultaneously. Both, however, have an influence on the parameter estimates. The direction of the impact of explanatory variables in these two situations may be different, e.g. positive (and high) growth rate of the broad credit for the private non-financial sector before the crisis may indicate an increased likelihood of a crisis happening after k periods, while a positive growth rate of the same variable close to the end of the crisis may signal an increasing probability of recovering from the crisis after k periods. Modeling of only the first situation is in the area of interest of this study, i.e. it is desirable to model $\Pr(Y_{i,t}=1,\ Y_{i,t-k}=0 \mid X_{i,t-k})$. Therefore, for explanatory variables an arbitrary number of lags equal to 8 quarters was introduced and observations for which $Y_{i,t}=0$ oraz $Y_{i,t-k}=1$ were removed from the sample. The number of models with such specifications that have passed all the tests described above and based on which the probabilities of systemic crisis were calculated is equal to 8. Model variables and parameter estimates are presented in Table 3.

[27] As mentioned before, due to delays in the publication of data, for most variables at the time of making the calculations, the most recent observation was the one from the third quarter of 2017.

Table 3. Estimation of the parameters of probit models with the basic specification.

	M1	M2	M3	M4	M5	M6	M7	M8
CapitalRatio_R	-0.4***	-0.396***	-0.399***	-0.398***	-0.40***	-0.416***	-0.66***	-0.69***
REER_d1	0.02	0.02	0.03	0.02	0.03	0.02	0.12*	
VIX_R	0.004	0.01	0.01	0.01	0.01	0.02		0.02*
RePPRindex_d4	0.08***	0.06***	0.05***	0.06***	0.05***	0.05**		
DSRBIS_d4	0.007							
CreditNarrowToGDP_gap		3.82**						
TotCNFC_d4			0.03**					
CreditBroadToGDP_gap				3.03*				
CreditBroad_d4					0.03*			
TotCHH_d4						0.03*		
PublicDebtToGDP_R							0.007	0.006
VAfinancialGDP_R							0.15***	0.16***
CAToGDP_R							-0.02	-0.03
N	675	732	732	732	732	732	591	591
No. of crisis observations	65	83	83	83	83	83	103	103
AUROC	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95
AIC	247.2	292.8	296.4	297.3	298	298.1	291.4	292.5

Symbols *, ** and *** denote, respectively, the significance level of 0.1, 0.05 and 0.01.

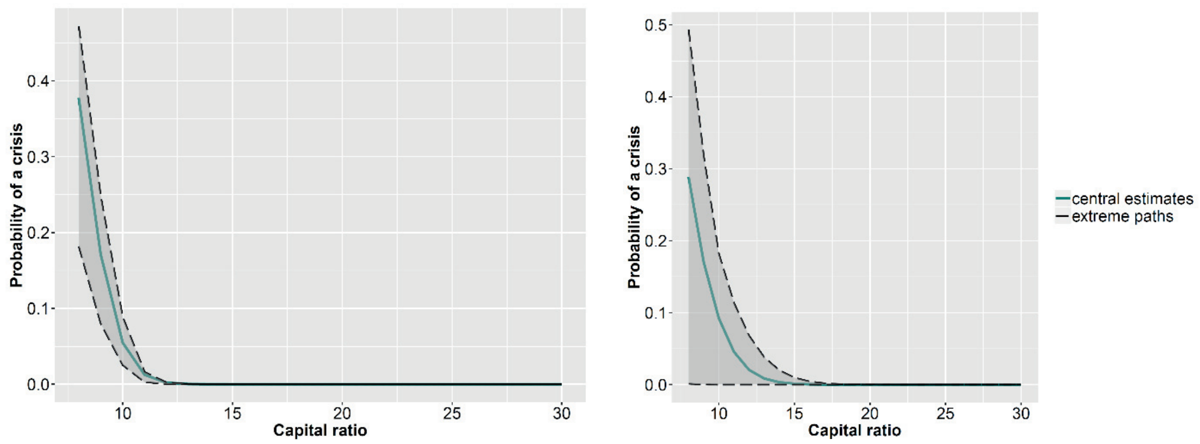
Another solution is to apply the method adopted for binary choice models in the literature on early warning systems.[28] According to this method explained variable in the pre-crisis boom periods[29] takes the value of 1, the observations for the crisis period, for a few quarters after the crisis and possibly for the period just before the crisis are removed from the sample, while in other periods the explained variable takes the value of 0. In these models there are no lags of explanatory variables. Since for the key variable (which is the capital ratio) relatively short time series are available, and the approach used in early warning models requires the removal of a large number of observations, the first of the described solutions with lagging explanatory variables was adopted as the base one. For the sake of comparison, pooled probit models with the same number of lags of explanatory variables and the same approach to excluding some observations from the sample as in the base approach, were estimated. Due to the larger number of pooled probit models that went through the testing successfully (almost 50 models),

[28] Behn et al. (2016), Bussiere and Fratzscher (2002), Drehman and Juselius (2013), Courdet and Idier (2016), Sarlin and Holopainen (2016).
[29] The length of the boom period is set arbitrarily.

the limits of the confidence interval for the weighted average probability from the models were set at 2.5th and 97.5th percentiles of the predictions from all those models.

There are differences in the probability of a crisis for different capital ratios in these three approaches (see Figure 2 and Figure 9). Due to the greater importance of assumptions regarding the value of crisis costs and very small changes in the probability of crisis for ratios higher than 15%, these differences do not significantly affect the value of the capital ratio, for which the net effect from its increase to this level is maximal. In the main analysis the base approach with lagging explanatory variables was used.

Figure 9. The probability of a systemic banking crisis for various Tier 1/RWA levels. Early warning probit models (left panel) and pooled regression probit models (right panel).



Bayesian model averaging

Following Babecky et al. (2012), to verify the significance of Tier 1 capital ratio as a factor influencing the probability of a banking crisis, bayesian model averaging was used. A slightly different class of models was used for BMA analysis: pooled regression logit models. Analysis of values of posterior inclusion probability[30] (the probability that a given variable will be in the true model) for each of the 15 variables, revealed that Tier 1 capital ratio has the highest posterior inclusion probability (PIP), so it is a significant variable influencing the probability

[30] Posterior inclusion probability reflects the strength of the relationship between the explanatory variable and the explained variable. Variables with a high value of this measure are considered to be important regressors.

of a banking crisis. Following Babecky et al. (2012) posteriori inclusion probability can be expressed by the formula:

$$PIP = p(\beta_\gamma \neq 0 \mid y) = \sum_{\beta_\gamma \neq 0} p(M_\gamma \mid y), \quad (4)$$

where β_γ is the coefficient standing next to a variable γ and M_γ are the models containing this variable.

Appendix III Technical aspects of the simulation based on microeconomic data that serves the purpose of exploring the benefits of higher capital ratios

In the second approach to calculating the probability of a systemic banking crisis at various levels of capital ratios, simulation analysis was used. Results of multiple draws from the multidimensional probability distribution with given parameters were mapped onto the distribution of bank losses. Following Brooke et al. (2015) it was assumed that banks in the sample are homogenous. Not only it was assumed that the banks' financial results are not determined by country-specific factors, but also that they are not time dependent, i.e. a Polish bank may currently incur a loss expressed as a percentage of risk-weighted assets equal to e.g. a loss of a UK bank (also expressed as a percentage of RWA) in the first quarter of 1990. The absolute values of losses are therefore scaled by the values of risk-weighted assets. Homogeneity of the banks' income profile across countries and time appears to be a relatively strong assumption. However, it is difficult to avoid due to a small number of Polish banks in the sample and the fact that in Poland over the years 1970-2017 there was no systemic banking crisis (apart from the crisis in the transition period from centrally-planned to market economy and such crises are excluded from the analysis due their idiosyncratic nature).

For the available set of banks,[31] the empirical distribution of net income to risk-weighted assets was calculated. Then, multiple random draws were taken from the n-dimensional multivariate cumulative t-distribution (copula t) and cumulative normal distribution (Gaussian copula),[32]

[31] From the *Bankscope* database those banks have been selected, whose business profile is similar to those operating in Poland (e.g. investment banks were excluded).

[32] The drawing procedure was carried out for different correlation coefficients and various degrees of freedom (tail dependence). The pairwise correlation of income of Polish banks in the period 1997Q1-2016Q4, for which data was available, was calculated. The simulation used a minimal positive correlation, average and maximum correlation, as well as values of 0.5 and 0.75. For the t-Student copula, 2, 5, 10, 25, 50 were taken as the number of degrees of freedom, where a smaller number of degrees of freedom means a stronger tail dependence. Intuitively, it is expected that the probability of a crisis will be the highest for maximum correlation and the lowest number of degrees of freedom, however, Koziol et al. (2015) noticed that it is not always the case. Probabilities of crisis at different capital

where n is equal to the number of active commercial banks in Poland, for which data on risk-weighted assets for the fourth quarter of 2017 was available (n = 35). In the next step values of draws were mapped onto the values from the previously fitted marginal empirical distributions of the net income to RWA for each bank. It allowed to determine the total loss of capital in the Polish banking sector in each draw (by multiplying results of the drawing[33] expressed in % of RWA by actual RWA of Polish banks in the fourth quarter of 2017).

The total capital surplus in the Polish banking sector in each draw for various hypothetical initial Tier 1 ratios (from 8.5% to 30%) was calculated as the product of Tier 1/RWA buffer over the regulatory minimum and the actual RWA of Polish banks in the fourth quarter of 2017. The minimum regulatory level for the Tier 1/RWA was assumed to be 6%.

Subsequently, a threshold for the loss of surplus of Tier 1 over regulatory minimum,[34] the breach of which historically was related to a crisis, was determined. For this purpose, a pooled regression logit model was estimated on annual data (for the same 45 economies, which were analyzed in an approach based on probit models). Then, using the method of searching for the optimal point on the ROC curve, the threshold value for the loss of surplus generating the systemic banking crisis was determined. The optimal point was taken to be the one minimizing the loss function defined in Appendix II, for the relative subjective ratio of costs of type I and II errors equal to 1:1. The explanatory variable in the model was defined as the aggregate size of banks' losses (negative net income) in the country *i*, and period *t* expressed as a percentage of the aggregate surplus of Tier 1 capital over the regulatory minimum in the banking sector in the country *i* and period *t-1*. The regulatory minimum was defined for each bank to be 6% of risk-weighted assets. The data was taken from the *Bankscope* database.

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ratios generated for 5 degrees of freedom and average correlation were used in the baseline scenario. In the extreme scenarios minimal and maximal probabilities from all simulations were used.

[33] To determine the aggregate loss in the Polish banking system, only those draws from the distribution of net profits to RWA were considered, which correspond to negative net profits.

[34] The regulatory minimum was assumed to be 6% for all countries and periods. This value corresponds to the Basel III regulatory minimum for the Tier 1/RWA capital ratio.

The explained variable takes value of 1 in periods in which there was a systemic banking crisis,[35] and 0 in other periods. According to the model, the loss of banking sector surplus over the regulatory minimum generating a systemic crisis is around 8%. For the purpose of using it in the sensitivity analysis of the results regarding the optimal capital ratio, confidence intervals for the ROC curve were determined using the bootstrap method (100 000 draws). For each generated ROC curve a point minimizing the loss function defined in Appendix II, for a relative subjective ratio of costs of type I and II errors equal to 1: 1, was found. For the set of probability values corresponding to such points, their 2.5th and 97.5th percentiles were calculated. Those percentiles correspond to losses of about 2% of the surplus and about 22% of the surplus.[36] The lower value was considered not to be supported economically and was excluded from further analysis. The upper one was used in the sensitivity analysis.

Knowing the value of the threshold for the loss of surplus that generates a crisis, the absolute value of capital over the regulatory minimum in the Polish banking sector (for various Tier 1/RWA ratios) and the total loss of capital in the Polish banking sector in each simulation, it was determined whether for individual draws the loss of surplus exceeded the threshold value and consequently whether the systemic banking crisis was generated. By dividing the number of generated crises by the number of draws, the probability of a systemic banking crisis in Poland was determined (for different capital ratios and different parameters of t-copula and Gaussian copula).

[35] The sources of the explanatory and explained variables are described in the section *Variables used in probit models* in Appendix I.
[36] The analytical transformation of the probability value into the value of the explanatory variable in the logit model with one regressor is described, among others in Cameron and Trivedi (2005).

Appendix IV Costs of banking crises

Table 4. Costs of banking crises in % of pre-crises GDP.[37]

Studies that estimate GDP loss in the crisis period	Cumulative GDP loss (in % of pre-crisis GDP)
Hoggarth et al. (2002)	16
Laeven and Valencia (2012)[38]	23
Haugh et al. (2009)	21
Cecchetti et al. (2009)	18
median	**19,5**

Studies that consider infinite time horizon (permanent effects of a crisis)[39]	Cumulative GDP loss (in % of pre-crisis GDP)
Cerra and Saxena (2008)	158
Turini et al. (2010)	197
IMF (2009)	210
Furceri and Zdzienicka (2010)	95
Furceri and Mourougane (2009)	42
Barrel et al. (2010a)	42
Boyd et al. (2005) Metoda 1	63
Boyd et al. (2005) Metoda 2	302
Haldane (2010)	200
median	**158**

All studies	Cumulative GDP loss (in % of pre-crisis GDP)
median	**63**

Source: own illustration based on BIS (2010).

[37] Costs are expressed in terms of pre-crisis GDP level.
[38] Instead of using the crisis database by Laeven and Valencia published in 2008 as in the BIS (2010) report, we refer to its updated version from 2012.
[39] GDP losses resulting from the downward shift of its trend were expressed in a cumulative form and future losses were discounted using a discount factor of 5%.

Appendix V Impact assessment of higher capital requirements on economic growth

Assumptions of analysis

In order to estimate the impact of higher capital requirements on economic growth, the following assumptions were made:

- the market value of Common Equity Tier 1 (CET1) ratio depends directly on the value of the supervisory capital adequacy ratio,
- banks create capital buffers as a surplus to the supervisory capital adequacy ratio,
- the aggregated buffer does not change as a result of changes in the supervisory capital adequacy ratio,
- the banks take into account "soft" supervisory recommendations regarding the value of the capital adequacy ratio, which is higher than the supervisory ratio,
- increase in supervisory requirements of any genesis causes an adequate increase in the aggregate market capital adequacy ratio,
- the impact of the capital adequacy ratio on economic growth is realized through the credit channel (credit supply) and the interest rate channel,
- real sector variables have an immediate impact on the banking sector variables,
- real sector variables react with a lag to banking sector variables,
- the mutual influence of variables in the real sector can be immediate or lagged,
- the mutual influence of variables in the banking sector may be immediate or lagged.

Our dataset consists of quarterly data covering the period from 2004Q1 till 2016Q4. There are two reasons for choosing this period:

- firstly, during 1997-1998, there was a period of economic slowdown in Poland caused by the Russian crisis (GDP growth rate decreased to 4.6% in 1998, compared to 6.5% in 1997); the next slow-down period, the most significant one so far, took place in 2001-2003 (then GDP growth rate decreased from 4.6% in 2000 to 1.2% in 2001, 2% in 2002 and 3.6% in 2003); both crises were related to the weakening of the global economic situation and limiting the inflow of foreign investments; the crisis in 2001-2002 was mainly related to the sell-off of the stock market after a period of uninterrupted growth of indices in the years 1995-2000 and the "dotcom speculative bubble"; the financial crisis in 2008-2010 had different fundamentals than the two previous crises and for the purposes of the current analysis its effects should be isolated in the statistical sample;

- secondly, in 2005 Narodowy Bank Polski (National Bank of Poland) started publishing statistical data on lending and deposit interest rates applied by banks according to the new methodology, which was adjusted to the harmonized requirements of the European Central Bank; it ensured comparability of data between the countries of the European Union; statistical series according to the old and new methodology published by the NBP are available for 2004, however the data for this year according to the new methodology should be treated with caution, as it was the period of implementation of this new measurement methodology; finally, time series for 2004 were adopted according to the old methodology for sample size reasons.

The statistical data

Table 5 presents the analyzed economic variables. The table contains the acronyms of variables, their definition, the scope of the sample, the number of observations and the source of data.

Table 5. SVAR model variables

Variable name	Definition of variable	Period	No. observations	Source
CET1	Tier 1 capital ratio for risk-weighted assets for commercial banks in Poland, per cent	1999Q2-2017Q1	72	NBP
CPI (log)	Consumer price index, percent (2010=100)	1995Q1-2017Q1	89	OECD
GDPSA (log)	GDP at constant prices (2005=100), seasonally adjusted, PLN million (until 2001Q4 according to ESA95, from 2002Q1 according to ESA2010)	1995Q1-2017Q1	89	Eurostat
I_LOANS	Lending interest rate on loans to households and non-financial corporations, per cent (old and new methodology)	1997Q1-2017Q1	81	NBP
LOANS_R (log)	Receivables of banks from the non-financial sector due to loans, million PLN, constant prices (2010=100), CPI deflator	1997Q1-2017Q1	81	NBP
WIBOR	3M WIBOR rate, per cent	1995Q1-2017Q1	89	Eurostat

Source: own elaboration.

The Model

A structural linear vector autoregressive model (SVAR) was used to perform the calculations. The reduced form of the model is the following (Lütkepohl, 2005):

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t,$$

y_t - vector $(K \times 1)$ of endogenous variables,

A_j - matrices $(K \times K)$ of parameters $(j = 1, \ldots, p)$,

u_t - K- dimensional error term, $u_t \sim (0, \Sigma_u)$.

The structural form of the model is as follows:

$$Ay_t = A_1^* y_{t-1} + \ldots + A_p^* y_{t-p} + \varepsilon_t,$$

$$A_j^* = AA_j,\ j = 1, \ldots, p,$$

$$\varepsilon_t = Au_t,\ \varepsilon_t \sim (0, \Sigma_\varepsilon),\ \Sigma_\varepsilon = A\Sigma_u A'.$$

The proper choice of matrix A means that the covariance matrix ε_t is diagonal.

In the case of Choleski's decomposition of error covariance matrix, it is assumed that:

$$\mathrm{A} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ a_{21} & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ a_{K1} & a_{K2} & \ldots & 1 \end{bmatrix}.$$

Initially $K(K-1)/2$ restrictions were imposed (they cannot be arbitrary) and then the impulse response functions (IRF) are just identified.

In order to identify short-term shocks, a Choleski's decomposition of error covariance matrix was adopted in two following settings:

- fixed ordering of variables,
- permuted ordering of variables.

The aim of application of permuted ordering of selected variables was to evaluate the robustness of impulse response functions to changes in the model specification. Consequently, the analysis was finally performed on the basis of a set of competing SVAR models. Hence, the analysis of the impact of changes in capital requirements on GDP growth takes seriously into account the uncertainty as to the assumed structure of dependencies in the SVAR model. This issue is omitted in the literature quite often. Authors usually rely on some structure of dependencies imposed a priori. Our results show that the impact of changes in capital requirements on the economic growth may vary across SVAR models substantially.

The assumption regarding stability conditions was adopted for the optimal selection of the SVAR model. In order to determine the lag-order, we utilise the Schwarz criterion.

The statistical significance of individual parameter estimates in the model was not examined, instead the focus was on the uncertainty of the IRFs and their economic interpretation.

Empirical results

A multivariate time series was used to obtain the estimates, whereas the analysis included only the GDPSA – CET1 relationship.

The SVAR model was estimated for six variables (in the order):

- GDPSA,
- CPI,
- LOANS_R,
- WIBOR,
- I_LOANS,
- CET1.

The variables were expressed as log-levels (GDPSA, CPI, LOANS_R) or levels (WIBOR, I_LOANS, CET1).

The set of selected endogenous variables serves the analysis in various ways. First of all, attention should be paid to the assumption regarding the identification of channels of macro-prudential policy impact on the real economy. The specification of the set of model variables, the way they are measured and the impact channels is of paramount importance in this case. It was assumed that the main channels of influence are: credit channel and interest rate channel. Consequently, the real credit to the non-financial sector and interest rates – WIBOR and lending interest rate to the non-financial sector – were included in the variable set. The analysis did not take into account the credit margin instead of the mentioned interest rates. It has been assumed that the interest rates taken into account are cointegrated and, consequently, their difference (margin) can be treated as a realisation of a stationary process. Due to the non-stationarity of other variables, it was not advisable to include interest rate margin. At the same time, it seems reasonable to include both WIBOR rate and lending rate due to the possibility of imposing short-term restrictions on their interaction. Due to the adopted ordering of variables and the Choleski decomposition, the immediate impact of WIBOR rate on lending rate was realized. Taking into account WIBOR rate, it was intended to reflect the nature of monetary policy in the form of changes in the reference rate. It was also assumed that WIBOR's impact on lending rate is more complex than the impact of the reference rate on WIBOR rate. Thus, two interest rates were finally included instead of three.

To compare the results, it was assumed that the variables: GDPSA, CPI, LOANS_R, WIBOR had a fixed ordering in the vector, while variables: I_LOANS, CET1 had a variable order (2!=2 permutations). Such an ordering enables that the first variable had an immediate effect on the others, the second on the others, except the first, etc. According to the adopted scheme, variables: I_LOANS and CET1 were to react immediately to all system variables. In particular, it was assumed that increasing the capital requirement CET1 would not result in an immediate adjustment of GDP. The consequence of this assumption is the lack of GDP response to CET1 change at the moment of a shock (IRF value is equal to zero), while adjustments in subsequent periods (shock to CET1) are possible.

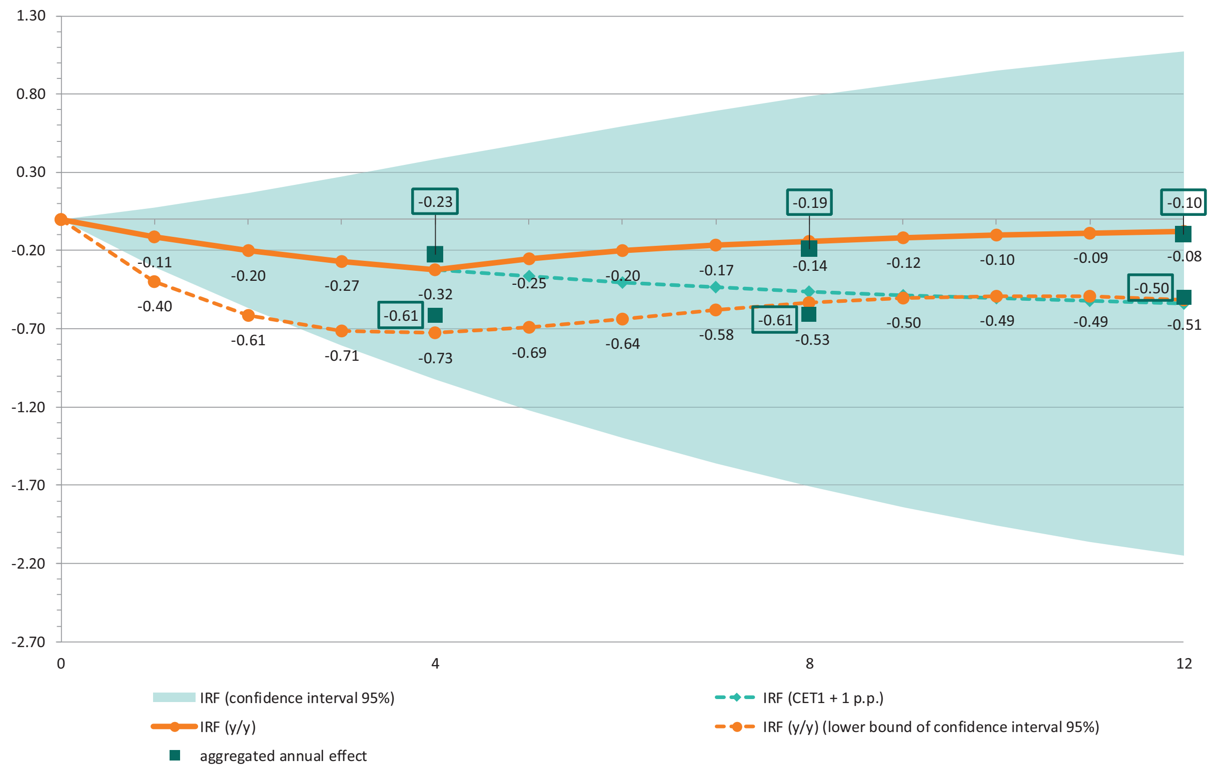
Based on the estimated IRFs (Figure 10), a general conclusion can be drawn that the impact of the CET1 increase on GDP is characterized by a high degree of uncertainty. In line with other studies in literature and expectations that CET1 increase is a cost for the banking sector in the short run, a negative reaction of GDP to CET1 was observed.

The IRF estimate denotes a multiplier response, expressed as the distance of the solution under shock at time t from the baseline scenario. In the case of SVAR model analysed for levels of variables, given negative IRF values, they should be interpreted as lower GDP due to the CET1 shock in relation to the baseline solution under no shock.

For the purpose of robustness check, various model specifications were compared with the use of other variables like real exchange rate or spread. In addition, the most parsimonious model was considered, where only GDP, credit and CET1 were taken into account. The final conclusion is that the resulting impact of CET1 on GDP is robust to changing the specification of the SVAR model. The use of only two variables, i.e. GDP and CET1, has shown that the failure to take credit into the transmission channel significantly changed the results. As a result of the tests, the credit channel is empirically the most important link in macro-prudential policy.

Figure 10 shows the IRF values for the shock in the form of an increase in the CET1 ratio by 1 percentage point (p.p.) in the first period of the forecast horizon. Three years were assumed as the forecast horizon, (h=12), which corresponds to the horizon of NBP inflation projection. On Figure 10 we put: (a) impact of the CET1 shock on GDP logarithm together with the confidence interval (95%) (light green), (b) the impact of the CET1 shock on GDP growth rate y/y with the lower end of the confidence interval (95%) (orange), (c) aggregated decline in GDP growth y/y (dark green).

Figure 10. Illustration of the effect of CET1 increase by 1 p.p. on GDP growth



Source: own elaboration.

Table 6. Estimates of the reduced annual GDP growth on increase in the CET1 capital requirement by 1 p.p.

Year	Variant	GDP growth rate (y/y)				
		quarterly effect				annual effect
		I	II	III	IV	
T+1Y	expected	-0,11	-0,20	-0,27	-0,32	-0,23
	pessimistic	*-0,40*	*-0,61*	*-0,71*	*-0,73*	*-0,61*
T+2Y	expected	-0,25	-0,20	-0,17	-0,14	-0,19
	pessimistic	*-0,69*	*-0,64*	*-0,58*	*-0,53*	*-0,61*
T+3Y	expected	-0,12	-0,10	-0,09	-0,08	-0,10
	pessimistic	*-0,50*	*-0,49*	*-0,49*	*-0,51*	*-0,50*

Source: own elaboration.

According to Figure 10, the IRF for the GDP-CET1 ratio is characterized by significant volatility and consequently the results should be treated with caution. It should also be assumed that the confidence interval for the estimate of the decline in GDP growth rate, given in Table 6, which is a non-linear transformation of the interval shown in Figure 10, would indicate that these estimates are also characterised by substantial uncertainty. In order to estimate this interval for GDP growth rates we estimated the VAR model for annual growth rates (including permutations of variables). Then, the bands of the 95% confidence interval for IRFs were simulated using the Monte Carlo method for n=9999 replications assuming normal specification errors. As a result, a confidence interval was obtained, the lower band of which is given in Figure 10 and Table 6. It allowed us to determine the variant of the pessimistic solution of a decline in GDP growth rates in the short and medium run due to an increase in the capital adequacy ratio. According to the interpretation of the confidence interval whose lower band we present, the GDP contraction that is deeper than the one described by the pessimistic variant may occur with a probability less than 2.5%.

The results shown in Table 6 indicate that in the central projection the annual GDP growth rate is lowered through the whole forecast horizon (as compared to the baseline scenario). The greatest drop (0.23 p.p.) – due to the adopted capital shock in the form of CET1 increase by 1 p.p. – may occur during the first year after the adoption of the disturbance. In the subsequent years, the decrease is estimated to be much smaller. The greatest reduction in GDP growth can be expected during the first two years after the shock. In the following year, the decrease in GDP growth rate did not exceed 0.1 p.p.

It should be noted that the aforementioned effect decays relatively slowly due to the high inertia of the system. It is caused by the dynamics of real factors – GDP and the CPI index. In the presented macro-financial analysis, the effects of the CPI index were important from the point of view of the monetary policy channel, also affecting the situation in the banking sector (supply of credit). This CET1 transmission mechanism represents two interest rates – WIBOR and lending rate to the non-financial sector. It has been assumed that due to the increase in the capital requirement, banks will limit the scale of lending (the loan will be rationed). The cost effect will be an increase in lending rate.

For comparative purposes, one can point to simulation research carried out for developed economies by other authors. These studies generally show that an increase in capital requirements leads to a reduction in economic growth. Extensive research in this area was carried out at the Bank for International Settlements (BIS) within the MAG group (Macroeconomic Assessment Group). The study by MAG (2010) shows that the increase in the capital adequacy ratio by 1 p.p. could lead – on average – to GDP decline by 0.22% after 35 quarters since the implementation of the new regulatory system. This translates into a reduction in the annual GDP growth rate by 0.03 p.p. These results represent the average on the basis of 97 models used by members of the MAG group, including 42 models of national economies, 40 IMF models and 15 ECB and the European Commission models. Research published by OECD (Slovik and Cournède, 2011) indicated that the impact of the capital adequacy ratio on economic growth could range from -0.05 to -0.15 p.p. annually. Research carried out by the European Commission (European Commission, 2011) indicates that the increase in capital adequacy ratio of banks in the euro area by 1 p.p. could bring a drop in the GDP growth rate by 0.15 p.p. during eight years. Research for Poland (UKNF, 2011) shows that the increase in the average capital adequacy ratio by 2.5 p.p. could lead to a drop in the annual GDP growth rate by 0.03 p.p. Berben et al. (2010) showed that new capital regulations could bring a drop in GDP growth rate by 0.1-0.3 p.p. in the Netherlands.

A direct comparison of the above-mentioned results is not possible because the analysis used different research methods for different economies and different periods of data were used in each case. However, one can accept the general conclusion based on empirical analysis that an increase in capital requirements may negatively affect the rate of economic growth in the medium term. The lower rate of growth ranges from a few hundredth of a percentage point to dozens of hundredths of a percentage point as a result of increase of capital requirement CET1 by 1 p.p.

Complementary calculations

In Figures 11-15 and Tables 7-11 we put results of the impact of different values of CET1 shock – 1, 5, 10, 15 and 20 p.p., respectively on the GDP growth rate (y/y). Again we analyse impacts for three year horizon. The results were obtained on the basis of bootstrap simulation of the SVAR model (for levels of variables), as a result of IRF transformation to y/y differences (n=999 replications, confidence interval 2σ).

Legend:

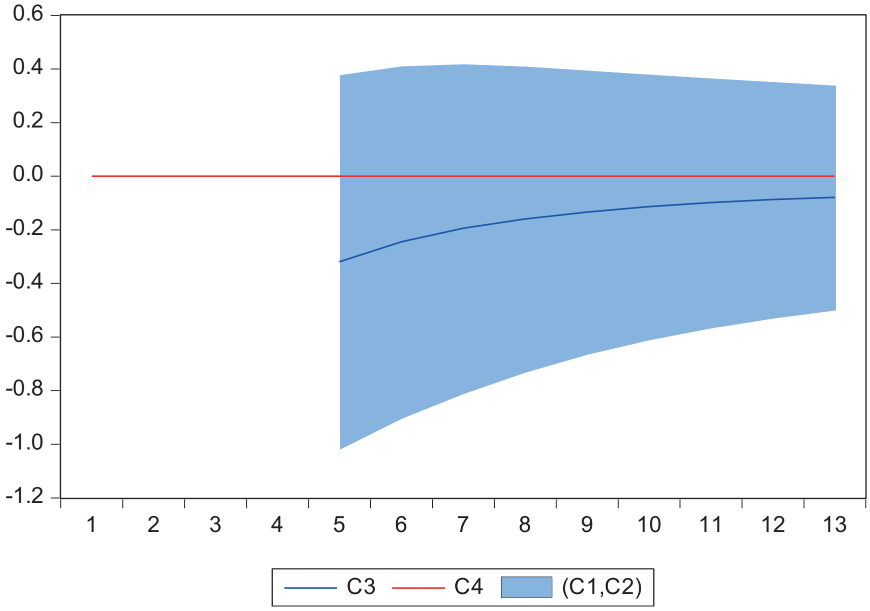
C1 - lower band of the 95% confidence interval,

C2 - upper band of 95% confidence interval,

C3 - central tendency.

On the X axis, successive periods of simulation are given. On the Y axis, the values of the annual GDP growth rate relative to the baseline scenario are given. In particular, for the central tendency C3, these values mean a reduction in the GDP growth rate due to the CET1 shock.

Figure 11. Illustration of the effect of CET1 increase by 1 p.p. on GDP growth rate



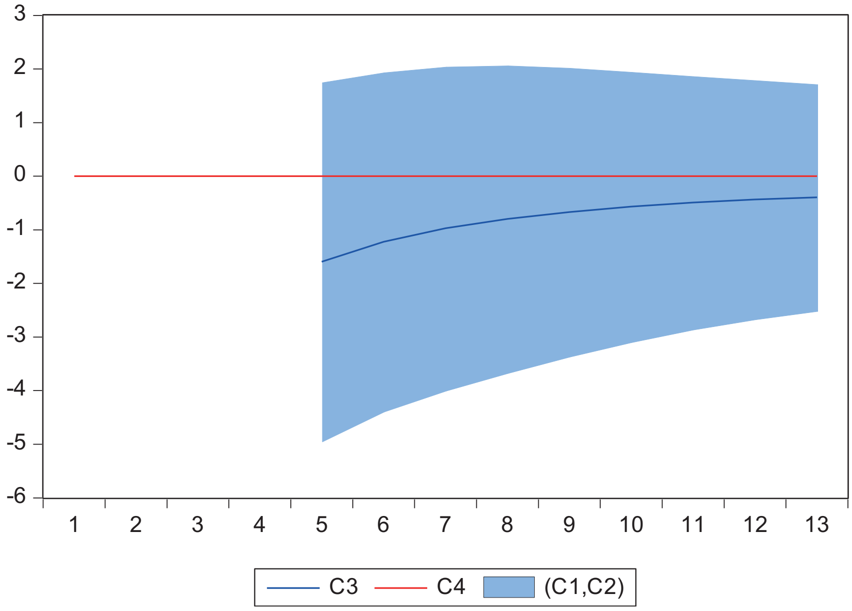
Source: own elaboration.

Table 7. Effect of CET1 increase by 1 p.p. on GDP growth rate

Specification	C1	C2	C3
2017Q4	-1,02	0,38	-0,32
2018Q1	-0,90	0,41	-0,24
2018Q2	-0,81	0,42	-0,19
2018Q3	-0,73	0,41	-0,16
2018Q4	-0,66	0,40	-0,13
2019Q1	-0,61	0,38	-0,11
2019Q2	-0,56	0,37	-0,10
2019Q3	-0,53	0,35	-0,09
2019Q4	-0,50	0,34	-0,08

Source: own elaboration.

Figure 12. Illustration of the effect of CET1 increase by 5 p.p. on GDP growth rate



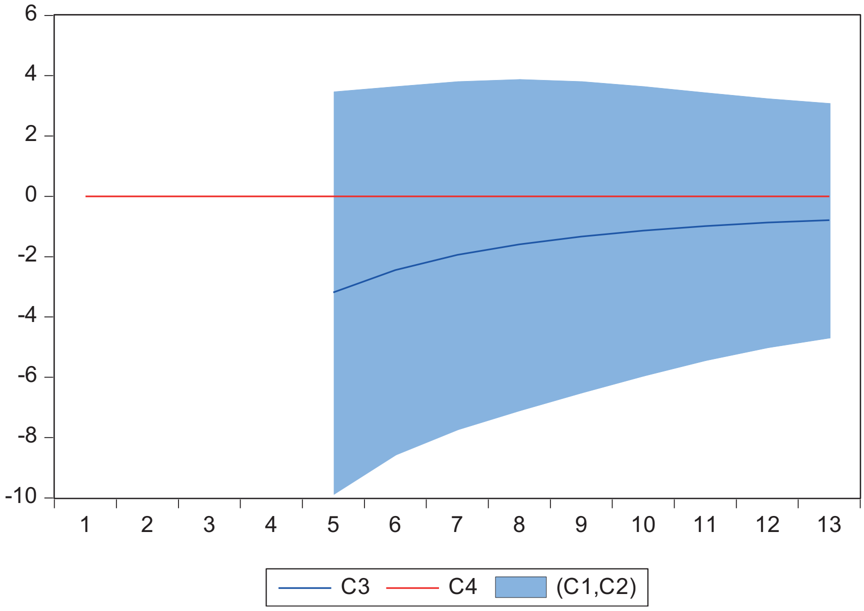
Source: own elaboration.

Table 8. Effect of CET1 increase by 5 p.p. on GDP growth rate

Specification	C1	C2	C3
2017Q4	-4,94	1,76	-1,59
2018Q1	-4,38	1,94	-1,22
2018Q2	-4,00	2,05	-0,97
2018Q3	-3,67	2,07	-0,80
2018Q4	-3,36	2,03	-0,67
2019Q1	-3,09	1,95	-0,57
2019Q2	-2,86	1,87	-0,49
2019Q3	-2,66	1,80	-0,43
2019Q4	-2,51	1,72	-0,39

Source: own elaboration.

Figure 13. Illustration of the effect of CET1 increase by 10 p.p. on GDP growth rate



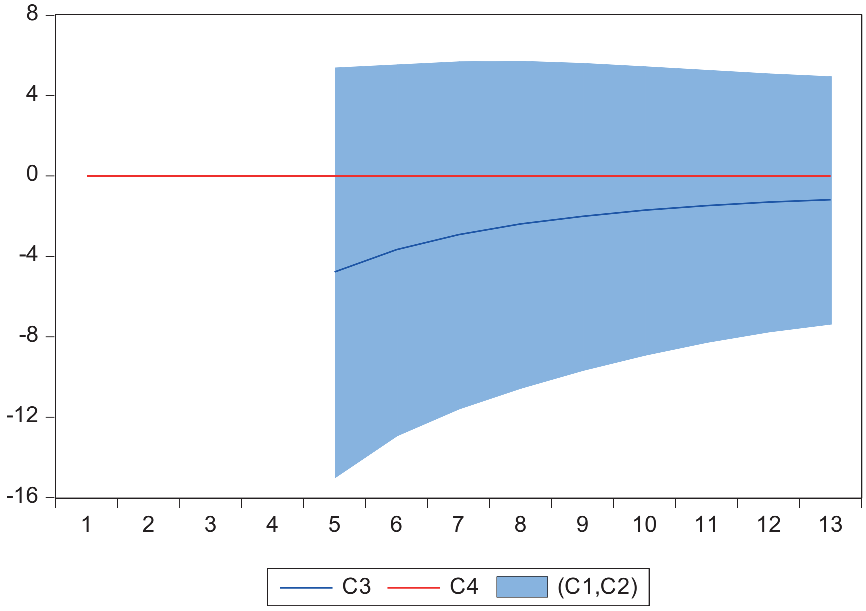
Source: own elaboration.

Table 9. Effect of CET1 increase by 10 p.p. on GDP growth rate

Specification	C1	C2	C3
2017Q4	-9,86	3,49	-3,19
2018Q1	-8,55	3,67	-2,44
2018Q2	-7,72	3,83	-1,94
2018Q3	-7,09	3,90	-1,59
2018Q4	-6,50	3,83	-1,33
2019Q1	-5,94	3,66	-1,14
2019Q2	-5,42	3,45	-0,98
2019Q3	-5,00	3,26	-0,87
2019Q4	-4,68	3,10	-0,79

Source: own elaboration.

Figure 14. Illustration of the effect of CET1 increase by 15 p.p. on GDP growth rate



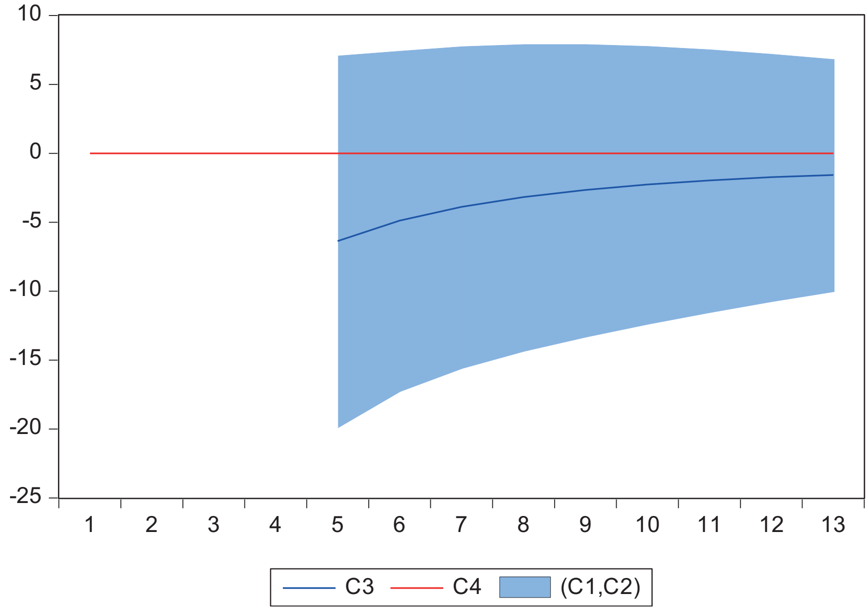
Source: own elaboration.

Table 10. Effect of CET1 increase by 15 p.p. on GDP growth rate

Specification	C1	C2	C3
2017Q4	-14,98	5,42	-4,78
2018Q1	-12,90	5,57	-3,67
2018Q2	-11,56	5,73	-2,92
2018Q3	-10,53	5,75	-2,39
2018Q4	-9,65	5,64	-2,00
2019Q1	-8,89	5,48	-1,71
2019Q2	-8,25	5,29	-1,48
2019Q3	-7,73	5,12	-1,30
2019Q4	-7,34	4,97	-1,18

Source: own elaboration.

Figure 15. Illustration of the effect of CET1 increase by 20 p.p. on GDP growth rate



Source: own elaboration.

Table 11. Effect of CET1 increase by 20 p.p. on GDP growth rate

Specification	C1	C2	C3
2017Q4	-19,85	7,11	-6,37
2018Q1	-17,23	7,46	-4,89
2018Q2	-15,57	7,79	-3,89
2018Q3	-14,32	7,95	-3,19
2018Q4	-13,28	7,94	-2,67
2019Q1	-12,36	7,81	-2,27
2019Q2	-11,50	7,57	-1,97
2019Q3	-10,71	7,23	-1,74
2019Q4	-10,00	6,85	-1,57

Source: own elaboration.

Appendix VI The net effect of increasing capital ratios

The net effect of increasing capital ratios was calculated according to the following formula:

$$\text{Net effect} = \text{Expected benefits} - \text{Expected costs}$$

The formula for calculating cumulative discounted expected benefits from higher capital ratios[40] can be written as:

$$\text{Expected benefits} = \sum_{k=1}^{10} \frac{\mathrm{C} * (p_0 - p_1)}{(1+\mathrm{i}(\mathrm{t}=1)) * (1+\mathrm{i}(\mathrm{t}=2)) * \ldots * (1+\mathrm{i}(\mathrm{t}=\mathrm{k}))}, \qquad (5)$$

where the annual discount rate i is set at the real GDP growth rate from the projection from NECMOD[41] model published in March 2018, C is the cost of a crisis expressed in % of real pre-crisis GDP, k is an index of a year, p_0 is the probability of a crisis for the Tier 1 capital ratio equal to 8.5% and current values of other explanatory variables for Poland and p_1 is the probability of a crisis for a given, higher capital ratio and current values of other explanatory variables. Both p_0 and p_1 in the baseline scenario are equal to the arithmetic mean of the corresponding probabilities from probit models and simulation, which can be written as $p_0 = \frac{1}{2}\left(p_0^p + p_0^s\right)$ and $p_1 = \frac{1}{2}\left(p_1^p + p_1^s\right)$, where indices p and s refer to the probit models and simulation respectively. This formula is applicable when calculating the benefits of increasing Tier 1/RWA ratio from any level by any value, provided that p_0 and p_1 can be determined.

The formula according to which the cumulative discounted costs of higher capital ratios were calculated, can be written as[42]:

[40] As mentioned earlier, it was assumed that the cost of a crisis does not change with an increase of capital ratios. Formula (5) applies to this case.

[41] For the time horizon longer than 3 years, the real GDP growth rate from the last available year of projection was used, i.e. from 2020. For the shorter time span, the discount rate varies depending on the period and the real GDP growth rate from the NECMOD projection for a given year. Therefore, in the formula for the benefits of increasing capital ratios, the discount rate is dependent on *t*.

[42] This formula is an approximation, because in reality quarterly and not annual data was used. Hence, in the numerator of the expression instead of the growth rates of annual GDP, YoY growth rates for quarterly data were used. This holds true also for the level of GDP, i.e. the level of quarterly and not annual real GDP was used.

$$\text{Expected costs} = \sum_{k=1}^{10} \frac{GDP_k^{NECMOD} - \left(1 + r_k^{NECMOD} + \Delta r_k^{SVAR}\right) * GDP_{k-1}}{GDP_0 * (1 + \mathrm{i}(t=1)) * (1 + \mathrm{i}(t=2)) * \ldots * (1 + \mathrm{i}(t=k))} * 100\%, \quad (6)$$

where r_k^{NECMOD} and Δr_k^{SVAR} refer respectively to the annual real potential GDP growth rate from the projection from NECMOD model and the adjustment (which is in most periods negative) to the real GDP growth rate obtained from the SVAR model. The latter is related to an increase of capital ratios. GDP_0 is the real Polish GDP in 2017, GDP_k^{NECMOD} is the level of real potential GDP from the projection from the NECMOD model for the k[th] projection year $\forall k \in \{1,2,3\}$, where k is an index of a year (for the time horizon longer than 3 years, i.e. $\forall k \in \{4,5,\ldots,10\}$, it was assumed that GDP_k^{NECMOD} will grow in line with the growth rate from the last year of the projection, i.e. $GDP_k^{NECMOD} = (1 + r_3^{NECMOD}) * GDP_{k-1}^{NECMOD}$ $\forall k \in \{4,5,\ldots,10\}$), and $GDP_k = GDP_k^{NECMOD}$ $\forall k \in \{1,2,\ldots,10\}$. In the same way as in the formula for expected benefits, the annual discount rate i was set to be equal to the real GDP growth rate from the projection from NECMOD from March 2018, and for the time horizon longer than 3 years, the real GDP growth rate from the last available year subject to projection, i.e. 2020.

Appendix VII The net effect of increasing Tier 1/RWA capital ratios

Figure 16. Net effect of an increase of Tier 1/RWA capital ratios from 8.5%, under the assumption that probability of a crisis changes in accordance with the results of probit models. Costs of increasing capital ratios are non-zero over the entire 10-year time horizon.

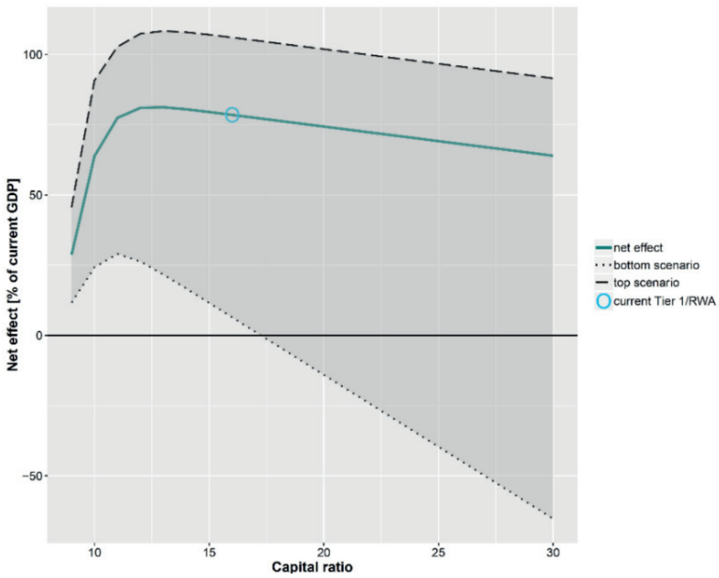


Figure 17. Net effect of an increase of Tier 1/RWA capital ratios from 8.5%, under the assumption that probability of a crisis changes in accordance with the results of the simulation. Costs of increasing capital ratios are non-zero over the entire 10-year time horizon.

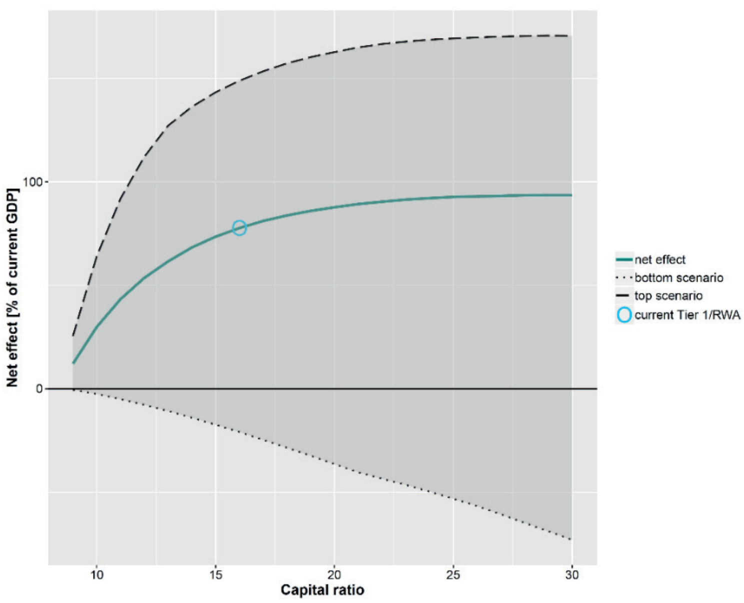
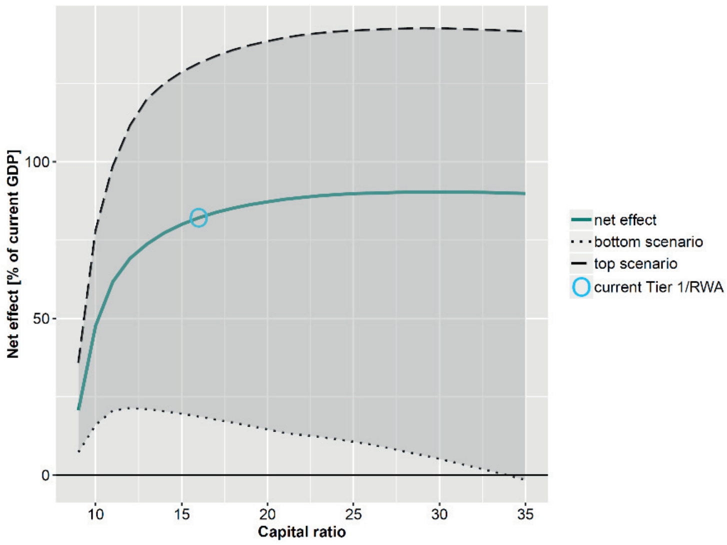
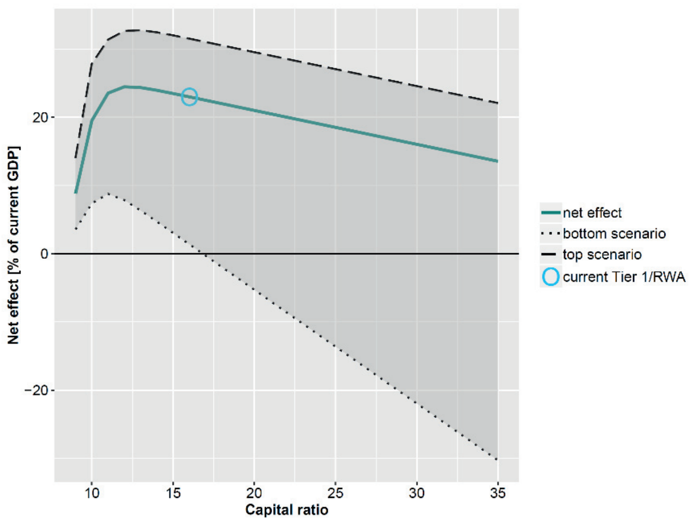


Figure 18. Net effect of an increase of Tier 1/RWA capital ratios from 8.5%, under the assumption that probability of a crisis changes in accordance with the average of results from probit models and the simulation. Costs of increasing capital ratios go to zero after 3 years.



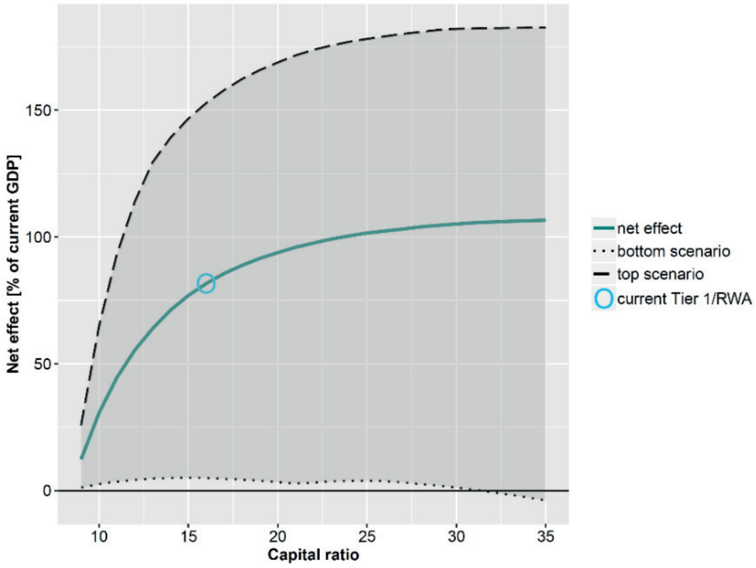
Notes: when taking average of crisis probabilities from probit models and the simulation, the largest net effects are achieved with Tier 1/RWA ratios at the level between 12% and 31%. This range is determined by the vertices of the parabolas (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of an increase of capital ratios.

Figure 19. Net effect of an increase of Tier 1/RWA capital ratios from 8.5%, under the assumption that probability of crisis changes in accordance with the results of probit models. Costs of increasing capital ratios go to zero after 3 years.



Notes: when taking crisis probabilities from probit models, the largest net effects are achieved with Tier 1/RWA ratios at the level between 12% and 14%. This range is determined by the vertices of the parabolas (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of an increase of capital ratios.

Figure 20. Net effect of an increase of Tier 1/RWA capital ratios from 8.5%, under the assumption that probability of a crisis changes in accordance with the results of the simulation. Costs of increasing capital ratios go to zero after 3 years.



Notes: when taking average of crisis probabilities from the simulation, the largest net effects are achieved with Tier 1/RWA ratios at the level from 15% to more than 35%. This range is determined by the vertices of the parabolas (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of an increase of capital ratios.

Appendix VIII Sensitivity analysis of results regarding the optimal level of capital

The study on the optimal level of capital is subject to considerable uncertainty due to the number of assumptions. In order to verify the weight of individual assumptions, the sensitivity analysis of results regarding the optimal level of capital presented in Figures 7-8 was carried out. Sensitivity to assumptions regarding the cost of a banking crisis, the discount rate of future costs and benefits from an increase of capital ratios and the adoption of an alternative time horizon of the analysis was tested. The sensitivity of the results to a change of the threshold for the systemic loss in the simulation of the probability of a banking crisis, as well as to the modelling approach used to determine the probability of a crisis were also analysed. In the following paragraphs, the mentioned aspects of the sensitivity analysis are described in more details.

In the first step, the sensitivity of the results for the optimal level of Tier 1 ratio to the assumptions regarding the cost of a banking crisis (crisis costs equal to 10% of GDP, 20% of GDP, ..., 160% of GDP), discount rates (1%, 2%, ..., 6%) of future costs and benefits of increasing capital ratios as well as to the adoption of an alternative time horizon of the analysis (5, 10, 15 years) was checked. The time horizons longer than 15 years were excluded from the spectrum of interest. It was a consequence of the model approach used in the study, in which the benefits of increasing capital ratios are of a long-term nature and concern all future years, while the costs of increasing the capital ratios expire in the long-run.[43] From the theoretical point of view, one can find arguments that an increase of capital ratios will generate permanent costs for the economy, as well as arguments that contradict this thesis. It is easy to predict that extending the time horizon of the analysis, under the model assumptions adopted in this study, would indicate relatively higher (in relation to costs) benefits from increasing capital ratios only due

[43] As mentioned before, in order to mitigate the effect of the model assumption (regarding the costs of increasing capital ratios) on the results, in this study, in the baseline scenario it was assumed that costs of increasing capital ratios will be non-zero over the entire 10-year period, i.e. for the time horizon between 4 and 10 years, a fixed value of the rescaled impulse response function from the 12th quarter from SVAR model was used. However, this is a simplistic approach as in the long term in the SVAR model the impulse response function goes to zero.

to the model approach used. Appropriate sensitivity analysis of results to the time horizon would require a change in the assumptions regarding the persistence of costs, which in turn would require a change of the modelling approach used to calculate those costs.

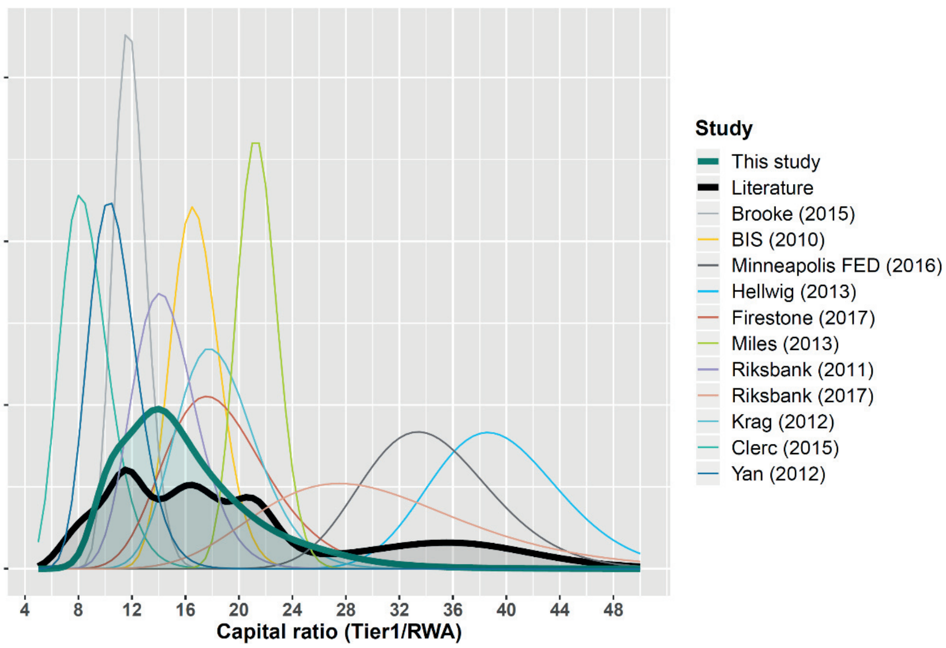
For each set of assumptions, the net effect of increasing capital ratios was calculated according to the same methodology as the baseline results presented in Figure 7.[44] This effect corresponds to a gradual increase of aggregate Tier 1/RWA from 8.5% to 9%, 10%, 11%, ... up to 30%. The range of capital ratios that includes the optimal Tier 1/RWA was determined based on the values for this net effect. The limits of this range are the vertices of parabolas (bottom, top and central scenario), which correspond to the low, high and moderate value of the net effect of an increase of capital ratios, analogously like with the baseline assumptions.

Then, similarly as in the baseline scenario, the lognormal distributions were fitted to the ranges for the optimal capital ratio obtained under mentioned assumptions regarding the costs of a crisis, discount rates and the time horizon of the analysis. Parameters of the distribution were selected in such a way that the value of the cumulative distribution at the lower limit of the range for the optimal capital ratio was 0.05 and for the upper limit 0.95.

Figure 21 presents distributions fitted to the ranges for the optimal capital ratio obtained in the sensitivity analysis of this study and ranges fitted to results found in the literature (as well as a distribution that averages the latter ones). Results from the literature converted into the same capital ratio measure, namely Tier 1/RWA were used.

[44] The remaining assumptions adopted in the baseline scenario for the purpose of calculating the net effect and determining the range of capital ratios that includes the optimal Tier 1/RWA, were not changed, i.e. the probability of a crisis is the average probability from probit models and the simulation; the cost of increasing capital ratios is non-zero over the entire ten-year period; the central scenario was obtained on the basis of central estimates of the likelihood of a crisis and the central path of the impulse response function from the SVAR model; the bottom scenario was constructed under the assumption of low probabilities of a crisis and the lower bound of the confidence interval of the impulse response function from the SVAR model (high costs of raising capital ratios); the top scenario was created by adopting high probabilities of a crisis and the central path of the impulse response function from the SVAR model.

Figure 21. Density of distributions for the optimal capital ratio obtained in the sensitivity analysis of this study and according to selected studies from different countries.[45]



Source: own study based on S&P Global Market Intelligence, BIS (2010), Yan et al. (2012), Miles et al. (2013), Brooke et al. (2015), Sveriges Riksbank (2011), Sveriges Riksbank (2017), Krag-Sorensen (2012), Clerc et al. (2015), Admati and Hellwig (2013), Firestone et al. (2017), Minneapolis FED (2016).

Notes: The green line labeled as "This study" represents the average of the lognormal density functions fitted to the results of this study assuming various costs of a crisis (10% of GDP, 20% of GDP, ..., 160% of GDP), discount rates (1%, 2%, ..., 6%) and the time horizon of the analysis (5, 10, 15 years). The probability of a crisis in each of these variants of the analysis is equal to the average of probabilities from probit models and the simulation with the baseline systemic loss threshold. The black line labeled as "Literature" presents the arithmetic mean of the values of the density functions fitted to the ranges of capital ratios from the literature.

Conclusions concerning the value of the optimal level of Tier 1 ratio that can be drawn from the sensitivity analysis do not differ much from those from the baseline scenario. Taking into account the results obtained from the sensitivity analysis and from the literature, the optimal

[45] For the purpose of the sensitivity analysis, values for Tier 1/RWA between 8.5% and 50% were in the area of interest. The upper limit of the range for the optimal capital ratio in each scenario of the sensitivity analysis was determined as min (50%, upper limit of the optimal capital ratio range).

level of Tier 1 capital to risk-weighted assets is around 18%.[46] The sensitivity analysis of the results of this study without taking into account the literature indicates that the optimal level of Tier 1/RWA is equal to 16%.

In the second part of the sensitivity analysis, apart from changes in assumptions regarding costs of crises, discount rates and time horizon of the analysis, sensitivity to the model approach used to determine the likelihood of a crisis was taken into account as well as an alternative systemic loss threshold in the simulation approach.

The value of the threshold for the systemic loss is one of the key elements of the simulation approach and has a significant impact on the results. The systemic loss threshold was defined as the percentage loss of the surplus of aggregate capital in the banking sector over the regulatory minimum. The process of determining this threshold is described in Appendix III. The sensitivity analysis took into account the nonparametrically estimated upper bound of the ninety-five percent confidence interval for the systemic loss threshold, equal to about 22% of the surplus. The lower bound of the confidence interval of around 2% was rejected as economically unjustified. Therefore, the probability of a systemic crisis from simulation is considered in two variants - a central estimation of the systemic loss threshold (about 8% of the surplus over the regulatory minimum) and the upper bound of the confidence interval (about 22% of the surplus).

Having calculated the probability of a systemic crisis in the simulation approach (for two thresholds of systemic loss) and knowing the probability of a systemic crisis obtained from probit models, separately for these three model approaches sensitivity analysis of the results for the optimal level of capital to the assumptions regarding the cost of a banking crisis, the discount rate and the time horizon was carried out.[47] Like previously, 6 values for a discount rate (from 1% to 6%), 3 different time horizons of the analysis (5, 10 and 15 years) and 16 crisis costs (from 10% to 160% of annual GDP) were taken into account. All combinations of these

[46] The average of the expected value from the study for Poland (taking into account various possible assumptions regarding the cost of a banking crisis, the time horizon of the analysis and the discount rate) and from the literature is around 18%. The expected value from the sensitivity analysis for Poland was calculated empirically and is around 16%.

[47] This part of the sensitivity analysis was also carried out under the assumption of non-zero (within 10 years horizon) costs of increasing capital ratios.

variables were examined for two variants of the simulation approach and for probit models. The calculations were performed in the same way as in the first part of the sensitivity analysis, assuming alternative thresholds for the systemic loss in the simulation and taking the probabilities of a banking crisis separately from the simulation (with two thresholds) and from probit models.

Figures 22-33 show the distributions for the optimal Tier 1/RWA ratio that correspond to different model approaches and selected costs of a crisis - probit models, simulation with a systemic loss threshold of approx. 8% and approx. 22% of the capital surplus over the regulatory minimum and the approach, in which the likelihood of a crisis has been averaged (average of probabilities from probit models and from simulation with the baseline systemic loss threshold).

Results obtained based on those model approaches differ substantially. The results based on probit models estimated on a wide sample of countries suggest that the optimal level of Tier 1 capital in the Polish banking system should not exceed 14% of risk-weighted assets. The basic problem in this approach is the lack of high capital ratios in the sample. The aggregate Tier 1/RWA ratio before the last financial crisis did not exceed 18% in any country, and values above 20% were sporadically appearing in the sample only in recent years. The probability of a systemic crisis for capital ratios higher than 20% obtained from the model estimated on such data must therefore be close to zero, which is not necessarily true. Therefore, this model potentially underestimates the values of the lower and upper limit of the range for the optimal capital ratio. The levels of the optimal capital ratio obtained from the sensitivity analysis in the simulation approach with the lower threshold are much higher. The simulation approach, however, has some flaws too. The parameters are calibrated, which gives the simulation approach a theoretical character, implying the necessity of introducing numerous assumptions. This approach, however, enables obtaining non-zero values for probability of a systemic crisis at higher capital ratios, which is not possible based on historical data. In the presence of strong interconnectedness in the banking sector, unequal allocation of capital, significant exposures to other countries and the problem of fire sales, a systemic crisis may also occur in a situation of good capitalization of the banking sector. The probit models and the simulation are not without flaws but using both of them allows to illustrate the range of uncertainty around the baseline results.

Results obtained within each of the model classes are also sensitive to assumptions. The results for the optimal Tier 1/RWA ratio show the greatest sensitivity to assumptions regarding the cost of a banking crisis. The greater the cost of a banking crisis, the higher the values of the lower and upper limits of the range determined by the parabola vertices describing the net effect of an increase of capital ratios for the bottom, top and central scenario. This is illustrated by a gradual shift in the mass of the log-normal distribution along with an increase of the cost of a crisis towards higher capital ratios. Since the benefits from higher capital ratios are of a long-term nature, and their costs in accordance with the adopted research method (SVAR model) are short-term, extending the time horizon of the analysis raises the upper and lower limits of the range for optimal capital ratios. A reduction of the discount rate has a similar effect. However, the results are relatively insensitive to changes in the discount rate of future costs and benefits.

The distributions that use results from probit models show the lowest sensitivity to assumptions (see Figures 22, 24, 26). The distributions using results from the simulation with the baseline threshold ("lower threshold" in the title of the figure) for the cost of a crisis equal to 19.5% are relatively strongly concentrated at the left end of the X-axis. This fact indicates that the net effect of raising capital ratios in this case is driven mostly by the low cost of a crisis, and the remaining assumptions (time horizon of the analysis and discount rate) are losing importance (see Figure 23). Figures 25 and 27 for the costs of a crisis equal to 63% of GDP and 158% of GDP show that results for the simulation with a lower threshold are more sensitive to other assumptions. Looking at the results of the sensitivity analysis for the simulation with the higher threshold (see Figures 28, 30, 32), it is visible that they are moderately sensitive to assumptions regarding the time horizon of the analysis and the discount rate for each of the costs of a crisis. Similarly, results are moderately sensitive when the probability of a crisis is accepted as the average of probit models and simulation with lower threshold (see Figures 29, 31 and 33).

Figure 22.[48] Probit model, crisis cost 19.5% of GDP.

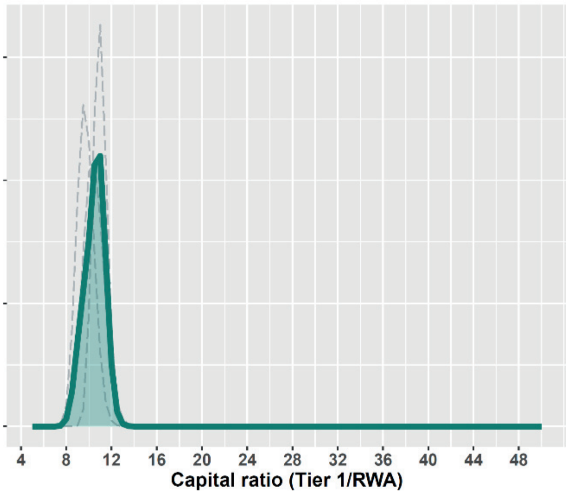


Figure 23. Simulation (lower threshold), crisis cost: 19.5% of GDP.

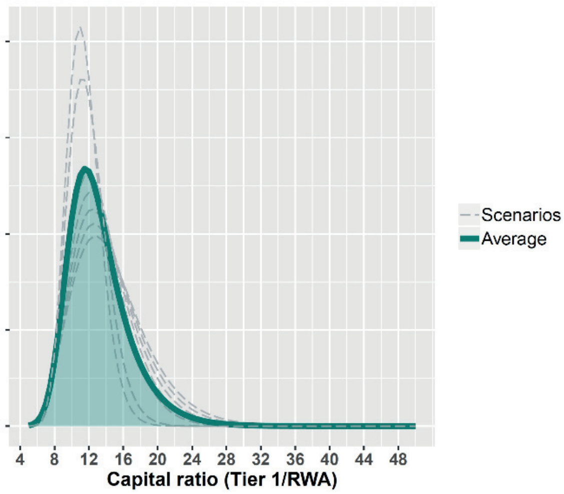


Figure 24. Probit model, crisis cost: 63% of GDP.

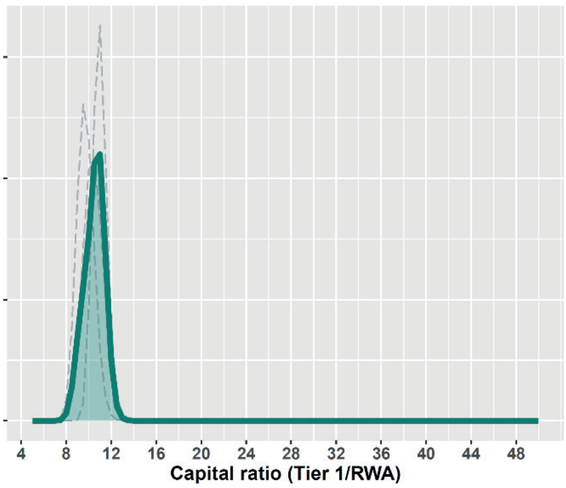
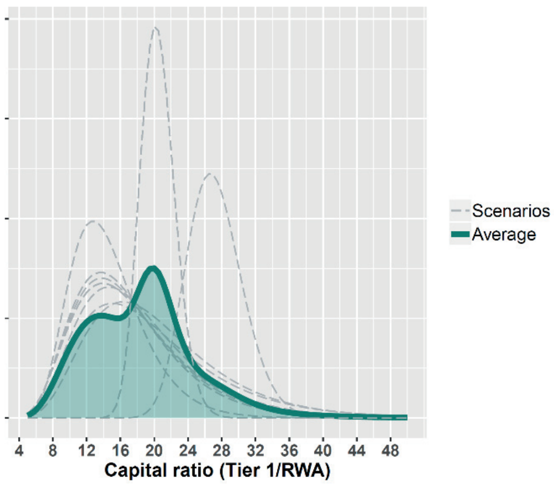


Figure 25. Simulation (lower threshold), crisis cost: 63% of GDP.



[48] Figures 22-33 show the lognormal distributions of the optimal capital level based on different approaches - probit models, simulations with a systemic loss threshold of about 8% of surplus capital over the regulatory minimum from the previous period ("lower threshold" in the titles of Figures 23, 25 and 27), simulation with a systemic loss threshold of about 22% of the surplus over the regulatory minimum from the previous period ("higher threshold" in the titles of Figures 28, 30 and 32) and the average of the probabilities from probit models and the simulation with the lower threshold. The green line is the average of 18 scenarios depicted with gray lines (3 different time horizons of the analysis and 6 discount rates).

Figure 26. Probit model, crisis cost 158% of GDP.

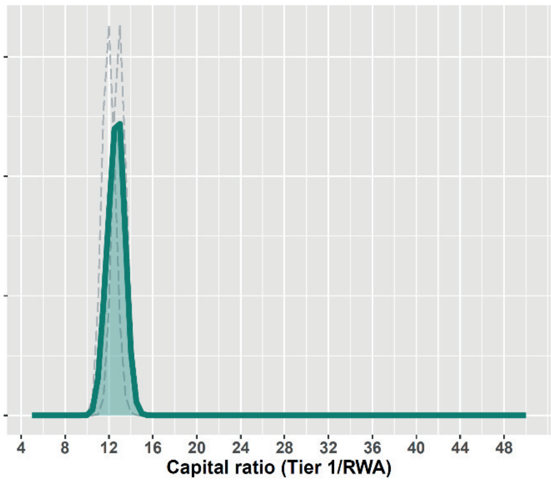


Figure 27. Simulation (lower threshold), crisis cost: 158% of GDP.

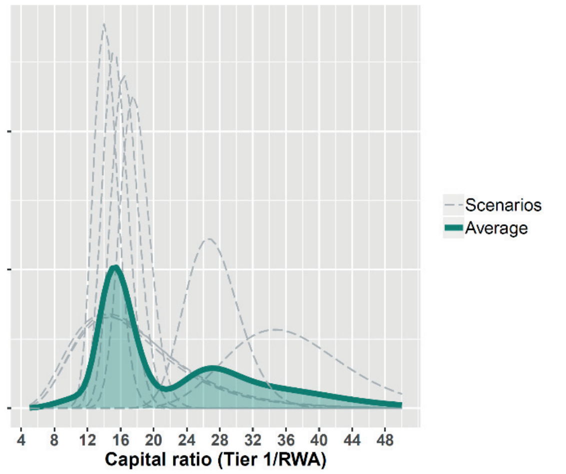


Figure 28. Simulation (higher threshold), crisis cost: 19.5% of GDP.

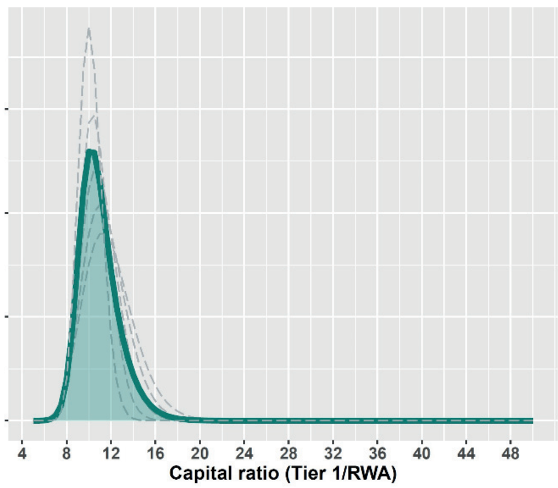


Figure 29. Average from probit models and simulation, crisis cost: 19.5% of GDP.

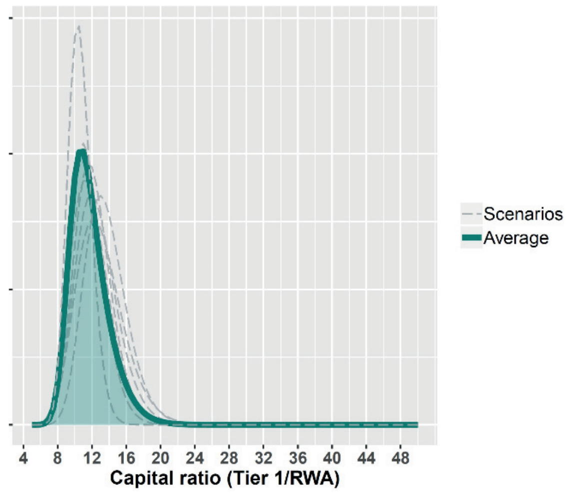


Figure 30. Simulation (higher threshold), crisis cost: 63% of GDP.

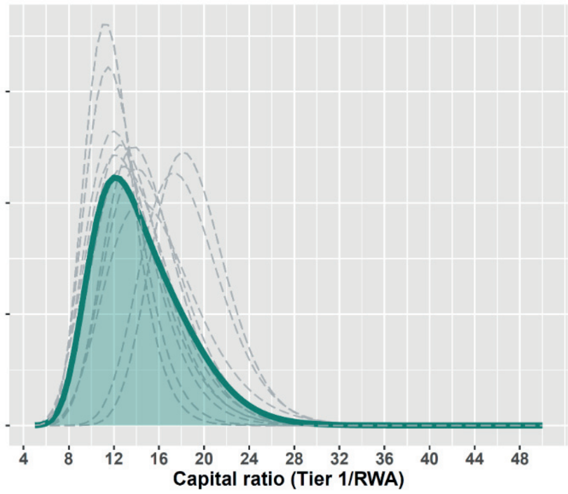


Figure 31. Average from probit models and simulation, crisis cost: 63% of GDP.

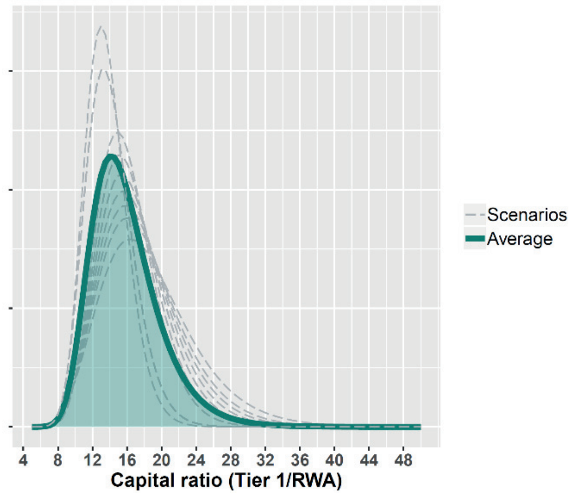


Figure 32. Simulation (higher threshold), cost: 158% of GDP.

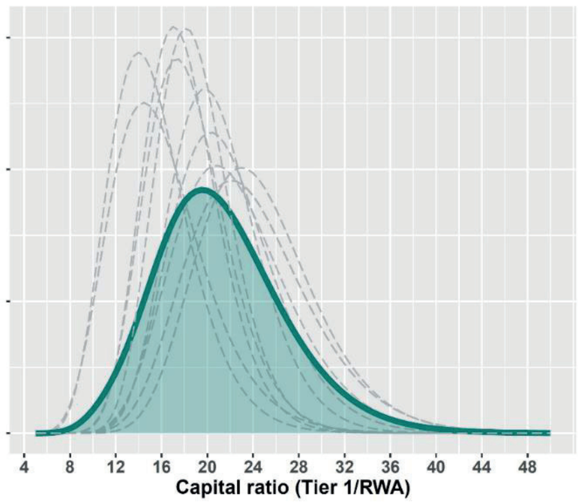
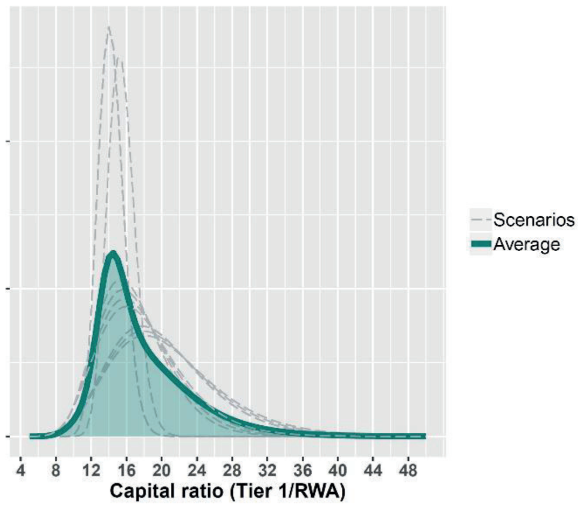
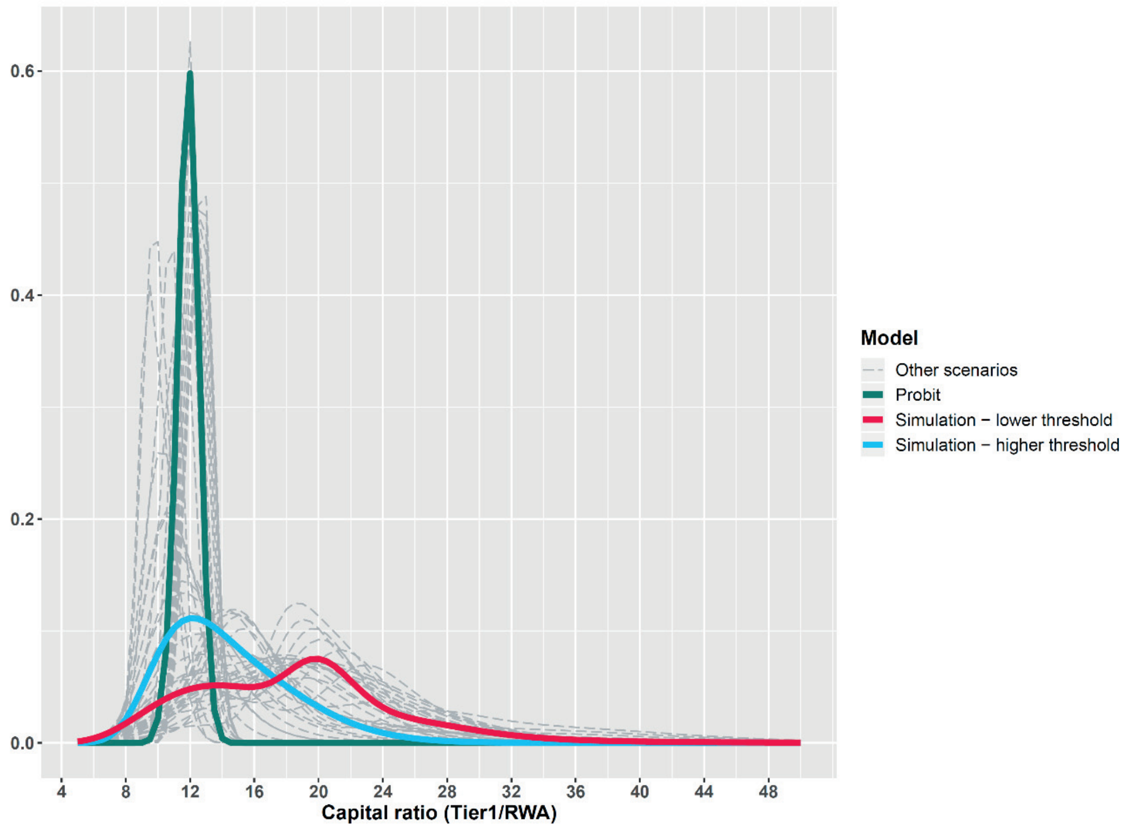


Figure 33. Average from probit models crisis and simulation, crisis cost: 158% of GDP.



To illustrate in a more concise way the results of the sensitivity analysis, Figure 34 shows the average lognormal distributions approximately corresponding to the ranges for the optimal capital ratio in each variant of the analysis.

Figure 34. Probability distributions of the optimal Tier 1/RWA ratio based on different models.



Notes: the green, red and blue lines show the distributions of the optimal level of the Tier 1 ratio for probit models and for the simulation with the adoption of a lower and higher threshold of the systemic loss respectively. Each of these lines was created by averaging the probability density function for 18 scenarios (3 time horizons of the analysis and 6 discount rates) for the cost of a crisis equal to 63% of GDP. Dashed gray lines are averaged (across the discount rates and the time horizons of the analysis) probability density functions for probit models and two variants of simulation for crisis costs between 10% and 160% of GDP.

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