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Economic Policy Analysis

Optimal capital ratios for banks in the euro area

Based on a cost-benefit analysis, we find optimal risk-weighted bank capital ratios in the euro area between 15 and 30 percent. The estimated optimum in all cases is higher than the current Basel III minimum requirements. More capital for banks can lead to higher lending rates on the one hand, but also to better absorption of financial shocks and mitigating banking crises on the other.

The optimum varies greatly between euro area Member States. We find lower estimates for Member States with a more stable economy and a banking sector that can easily attract funding.

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Abstract

In this paper we estimate the optimal level of capital for banks in the euro area. Higher bank capital requirements may be socially costly, as rising funding costs might result in higher lending rates. On the other hand, if increasing bank capital is socially costly, so too is not raising bank capital sufficiently. Reserves help banks absorb financial shocks and thereby reduces the likelihood of banking crises. Our baseline estimates show an optimal risk-weighted capital ratio of around 22%. Alternative estimates by varying assumptions yield a range of optimal ratios between 15% and 30%. Despite this considerable spread, this means that the estimated optimum is higher than the current Basel III minimum requirements in all cases. We also find substantial heterogeneity across member states. Optimal ratios range from 27% for banks in Cyprus to as low as 8% in Belgium. This suggests that optimal ratios are likely inversely related to the resilience of national economies and the ease with which banks in different member states can raise capital.

Key words: Bank regulation, capital structure, macroprudential policy.
JEL classification: C33, C54, E44 , G15, G21.

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1 Introduction

Bank capital provides an important buffer to help absorb financial shocks. This, in turn, helps to stabilize the real economy. Following the Great Recession, policymakers and academics have debated about the level of bank capitalization needed to safeguard the economy, because an international banking crisis played a central role during the onset of the crisis (see, e.g., Admati *et al.*, 2010; Meh & Moran, 2010). In the euro area, the role of banks was tested a second time during the Euro crisis.

Prior to the financial crisis, reforms on banking supervision and regulation were already internationally organized, but this intensified after the recent crises episodes (Kapstein, 1989; Schoenmaker, 2013; Penikas, 2015). In 1988 a risk-weighing scheme was introduced by the Basel I reform, in order to take the differences in risk of asset classes into account (BIS, 1988). The minimum required capital was set at 8% of risk-weighted assets.[1] Bank regulation was tightened internationally by the Basel II capital accord in 2006 (BIS, 2006). In this accord, capital adequacy requirements were set and the framework of risk-weighted assets amended. Additional supervisory review was strengthened, and banks had to disclose more information to ensure market discipline. The Basel III reforms (BIS, 2010b) have set the minimum risk-weighted capital requirement higher in response to the deficiencies in financial regulation during the crisis and to strengthen to shock absorbing capacity of banks, exemplified by a minimum of 12.5% for Global Systemically Important Banks (G-SIBs).[2]

However, higher bank capital requirements may have a negative impact on credit supply and therefore the economy, as rising funding costs might result in higher lending rates (and thus lower lending volumes, see e.g. Aiyar *et al.*, 2016 and Meeks, 2017). If this is the case, then raising the capital requirements would be socially costly. On the other hand, if increasing bank capital is socially costly, so too is not raising bank capital sufficiently. Reserves help banks absorb financial shocks and thereby reduces the likelihood of banking crises. Insufficient capital thus poses a risk to the financial sector and the economy as a whole.

In this paper we provide estimates of the optimal level of bank capital for banks in the euro area by weighing the costs against the benefits of higher reserve requirements. To our knowledge, these represent the first empirical estimates for the euro area as a whole. We also obtain estimates for individual euro area countries.

Our baseline largely follows the analysis of optimal bank leverage for the United Kingdom in Miles *et al.* (2013), hereafter referred to as Miles. Our multi-country approach, however, allows us to extend our analysis further to investigate whether there are differences in the optimal level

[1] That is, the ratio between total capital and risk-weighted assets. Before the introduction of this framework, leverage ratios (total assets over total capital) were most commonly used in supervision.

[2] Capital ratios of 12.5% core capital relative to risk-weighted assets often implies only around 4-5% unweighted.

of bank capital caused either by differences in the resilience of the Euro member states' banking sectors, or by differences in the levels of financial frictions across Euro member countries.

Our results show an optimal level of risk-weighted capital for banks in the euro area centers around 22%. This outcome is fairly robust to several sensitivity checks, and suggests that optimal capital ratios are in all cases higher than the current Basel III minimum requirements. Additionally, it indicates that European banks require higher reserves than they currently hold. Other studies for the UK and US, and one theoretical study for the euro area, find optimal ratios ranging from around 10% to 25%. We will elaborate on the differences in these studies in the next section. When exploring heterogeneities between member states, we find the optimal ratio to range between 27% in Cyprus to 8% in Belgium. This finding indicates that optimal ratios are inversely related to the resilience of national economies and the ease with which banks in different member states can raise capital.

The remainder of the paper is structured as follows. Section 2 provides a review of the literature, and Section 3 places our study in a historic perspective of bank reforms and crises. Section 4 presents the empirical methodology, and describes the data we use in our analysis. In Section 5 we discuss our baseline results. In Section 6 we present our robustness checks. Finally, in Section 7 we end with some concluding remarks.

2 Literature review

The body of empirical literature on optimal bank capital is modest. Birn *et al.* (2020) provide a valuable overview. Our contribution to the existing literature is twofold. First, we provide empirical estimates for the euro area. To our knowledge, we are the first to take on this task. Second, due to the granularity of our data we are also able to provide estimates for individual member states.

The seminal paper on optimal bank capital is by Admati *et al.* (2010). In this work the authors advocate for higher capital ratios, because, they argue, attracting more capital is not socially expensive. They argue that high leverage (i.e. weak capitalization) actually makes banks more inefficient and poses risks created by the expectation of bailouts. The authors, however, do not provide empirical estimates of optimal ratios, but nonetheless argue that unweighted capital ratios be increased to around 20% to 30%.

The Basel Committee on Banking Supervision (BCBS) delivered an empirical assessment of the impact of measures to strengthen the position of banks (BIS, 2010a). The analysis relies on the trade-off between the benefits of higher capital ratios, in terms of reducing the probability of a crisis and the amplitude of GDP variability, and the costs, via increased lending rates. For estimating benefits, they consider both a top-down approach, using country level data to estimate the relation between crises and bank capital, and a bottom-up approach, estimating the relation between capital and default risk on a bank level and then extrapolating this to the country level. The analysis considers other regulation constant, except for some allowance for liquidity regulation. In their model they take representative banks from 13 countries over the period 1993 to 2007.[3] Ultimately, they find optimal risk-weighted ratios of between 10% and 15% depending on the extent to which permanent output effects are assumed to follow from a banking crisis.

For a subset of BCBS members, Fender & Lewrick (2016) update the BIS (2010a) framework with a new regulatory environment, including more restrictive capital definitions, more stringent requirements for the calculation of risk-weighted assets, liquidity regulation, and capital surcharges for Global Systemically Important Banks (G-SIBs). Also they use historical data in their estimations of costs and benefits. They find optimal ratios of between 10% to 11% for Core Equity Tier 1 ratios (CET1). Barrell *et al.* (2009), Bank of Canada (2010) and Kato *et al.* (2010) provide other early assessments of the merits of bank capital, but do not estimate optimal ratios.

In Miles the authors were the first to estimate optimal risk-weighted ratios for banks in a single country. They estimate optimal risk-weighted capital ratios for banks in the United Kingdom (UK) based on data from 1992 to 2010. They use the bottom-up approach in estimating the benefits of bank capital, with a one-to-one relation between bank assets and permanent output effects, and rely on the volatility of the entire economy to prevent with bank capital instead of only with a financial nature. Regarding costs, they use a structural model to relate changes in banks' funding costs to social costs, including a Modigliani-Miller effect of 45%. Their cost-benefit analysis of acquiring more capital results in optimal ratios in the range of 16% to 20%.

In the framework of BIS (2010a), but estimating the model for banks in the UK, Schanz *et al.* (2011) find ratios to be between 10% to 15%. Brooke *et al.* (2015) provide estimates for the UK as well, but take a wider perspective on the shock absorbing capacity of banks by considering the Total Loss Absorbing Capacity (TLAC). Additionally, they assume that a credible resolution regime lowers the costs of future banking crises, due to effective action by regulators. They also use a combination of semi-structural models in which more bank capital reduces real investments, and in turn potential output. With a full-pass trough of funding costs to customers, they find optimal ratios in the range of 10% to 14%.

In a study on optimal capital ratios for banks in the United States (US), Barth & Miller (2018) find an optimal baseline estimate of 19%. They estimate a Modigliani-Miller effect of zero in their calculations of the costs of bank capital, and use the top-down approach for estimating

[3]Banks from the following countries are included in the analysis: Australia, Canada, France, Germany, Italy, Japan, Korea, Mexico, the Netherlands, Spain, Switzerland, the United Kingdom and the United States.

marginal benefits. The Federal Reserve Bank of Minneapolis (2017) use a model to convert nonperforming loans into capital losses, and then estimate the marginal benefit of avoiding a crisis through additional capital. Furthermore, they take the FRB/US macromodel to estimate the social costs of additional bank capital via lending rates. They derive an optimal ratio of 23.5%. Combining an estimate for the short- and long-term costs of a banking crisis, and the same approach for costs as Federal Reserve Bank of Minneapolis (2017), Firestone *et al.* (2017) find optimal ratios of between 13% to 25%. Using estimates for the US, with a top-down approach for benefits and a different CAPM approach than Miles *et al.* (2013), but extending the results also to Japan and Western Europe by extrapolation, Cline (2017) finds optimal core capital ratios between 12-14%. Finally, using DSGE models to estimate the social costs of a banking crisis Almenberg *et al.* (2017) find optimal ratios for Swedish banks of between 10% to 24% of core capital.

Most previous studies, like Miles or Barth & Miller (2018), model an inverse relation between bank capital and the likelihood of a banking crisis, whilst assuming that the cost of a banking crisis is independent of the level of bank capital. This is also our approach to modeling the marginal benefits of bank capital. Recent work by Jordà *et al.* (2021), however, shows that bank capital is unrelated to the likelihood of banking crises for the period 1870-2015, but that the severity of banking crises' does decrease with bank capital. This suggests that an alternative way to view the benefits of bank capital is not in their role in making crises less likely but in making them less costly. In either view, there are social benefits to increasing bank capital which can be weighed against its costs.

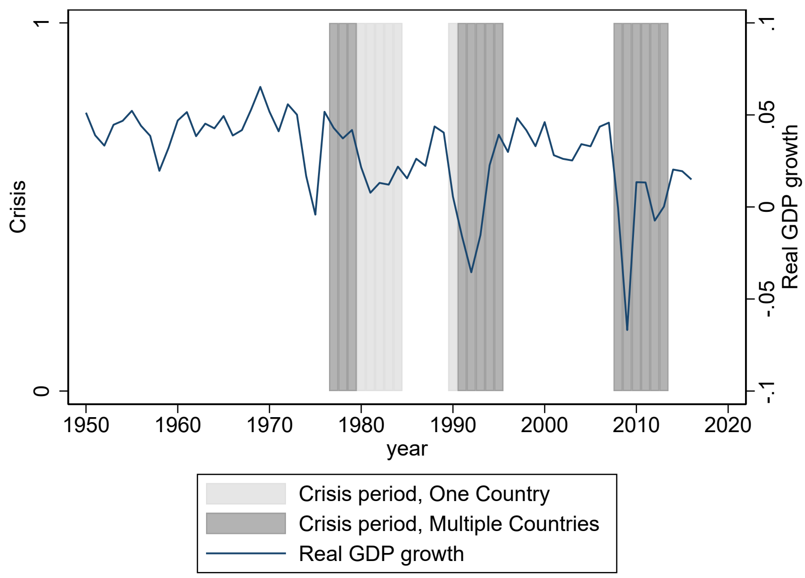
The only study with a specific focus on optimal capital ratios for European banks is by Mendicino *et al.* (2020). Using a theoretical model, the authors focus on the twin risks from defaultable loans by clients and from defaults by banks. Calibrating the model to the European banking sector, they ultimately find an optimal ratio of 15% to avert twin crises.

3 Euro area banking reforms and crises

Europe has a long history of banking crises, dating back at least to the banking crisis in Amsterdam in 1763 with the collapse of two substantial banks; subsequently, financial uncertainty spread to banks in Germany and Scandinavia (Quinn & Roberds, 2015). Thereafter, several banking crises followed, mainly due to the growing role of banks in the financial sector of Europe. The dark grey shaded areas in Figure 1 show that the euro are faced banking crises on multiple occasions and often in prolonged subsequent periods (the dating of banking crisis is based on Reinhart & Rogoff, 2009 and Laeven & Valencia, 2012). The light shaded areas show crisis periods for a single European country. A substantial drop in GDP growth can be seen in the same period, displaying how banks and the real economy are inextricably intertwined. This relation runs both ways: banking crises can cause damage to the real economy, but, vice versa, real economic shocks can also be a driver of banking crises.

Three major periods of banking crises stand out, with the most prominent periods of crisis being the Great Financial Crisis of 2007/08 and the following Euro crisis, during which average GDP of European countries declined by roughly 7 percent. Another period of banking crises occurred in the early 90s in tandem with the European Monetary System (EMS) crisis, with banking crises in Italy, Finland, Greece and France (Reinhart & Rogoff, 2009). In these countries, GDP declined accordingly by a little over 4.5 percent. In the late 70s the banking sectors in Germany and Spain faced considerable financial stress in the wake of the oil crisis; for Spain, this stress lasted until the early 80s (see e.g., Caprio & Klingebiel, 1996 and Caprio, 2003). In the early 80s also some Dutch mortgage banks faced bankruptcies. In this period, GDP growth in the euro area fell from roughly 5 percent to 0 percent.

Figure 1: Periods of crisis in European countries since 1950



Note: The blue line represents the average of GDP growth for European countries according to their 2020 membership to the EMU. GDP growth is based on the Maddisson dataset. Crisis periods are derived from the Reinhart & Rogoff (2009) and Laeven & Valencia (2012) databases.

Before these crises, discussions were initiated on the integration of European banking regulation and supervision. The European Commission launched these discussions in 1965 (see, e.g., Mourlon-Druol, 2016). In 1969, the group 'Coordination of Banking Legislations' reiterated discussions on the harmonization of banking sector supervision and regulation, without concrete results in terms of harmonizing bank regulation. Eventually in 1986 the Single European Act was accepted, which was to create a single market within the European Union and commence banking sector coordination. Finally, the process of integrating the European banking sector reached a crucial stage with the creation of the single currency with the Maastricht Treaty of 1992 and the approval and implementation of the Financial Services Action Plan in 1999.

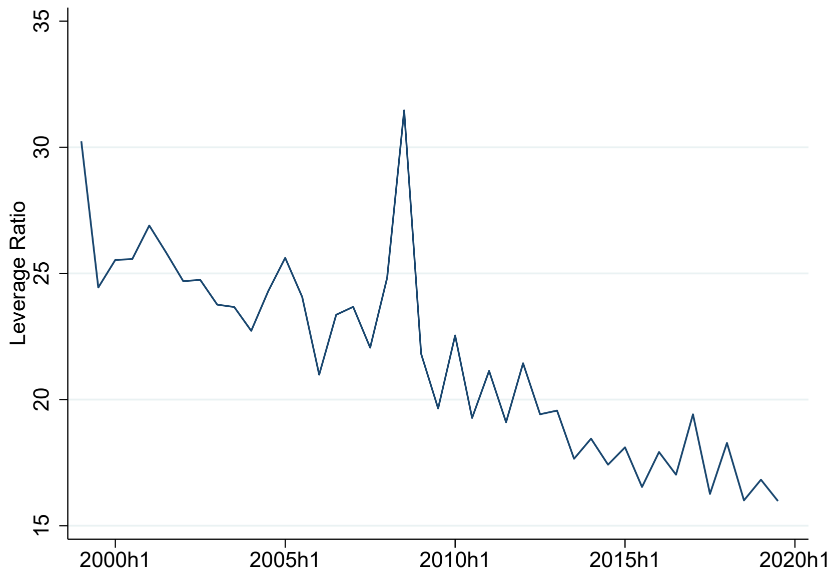
The financial crisis of 2007/08 and European sovereign debt crisis of 2010 raised the risk of contamination of financial uncertainty among European countries. To this end, the European Central Bank (ECB) conducted the first of several EU-wide stress tests in 2009 to evaluate the resilience of the European banking sector.[4] In 2011, the European Banking Authority (EBA) established a European oversight body for the banking sector. With the Banking Union roadmap of 2012, the Single Supervisory Mechanism (SSM) and Single Resolution Mechanism (SRM) were created (see, e.g., Kern, 2015; Quaglia, 2010; Howarth & Quaglia, 2013). To organize a structured resolution scheme for banks with additional funding, the Single Resolution Fund was set up in 2015 (gradually being filled until 2024).

In light of the developments concerning crisis episodes and regulatory changes, leverage ratios (total assets/capital) for banks in the euro area fell from around 30 in 1999 to close to 16 in 2019 (see Figure 2).[5] Over time banks improved their capital position, creating a larger buffer to absorb financial shocks. A large spike can be observed in 2007-08 due to the financial crisis depleting bank reserves. As the current international standard for macroprudential policy is risk-weighted capital ratios, we now turn to the most recent capitalization of banks in the euro area. At the end of our sample, December 2019, the average common equity tier-1 ratio for all banks in our dataset stands at roughly 16%. For individual member states, the average ranges from over 12% in Portugal to 22% in Belgium, which are on average close to or above the 12.5% minimum required by Basel III standards for systemic banks. The union- and country averages are displayed in Appendix B.

[4]Since then, the ECB, and later the European Banking Authority (EBA), conducted six EU-wide stresstests, in 2010, 2011, 2014, 2016, 2018 and 2020.

[5]Due to data availability, we display leverage ratios instead of risk-weighted capital ratios. Accounting standards required banks to report leverage ratios, and not necessarily risk-weighted capital ratios. This is also the reason to use leverage ratios in our estimation procedure, as will be presented in Section 4. Eventually we will translate our outcomes to risk-weighted capital ratios in order to match with the current macroprudential standard.

Figure 2: Leverage ratios of banks in the euro area



Note: The blue line represents the average of banks in the euro area in our sample over 1999-2019. See Section 4.1 for a description of our dataset.

4 The costs and benefits of bank capital

Informed decisions about banking sector harmonization in the EMU are dependent on estimates of the optimal bank capital ratios. Stronger capitalized banks benefit from more shock absorbing capacity, reducing the probability and impact of potential future banking crises. Conversely, raising more capital may be costly, both for banks and for the society. In this section, we will investigate the costs and benefits of requiring more capital for European banks. Our cost-benefit analysis is based on Miles, which we reproduce and extend here to the European setting. To perform an analysis on the optimal level of bank capital, we need to find an expression for the present discounted value of the marginal cost of bank capital and one for the marginal benefit.[6]

4.1 Costs

The channel through which the costs of bank capital affect the real economy involves a sequence of economic effects. In the first instance, raising bank capital can lead to increasing funding costs for banks. We describe the methodology and estimation outcomes of this step in Section

[6] Throughout our analysis, we assume all other factors are held constant, including other macroprudential policy instruments. This means we disregard potential interactions of bank capital with instruments such as liquidity requirements or changes in bank resolution policy. We also do not take into account the impact of capital requirements on the risk incentives of banks, and the competition across banks. Both can have an effect on the marginal costs and benefits of bank equity (for this, see e.g. Gersbach, 2013).

4.1.1. As banks are financial intermediaries, they can pass this increase in costs on in the form of higher lending rates. This in turn leads to less credit provision, resulting in lower economic activity. Section 4.1.2 describes the empirical approach and outcomes for the social costs of acquiring bank capital. For the estimation procedure, we make use of leverage ratios due to data availability, but to make the translation to the current Basel III standard for minimum required risk-weighted capital we ultimately convert the outcomes to risk-weighted capital ratios.

4.1.1 Costs for banks

To begin with, we derive the costs of acquiring capital funding for banks. For this step, we rely on the Capital Assets Pricing Model (CAPM) to derive the Weighted Average Cost of Capital (WACC) for banks' funding decisions. Equation (1) shows the WACC relationship between the return of equity, R_e, and the return on (risk-free) debt, R_d, for the respective equity, E, and debt, D, financing relative to the total funding, $D + E$. Tax advantages for debt funding might affect funding structures of banks. As the degree to which this effect affects bank funding costs is unclear (see, e.g., Auerbach, 2002), we set τ equal to zero in our baseline. This also serves as an upper bound on the WACC, as tax advantages would result in a lowering of marginal costs. Later on, in Section 5, we will present the lower bound of our estimates by using national corporate tax rates. The WACC is expressed as follows:

$$WACC = R_e \frac{E}{D+E} + (1-\tau)R_d(1 - \frac{E}{D+E}) \tag{1}$$

The costs of raising bank capital therefore relies on the return investors demand for providing equity funding. The return on equity, R_e, can be approximated by estimating the equation, using CAPM:

$$R_e = R_f + \beta_e R_p \tag{2}$$

in which the return on equity relies on the risk free rate, R_f, the market equity risk premium, R_p, and the equity beta, β_e. The equity beta thus captures the responsiveness of a bank's return on equity to national financial market development. For the risk-free rate we take the average 10-year government bond rate of euro area member states, and for the risk-premium we use the estimate for the average of the euro area from Absolute Strategy Research (ASR), both obtained from Datastream for the period 1992-2019. The average risk-free rate is 4.74%, and the average market equity risk premium 4.11%.[7]

In addition to the risk-free rate and market equity risk premium, (2) is also dependent on the equity beta, β_e. In the CAPM model, it turns out that β_e is itself a function of leverage. To

[7] We also consider using the 10-year government bond yields and risk-premiums for individual countries. The risk-premium is, however, not available for all countries. When unavailable, we have used the average for the euro Area. We note that the cost estimates are almost identical, these results are available upon request.

demonstrate this, we start with the original CAPM equation:

$$\beta_a = \beta_e \frac{E}{D+E} + \beta_d \frac{D}{D+E} \tag{3}$$

where the total beta of bank assets, β_a, is given by the weighted sum of the bank's equity beta, β_e, and debt beta, β_d.

Adopting the approach taken in Miles and Barth & Miller, 2018, we assume that β_d is zero and that the return on debt R_d is therefore equal to the risk-free rate R_f. The existence of deposit insurance ensures that a bank's deposit liabilities are close to being risk-free. The assumption of zero risk for non-deposit debt is less obvious, but in the context of the CAPM, risk-free only implies the weaker condition that any fluctuation in the value of debt is not correlated with general market movements: $\beta_d = 0$.

Now solving (3) for our unknown β_e, then yields the equation,

$$\beta_e = \frac{D+E}{E} \beta_a \tag{4}$$

This demonstrates that β_e is inversely related to a bank's capital ratio, $\frac{E}{D+E}$. If we assume that β_a is constant over time, and if we can obtain a measure for β_e, then we can estimate the relationship between β_e and the inverse of leverage. This in turn can be substituted into the WACC in (1) to obtain costs as a function of leverage. It is from this last result that we can eventually obtain the marginal cost of leverage.

To derive the WACC equation, we thus need to find estimates for β_e and the relationship with leverage ratios. We therefore now turn to the estimation of the components needed for the WACC of acquiring additional bank capital. Starting off, to estimate the relationship in (4) we require the equity betas of banks. As these values are not directly observed, we estimate them using the market model, relating the daily changes in the share price of bank i at time t to the respective national stock market j on which they are listed (see for example Baker & Wurgler, 2015). To estimate this relationship, we use daily stock prices from Refinitiv Datastream. The market model is given by:

$$\Delta S_{it} = \beta_{e,it} \Delta S_{jt} + \epsilon_{it} \tag{5}$$

After estimation of equation (5), we take bi-annual averages of the equity betas by bank to match the frequency of leverage ratios. In total we have 87 euro area banks in our sample over the period 1992-2019, which have at least 10 observations for both variables.[8] We require a minimum of 10 observations per bank to ensure that our estimates are not primarily representative for a

[8] Several euro area banks either have no stock listing or do not have data on leverage ratios publicly available. Therefore, we miss Latvia, Luxembourg, and Slovenia in the sample.

specific time period. We use data on a bi-annual basis to increase the number of observations.[9] The leverage ratio is expressed as $(\frac{D+E}{E})$, which implies that higher bank leverage ratios are associated with lower capital ratios, as we saw earlier in (4). In Appendix A we list the banks in our sample by country.

We note that in some cases a small number of banks show extreme levels of either bank equity estimates or leverage ratios. As a result, we omit observations that are more than 4 standard deviations from the country mean and remove observations with negative leverage ratios.[10] Table 1 displays the average (bi-annual) bank equity betas and leverage ratio of banks per country.

Inspecting the values of equity betas, we see that the estimates show considerable dispersion across countries. The mean ranges from around 0.4 in Finland, France and Austria to 3.6 in Lithuania. Given this range, it appears that in some cases attracting more capital can have a considerable impact on funding costs. The average equity beta for banks in the euro area is 0.89. The dispersion in equity betas within countries is even larger: in Lithuania the equity betas range from -15 to 21.5 but also in Germany the dispersion is quite large from -24 to 2.3. This large dispersion is mainly driven by small banks with large equity beta estimates.[11] This large within country dispersion is also present in the estimations of, for example, Miles for the UK and Barth & Miller (2018) for the US.

When we consider average leverage ratios in Table 1, we see that they range from close to 7 in Lithuania to around 28 in Belgium, France and Germany. This would seem to imply that banks in the latter set of countries have lower capital ratios. Although generally true during the first part of the sample period, over time banks improved their capital ratios. For example, German banks had an average leverage ratio of 34 in 1999, yet this decreased to 22 in 2019. Here too we see a high degree of dispersion among banks within a given country. In Germany, for example, the leverage ratios vary from 2 for the Umweltbank to above 121 for the Deutsche Pfandbriefbank. The average leverage ratio for banks in the euro area in our sample is 19.95.

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[9] Not all banks have publicly available (bi-annual) balance sheet information. For those banks missing bi-annual data we only consider the year-end observations. For a list of all listed and non-listed banks in Europe, see for exampe Schoenmaker & Véron (2016).

[10] The descriptive statistics show quite some dispersion, both for leverage ratios and equity betas. Using a more restrictive approach, in which we purge observations with two or three standard deviation from the country mean yields fairly identical results. These results are available upon request.

[11] Excluding these banks with the more restrictive purging method, with 2 or 3 standard deviations from the country mean, does not change our results.

Table 1: Descriptive statistics: leverage ratios and equity betas

	Leverage Ratio $\frac{(D+E)}{E}$				Equity Beta, $\widehat{\beta}_e$			
Countries	Mean	Min	Max	N	Mean	Min	Max	N
BG	28.02	15.72	71.38	74	1.14	−1.08	3.21	96
CY	14.42	7.92	32.24	44	1.03	−0.58	2.81	96
DE	28.05	2.10	121.34	260	0.74	−23.97	2.25	350
EL	12.78	6.42	35.95	87	1.45	−0.18	3.97	281
EO	12.62	1.41	34.67	26	0.88	0.05	1.87	9
ES	19.81	11.96	54.13	190	1.18	0.11	1.96	273
FN	23.42	3.46	33.91	121	0.43	−1.63	1.76	143
FR	27.92	6.87	58.36	218	0.39	−0.32	2.17	758
IE	18.75	9.07	66.19	98	1.17	−0.80	3.26	134
IT	16.46	2.71	54.00	552	0.82	−0.41	5.03	762
LT	6.94	2.19	18.03	25	3.58	−15.17	21.50	40
MT	12.32	5.24	29.55	64	2.01	−7.25	12.37	116
NL	22.25	13.16	49.50	141	0.82	−0.07	2.52	196
OE	15.89	2.29	51.52	183	0.39	−14.06	10.65	349
PT	16.27	12.61	26.22	26	1.40	0.16	2.45	55
SK	12.95	9.69	21.24	59	2.53	−10.10	22.82	104
EA	19.95	1.41	121.34	2168	0.89	−23.97	22.82	3762

Note: Purging observations with more than 4 standard deviations from the country mean leads to a drop of a mere 27 observations. BG=Belgium, CY=Cyprus, DE=Germany, EL=Greece, EO=Estonia, ES=Spain, FN=Finland, FR=France, IE=Ireland, IT=Italy, LT=Lithuania, MT=Malta, NL=the Netherlands, OE=Austria, PT=Portugal, SK=Slovakia, EA=euro area average.

With the estimates of the equity betas $\hat{\beta_{e,it}}$, we can assess the relationship between bank equity betas and leverage ratios ($\frac{D+E}{E}$, from here noted as λ) as expressed by equation (4). We estimate this relationship using the following panel fixed effects regression, with bank (α_i) and period (α_t) fixed effects.[12]

$$\widehat{\beta_{e,it}} = a + b\,\lambda_{it} + \alpha_i + \alpha_t + \mu_{it} \tag{6}$$

where the μ_{it} are the residuals, which are components of the equity beta that are not explained by either the leverage ratio of a bank, or the fixed effects.

As the estimation of equity betas is subject to empirical uncertainty, in section 6 we will extended the empirical analysis in Miles by performing within-bank block bootstrapping on the residuals ϵ_{it} from (5). We do so because the equity betas are used in equation (6), this uncertainty

[12]In our baseline setting, we use bi-annual FE, but using year FE yields similar results. We note that we are unable to include country effects as they are no longer identified once the model includes bank effects.

might also feed through to the relationship between leverage ratios and equity betas.[13]

Before turning to the results of the panel estimations of equation (6), we note that the econometric literature has shown that the appropriate normalization of fixed effects is essential when applying the estimated constant parameter, a, in further analysis (Suits, 1984 and Teulings *et al.*, 2016).[14] Therefore, we want to avoid that the normalization by statistical software to different year or bank observations affects the estimation of a. To solve this, we normalize the fixed effects to zero and add the mean of the fixed effects to the estimated constant. Papers focusing on one country, such as Miles, will suffer less from this problem as normalizing to a different time period or bank by statistical software will occur less frequently. However, even in the case of a single-country analysis, splitting the sample into two groups in the estimation may allow the normalization to different time periods or banks to influence the constant substantially. For example, Barth & Miller (2018) perform such a split to obtain estimates for both large and small banks. Not correcting for this normalization might complicate the use of a constant in further analysis.

In Table 2, we report the estimates we obtain based on (6), using the appropriate normalization. In addition to the panel FE specification, we also estimate the model with random effects. The Hausman test shows that the FE specification is statistically preferred. We therefore opt for using the FE based estimate in our baseline for the remainder of the paper.[15]

We can then substitute β_e out of (2) using the estimated intercept $\hat{a}$, including the normalization, as well as the estimated coefficient for leverage, $\hat{b}$. The estimated coefficient $\hat{a}$ reflects the constant part of the equity beta, and hence captures the time-invariant impact of the risk exposure of the bank to equity for its return on equity. The time-varying impact of a bank's capitalization on the return on equity is captured by $\hat{b}$. At the same time, this reflects the extent to which an MM-offset is present, as it displays the extent to which changes in capital will lead to a change in the bank's funding costs through equity. The substitution of β_e allows us to rewrite (2) as a function of leverage, λ, and the observed risk-free rate, R_f, and market equity risk premium, R_p:

$$R_e = R_f + (\hat{a} + \hat{b}\,\lambda)R_p \tag{7}$$

Like Barth & Miller (2018), we do not consider the presence of a Modigliani-Miller offset,

[13] The residuals are redrawn 1000 times in random order, within each bank and by each half-year period. This is thus a within-bank block bootstrapping approach. The procedure is chosen as some time periods have substantial more uncertainty then others, e.g. during the financial crisis.

[14] That is, choosing a different time period in a panel fixed effect estimation procedure may result in a substantial difference in the estimated constant parameter if not normalized appropriately. This could then have a sizable impact on the calculation of the cost of additional bank capital.

[15] Even though the Hausman test statistically rules out the Panel RE estimator, we opt for analyzing the sensitivity of our results to using either the Panel RE or Panel OLS estimators. Results are fairly similar using the other estimators, and are available upon request.

Table 2: Estimates from panel regressions

	All Banks		
	Pooled OLS	Fixed Effects	Random Effects
Leverage, $\hat{b}$	0.006	0.000	0.002
	[0.006]	[0.002]	[0.004]
Intercept, $\hat{a}$	1.314	1.034	1.353
	[0.177]	[0.051]	[0.165]
N	2092	2092	2092
Rsquare Within		0.035	0.034
Rsquare Between		0.007	0.390
Rsquare Overall	0.176	0.019	0.169
Hausman p-value		0.002	

which means that we do not restrict the effect of $\hat{b}$, whilst Miles considers an MM-offset of 45%. We note that we can construct plausible bounds for $\hat{b}$ based on the degree to which we assume that the Modigliani-Miller (MM, Modigliani & Miller, 1958) effect holds. The MM-theory states that the costs of raising additional equity is exactly offset by the resulting decline in the interest rate, R_e caused by the lower perceived riskiness of bank equity. This implies that R_e in (2) and (7) will fall whenever leverage declines. By a MM-offset of 100%, this decline in R_e leaves the WACC in (1) unchanged. In this case $\hat{b} > 0$ and is large enough to ensure that R_e sufficiently declines to leave costs unchanged. This implies a reasonable upper bound on the value of R_e.

By an MM-offset of 0%, we might expect that R_e does not respond to leverage, with the result that total capital costs rise with declining leverage.[16] This implies that $\hat{b} = 0$, and could reasonably taken to be a lower bound. In the case of our baseline estimate based on FE, $\hat{b}$ is not significantly different from zero.[17] This is consistent with the lower bound of $\hat{b} = 0$. We note that the size of the MM-effect has been empirically estimated, for example by European Central Bank (2011) for large international banks, and has been found to range from 41% to as much as 73%. The implicit estimates of Kashyap *et al.* (2010) are close to these estimates, with an MM-offset ranging between 36% and 64%. These estimates are consistent with $\hat{b} > 0$. Furthermore, while we do obtain positive estimates of $\hat{b}$ using OLS and RE estimators, these values are also not significantly different from zero.

Using equation (7), and the average risk-free rate of 4.74%, market equity risk premium of

[16] It is however also conceivable that R_e actually increases with declining leverage. In this case $\hat{b} < 0$.

[17] To derive the WACC of acquiring more bank capital, we need an estimate for $\hat{b}$. Even though $\hat{b}$ is not significantly different from zero, it is the best fit to the data, and we will use the panel FE estimators in the remaining derivations. In Section 6 we will display the results relying on a within-bank block bootstrapping procedure for equity betas, which include a wide range of $\hat{b}$ estimates, including statistically significant coefficients, without affecting the final estimates of optimal capital ratios substantially.

4.11% and leverage of 20 (the euro area average, see Table 1), the return on equity equals 8.98% for the average of euro area banks. These estimates lie somewhat below those of Miles, which finds a return on equity of 14.85% for a leverage of 30, but close to those of Barth & Miller (2018) for a leverage of 25 as they find a return on equity of 8.08% for banks with at least $1bln in assets and 9.73% for more than $10bln.

From equation (1), with no tax advantage of debt and no MM-offset, we obtain an average WACC equal to 4.95% when the average euro area bank leverage equals 20, rising to 5.17% when leverage falls to 10. Again, these estimates are close to those of Miles and Barth & Miller (2018). The former derives the average WACC to increase from 5.33% for a leverage of 30 to 5.66% for a leverage of 15, where the latter derives an average WACC of 5.19 for a leverage of 25 increasing to 5.71 when leverage falls to $6\frac{2}{3}$.

4.1.2 Costs for the economy

In what follows, we relate the WACC of a bank to the macroeconomic implications, through the lending channel. That is, higher costs of funding via additional bank equity can be passed on to customers and result in lower credit provision. This, in turn, has a negative impact on economic activity. Here we report the macroeconomic implications for the average of all euro area banks in our sample. We first derive the present value GDP effects of a change in leverage ratios, but eventually convert to the effects due to a change in risk-weighted capital ratios. This latter instrument is the most prominent instrument used by policymakers internationally to set minimum capital requirements to banks.

We first determine the effects of a change in the price of capital, P_k, on output, Y. We then calibrate how the marginal cost of capital is affected by to a change in leverage affects P_k. This enables us to combine the marginal cost of leverage with the marginal change in output to obtain the total cost of a change in leverage.

To begin with, we assume that Y is produced via a production function with constant elasticity of substitution between the two inputs capita, K and labour L. From here, we can obtain the following expression for the marginal effect of P_k on Y:

$$\frac{\partial Y}{\partial P_k}\frac{P_k}{Y} = \left(\frac{\partial Y}{\partial K}\frac{K}{Y}\right)\left(\frac{\partial K}{\partial P}\frac{P}{K}\right)\left(\frac{\partial P}{\partial P_k}\frac{P_k}{P}\right)$$

Here we have defined the price P to be the relative price of capital to labour: $P = P_k/P_l$. This expression relates the elasticity between output and the price of capital to the elasticity of output with respect to capital, the substitution elasticity between capital and labor, and the elasticity of relative price to the cost of capital. This combination results in the sensitivity of output to the cost of capital. Miles show that this can be rewritten as

$$\frac{\partial Y}{\partial P_k}\frac{P_k}{Y} = \alpha\sigma\frac{1}{\alpha - 1} \tag{8}$$

where α represents the elasticity of output with respect to capital, σ the substitution elasticity between capital and labour, and $\frac{1}{\alpha-1}$ is the elasticity of the relative price with respect to the cost of capital. We use an α of 0.37 (the same calibration is used in Havik *et al.*, 2014 and European Commission, 2018), and a σ of 0.5. For an overview of the literature on σ estimates see, e.g., Klump *et al.*, 2012. This parameter setting implies, based on (8) that a 1% increase in firms' cost of capital could lead to a reduction in output of 0.29%. In Table 3, we display all technical assumptions, including those of the production function. In section 6, we check the sensitivity of our estimates to these and several of the other parameters.

Table 3: Technical Assumptions

Assumption	**Parameter**	**Value**
Share of bank lending	Ω	0.45
Substitution elasticity	σ	0.50
Share of capital	α	0.37
Discount rate	δ	0.025
CET1 ratio	CET1	0.95
RWA Basel conversion	RWAconv	1.25

Now we can combine the channels to derive the present value GDP effects of additional bank capital. The cost of additional capital is given by the difference in WACC due to the increase (decrease) in capital (leverage) multiplied by the cost of capital for firms (CoC, that is the risk-free rate plus the market equity risk premium). This is then multiplied by the share of bank financing for non-financial corporations, Ω, which we calibrate to be 45% (see for Europe e.g., Adalid *et al.*, 2020).[18] This in turn can be multiplied by the production function elasticities in (8) to obtain the loss in economic activity as a result of additional bank capital.[19] To obtain the present discounted value, we discount the result by δ:

$$PV_{GDP} = \frac{\alpha\sigma\Omega(\Delta(WACC) * CoC)}{\delta\,(\alpha - 1)} \tag{9}$$

[18]Admittedly, assuming a constant share of bank financing over time and across countries is a simplification. This share is likely to vary, and could change in response to the actual costs of capital, driving possibly towards more market financing. Investigating the relationship between the costs of additional bank capital and the share of bank financing is left for further study.

[19]This ensures that we only consider the economic implication of bank costs related to its funding, and not to other costs such as labor or overhead costs. We do not account for taxes, because they redistribute part of the social costs, but do not change them.

Without an MM-offset, the firms cost of capital is likely to increase by a little under 10 bps (22bps increase in the WACC multiplied by the share of bank lending of 0.45). Assuming that the cost of capital is around 9% (risk-free rate plus market equity risk premium), this translates into a increase 0.9% in the cost of capital for firms. Using a discount rate of 2.5%, and the outcome of (8) this results in a permanent fall in output of around 10% or 1000bps (that is, (0.9%x0.29%)/2.5%). That is, a capital ratio increase which lowers leverage to half its original value would lead to a permanent fall in GDP.

The present value of the cost of bank capital should be translated to marginal costs in order to compare it with the marginal benefits. Therefore, like Miles we divide the PV_{GDP} by the change in risk-weighted capital. For this, we translate the change in the leverage ratio from 20 (λ_1) to 10 (λ_2) to risk-weighted capital.

$$\Delta(CapitalRatio) = (\frac{CET1}{\lambda_2} * \frac{A}{RWA} * \frac{1}{RWAConv}) - (\frac{CET1}{\lambda_1} * \frac{A}{RWA} * \frac{1}{RWAConv}) \quad (10)$$

We therefore first rescale the leverage ratio, λ, with the ratio of Common Equity Tier-1 capital to Tier-1 capital (CET1). On average, this is 0.95 over our sample, for which a leverage ratio of 20 (TA over Tier1 capital) corresponds with a leverage ratio of 21 (TA over CET1-capital). We use assets to Basel II RWA of around 204% in our sample of euro area banks (A/RWA), and the same conversion factor as Miles of 1.25 to turn Basel II in Basel III RWA (RWAConv). Together, the change in risk-weighted capital ratios increase from 7.8% (leverage of 20) to 15.5% (leverage of 10).

Based on the derivation above, which includes some rounding and thus deviates slightly from our actual derivation, for each 1%-point increase in risk-weighted capital ratios marginal costs are around 130bps (that is, present value of costs of 1000bps divided by the change of 7.7% in risk-weighted assets).[20] The marginal costs are fairly close to those derived by Miles for banks in the UK, as they find marginal costs of around 149bps for each 1%-point increase in risk-weighted capital ratios.

4.2 Benefits

If increasing bank capital is socially costly, so too is not raising bank capital sufficiently. In the previous section we measure the private costs (to banks) of raising additional capital, and argue that these carry over to societal costs, by increasing lending costs. The benefits of increasing

[20] Admittedly, the empirical approach leads to a marginal cost estimate that is not dependent on the amount of bank capital. Most likely, banks that hold almost no reserves will face substantially higher funding costs than banks with plentiful reserves. In Section 6 we explore this potential non-linearity with piece-wise linear estimation techniques, but due to data availability constraints we are unable to create bins for banks for small ranges of capital levels (for example, bins for banks with 0-1% capital).

bank capital occur at a societal or macro level, because higher bank capitalization decreases the risk of a banking crises. This benefit of raising capital is what we model in this section.

Following the analysis in Miles, we assume that more bank capital, or lower leverage, increases banks' ability to absorb macroeconomic shocks. The idea is that recessions lead to business failures which, in turn, lead to a loss on banks' loan portfolios. If the aggregate loss on loan portfolios exceeds the amount of capital that banks hold, a banking crisis ensues. As a result, higher levels of bank equity reduce the likelihood of a banking crisis.

We assume that there is a one-for-one relation between GDP losses and losses on bank assets. In other words: a percentage decline in GDP results in the same percentage decline in the total value of bank assets. A banking crisis then occurs whenever the percentage decline in GDP exceeds the average bank capital ratio. Miles present evidence in favour of this one-for-one relation in their Appendix B, which is based both on the Great Financial Crisis and selected financial crises from the 1990s.[21]

We formalize this as follows. We denote the probability of a banking crisis by p_b, the percentage lost on bank asset values by l_a, the percentage change in GDP by y, and the capital ratio by λ^{-1}. We then have the following:

$$p_b = prob(l_a > \lambda^{-1}) \tag{11}$$

We further assume that $l_a = -y$ when $y < 0$, and $l_a = 0$ otherwise. If we substitute $-y$ into this expression, for when $y < 0$, then we have the following:

$$p_b = prob(y < -\lambda^{-1}) = F_y\left(-\lambda^{-1}\right) \tag{12}$$

where F_y denotes the cumulative density function of y. Note that in the latter expression we have that $y < -\lambda^{-1} < 0$, so that $y < 0$ holds. This formalizes our assumption that the benefit of a lower leverage ratio is to reduce the chance of a banking crisis.

The assumption that a banking crisis occurs whenever the percentage decline in GDP exceeds the average bank capital ratio is admittedly simplistic, with no risk of a banking crisis until the threshold drop in GDP is exceeded. It would be arguably more realistic to assume an increasing risk of a crisis as a function of the size of the decline in GDP. In practice this would produce a somewhat more smeared out distribution in (4.2) which would not only be dependent on the distribution of the growth rate of GDP. Implicitly we assume that the distribution of the growth rate of GDP captures most of this uncertainty. We leave a more nuanced modeling of (4.2) for

[21] Note that results do change if this relation is assumed to be different. If GDP shocks induce bank asset losses that are as a percentage twice as large, the optimal capital ratio will also be twice as large.

future research.[22]

4.2.1 The Distribution of GDP growth

To measure the probability of a banking crisis, we require a probability distribution function for GDP fluctuations. We therefore estimate the probability distribution of fluctuations of GDP per capita. We deviate from Miles in two respects. Firstly, we allow for, and test for the fitness of, alternative parametric forms of the distribution of GDP per capita growth. We expand on this matter in the next few paragraphs. Secondly, we use data for the annual growth of GDP per capita for EMU member states between 1950 and 2016, taken from the Maddison Project (Bolt, Jutta and Van Zanden, Jan Luiten, 2014). Given the focus of our study, this seems like the most relevant sample. We note that Miles calibrate their model based on an international sample of high income countries, covering the period from 1820 to 2008 annually. This covers a period that obviously includes a number of catastrophic events such as the World Wars. Whether or not this longer sample is to be preferred depends on whether or not one believes banking sectors should be robust to such events. We opt to use a post-war period from 1950 to 2016 as our baseline sample, and thereby implicitly consider World Wars as lying outside the set of events which the banking sector should be able to absorb. We also note that our robustness checks include estimates based on a longer sample period, which includes both World Wars.[23]

GDP growth is well-known to be fat-tailed, see for example Fagiolo et al. (2008), Gabaix (2016) and Williams et al. (2017). Additionally, GDP growth may well be asymmetrically distributed, where large negative shocks are more likely than similarly large growth events. It is therefore important not to model GDP growth as normally distributed; rather, one requires a distribution that allows for excess kurtosis as well as left-skewness.

In Miles, the authors opt to capture these characteristics by modelling the GDP growth distribution as a normal distribution supplemented with two types of shocks. In their model, GDP growth is normally distributed, with in any year the possible addition of one of two possible shocks: a c-type or a b-type shock. The c-type shocks are events that involve either the addition or subtraction of c to the mean of the normal distribution. The addition and subtraction of c are equally likely. One can think of these events as typical recessions or boom years. On the other hand, a b-type shock is a more extreme event and always implies the subtraction of b from the mean of the normal distribution. For this, one can think of a catastrophic event such

[22] We note that in (4.2) we also do not explicitly differentiate between measures of leverage based on risk weighted assets or based on all assets. Here too we are implicitly assuming that this distinction produces an effect that is only of second order in size.

[23] Including the World Wars give more variability to the GDP distribution, and hence more extreme crisis periods. This might also proxy for other crisis events that origin from outside the banking sector, such as the COVID-19 pandemic.

a war or natural disaster. This b-type shock is inspired by Barro's (2006) hypothesis that asset prices incorporate small but meaningful risks of disasters. The probabilities of c- and b-type shocks transpiring are denoted by p_c and p_b, respectively. GDP growth is therefore assumed to be generated as follows:

$$y_t = \epsilon_{t-1} + \zeta_{t-1}, \quad \text{where} \quad \epsilon_t \sim N(\gamma, \sigma^2) \tag{13}$$

and $P(\zeta_t = 0) = 1 - p_c - p_b$, $P(\zeta_t = -b) = p_b$, $P(\zeta_t = -c) = p_b/2$, $P(\zeta_t = c) = p_c/2$.

Although the distribution of Miles accommodates both the skewness and kurtosis, it comes with two main drawbacks. Firstly, depending on the parameters, the distribution of GDP growth may become bi-modal. This is the case with the parametrization found in Miles where b is 35%. As a result, a GDP-decline of 35% is more likely than one of, say, 20% or 25%. This is not well supported by the data. Secondly, left-skewness is imposed in this distribution, and only captured by the b-parameter. A more flexible functional form, which can also match data that are not left-skewed, is to be preferred if one wants to fit the family of distributions on various (sub-)samples.

Fagiolo et al. (2008) test to what extent GDP fluctuations can be described by various families of distributions. Testing a host of families, they reach the conclusion that the so-called Exponential Power (EP) distribution well describes GDP fluctuations for nearly all OECD-countries in the post-World War Two era. The density of the EP distribution is presented in equation 14 and it is characterized by three parameters: m, a, and b. The parameter b is the shape parameter: lower values of b correspond to distributions with fatter tails. The normal distribution is nested in the EP-distribution, where $b = 2$.

$$f_{EP}(x; m, a, b) = \frac{1}{2ab^{1/b}\Gamma(1+\frac{1}{b})} e^{-\frac{1}{b}|\frac{x-m}{a}|^b} \tag{14}$$

Fagiolo et al. (2008) further test whether the Asymmetric Exponential Power (AEP) distribution outperforms the EP-distribution, and conclude that in general it does not. This AEP is similar to the EP distribution, but accommodates different parameter values for a and b on the left and right half of the distribution. We present this distribution in equation 15.

$$f_{AEP}(x; m, a_l, a_r, b_l, b_r) = \begin{cases} K^{-1} e^{-\frac{1}{b_l}|\frac{x-m}{a_l}|^{b_l}} & \text{if x<m} \\ K^{-1} e^{-\frac{1}{b_r}|\frac{x-m}{a_r}|^{b_r}} & \text{if x}\geq\text{m} \end{cases} \tag{15}$$

where $K = a_l b_l^{1/b_l}\Gamma(1+\frac{1}{b_l}) + a_r b_r^{1/b_r}\Gamma(1+\frac{1}{b_r})$.

We fit the distribution proposed in Miles, the EP and the AEP, and a number of alternative distributions to the data.[24] We then perform a number of Goodness-of-Fit tests to evaluate whether the data can in fact be described by the distribution at hand. Aside from the sample of countries, our analysis differs from that of Fagiolo et al. (2008) in two important respects. Firstly, we use the annual growth rate of GDP per capita, as opposed to the growth rate of GDP. Secondly, we fit the distributions based on the growth rates from the entire panel, whereas Fagiolo et al. (2008) fit the distribution for each individual country. Given these differences, we have opted to explore which distribution best fits the data.

Table 4 presents the outcomes of Goodness-of-Fit tests. The value of each test statistic is shown with the p-values underneath in parentheses. The three Goodness-of-Fit tests we perform on all distributions are the Kolmogorov-Smirnov (KS), Cramér-von Mises test (CvM), and Anderson-Darling (AD) test. For all three tests, the null hypothesis is that the data can be described by the fitted distribution.

Table 4: Goodness-of-Fit Tests

	test		
Distribution	Kolmogorov-Smirnov (KS)	Cramér-von Mises (CvM)	Anderson-Darling (AD)
Asymmetric Exponential Power (AEP)	0.022	0.059	0.423
	(0.642)	(0.817)	(0.825)
Exponential Power (EP)	0.039	0.368	2.785
	(0.064)	(0.088)	(0.035)
Cauchy	0.054	0.681	8.157
	(0.003)	(0.014)	(0.000)
Gaussian	0.104	3.702	22.165
	(0.000)	(0.000)	(0.000)
Lévy-Stable	0.032	0.253	2.126
	(0.197)	(0.185)	(0.078)
Miles	0.030	0.196	1.381
	(0.254)	(0.275)	(0.208)

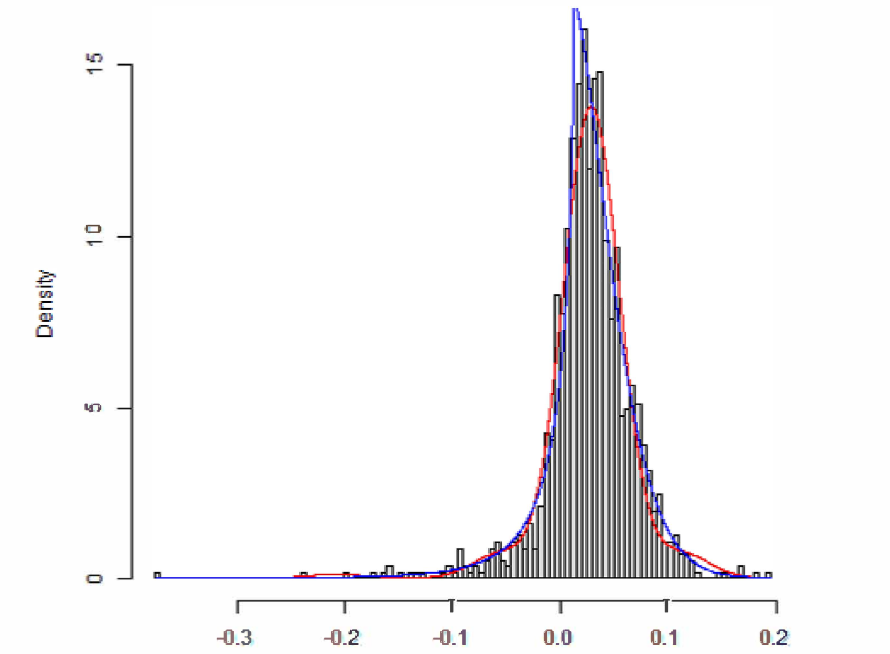
Note: For all three tests, the null hypothesis is that the data can be described by the fitted distribution. P-values are shown in parentheses.

The p-values of the Goodness-of-Fit tests indicate that the AEP distribution is best suited for our sample of data. This is in line with the conclusions of Fagiolo et al. (2008). We therefore opt to use the AEP distribution in our baseline analysis. For comparability with Miles, we include their distribution as one of our robustness checks; as Table 4 shows, Miles' distribution also passes the Goodness-of-Fit tests. In Figure 3, we show the histogram of the growth rates

[24]The other distributions we fit are the Gaussian, Cauchy, and Lévy-Stable distributions.

together with the fitted AEP and Miles densities.

Figure 3: Fitted AEP and Miles Densities and Histrogram



The AEP fitted density is shown in blue. The fitted Miles density is shown in red.

4.2.2 The Benefit of Averting a Banking Crisis

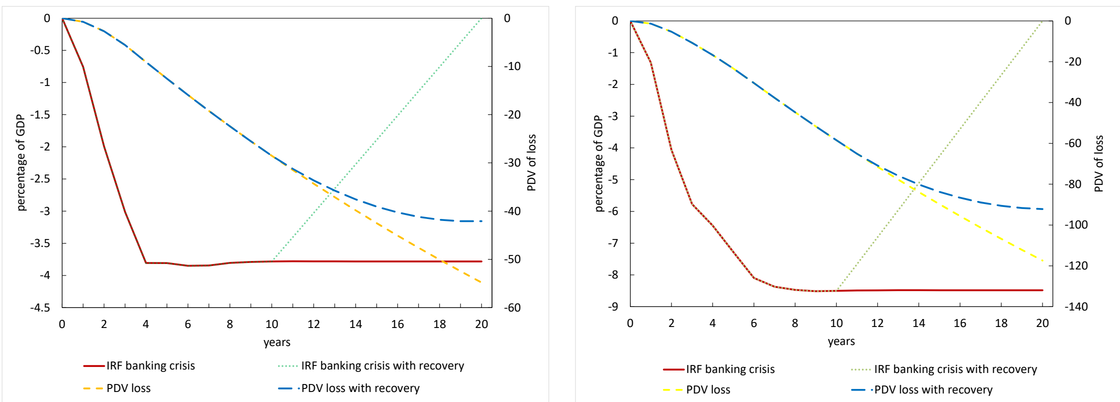
If a banking crisis can be prevented from occurring, then the loss in output associated with the crisis can be avoided. This represents the benefit to society of lowering the leverage ratio. We note that there are presumably other benefits which we could also consider. For example, lower bank leverage most likely would result in lower deposit insurance premiums for banks, because the chance of default would be reduced. Such benefits are, however, likely to represent second order effects, and pale in comparison with the large costs in terms of lost output due to a banking crisis. As a result, we only consider the present discounted value of lost output due to a banking crisis in our calculation of the benefits of increased bank capital.

We calibrate the present discounted value of the loss in output due to a banking crisis for high income economies based on Luginbuhl & Elbourne (2019).[25] In their article, the authors estimate impulse response functions, IRFs, of a banking crisis using the banking crisis dates

[25]Their estimated loss is one third smaller than that found in Cerra & Saxena (2008) due to the fact that the model in Luginbuhl & Elbourne (2019) also accounts for temporary losses caused by the business cycle. Miles calibrate the cost of a banking crisis based only on the 2008 financial crisis.

produced by Reinhart & Rogoff (2009), or R&R, as well as those produced by the International Monetary Fund in Laeven & Valencia (2008) and Laeven & Valencia (2012), or IMF. Both IRFs are shown in Figure 4.[26] The figures include the original estimated IRFs (shown in red) together with the IRFs that result when we assume that a banking crisis has no hysteresis (shown as the dotted green line). We calibrate IRFs with no hysteresis by assuming that five years after the onset of a banking crisis, output linearly grows back to the baseline level within the following 5 years.[27] Each figure also contains the corresponding plots of the cumulative sum of the present discounted value of the loss, expressed as a percentage of GDP. The dashed yellow lines show the cumulative sum based on the original IRF estimates, while the dashed blue lines correspond to the sum for the calibrated IRFs without hysteresis. These cumulative sums converge to the total present value as the number of years goes to infinity.

Figure 4: IRF of GDP loss following banking crisis & Present Discounted Value of the Loss



(a) Model with R&R banking crisis dates

(b) Model with IMF banking crisis dates

The total present value of these output losses, L_c, is given in Table 5. In our calibration we take the two extreme values of 320% and 40% as upper and lower bounds, respectively depending on the use of IMF or R&R dummies and presence of hysteresis. We use 150% as our baseline value. Note that the lower value of 40% assumes that the economy suffers no permanent loss in output from a banking crisis.

Table 5 also lists the benefit, B_c of a 1% decrease in the chance of a banking crisis due to

[26] We note that the IRF shown in 4a is based on the same sample period of 1973 to 2015 used in 4b. In their original article, the IRF based on the R&R dates used a shorter sample period ending in 2001. The authors provided us with the updated IRF 4a.

[27] The period of five years corresponds to the IMF banking crisis dates which assume that the end of a crisis is no more than 5 years after its onset.

Table 5: Present Discounted Value of the Loss due to Banking Crises

	Banking Crisis Dates			
	IMF		R&R	
Hysteresis	yes	no	yes	no
L_c	320%	90%	150%	40%
B_c	128%	36%	60%	16%

The values are given as a percentage of GDP.

a decrease in leverage. A decrease in leverage will reduce the chance of a crisis in the current year, but also in all future years. As a result, the expected benefit is given by:

$$B_c = 0.01 \frac{L_c}{(1-\delta)} \tag{16}$$

We can now obtain the total benefit of a change in leverage, B_λ, by multiplying B_c by p_b from (4.2). This then results in the following expression

$$B_\lambda = B_c F_y \left(-\lambda^{-1}\right) \tag{17}$$

for the benefit to society of a reduction in leverage.

5 Optimal bank capital ratios

Having derived expressions for the societal costs and benefits of a change in the capital ratio in the previous section, we are now in a position to derive the optimal ratios. We begin by determining the optimum for banks in the euro area. We then turn to the analysis of individual countries, and then to the analysis of subgroups of countries.

5.1 Main Results

Figure 5 displays the optimal capital ratio for European banks. The figure displays risk-weighted capital ratios on the horizontal axis, and the present value of GDP effects on the vertical axis. In our baseline setting, as presented in Section 4.1.2, the marginal costs are 128bps for each 1%-point increase in risk-weighted capital ratios. The intersection of our baseline estimates for costs (solid black line) and benefits (red line) occurs at a capital ratio of 22%. Table 6 displays the range of estimates we obtain based on various alternative assumptions about the costs and benefits of additional capital.

If we only change the cost parameters, then the lowest optimal capital ratio we obtain is 20%. This occurs when we calibrate the MM-offset to be 0 and also take national corporate tax rate (for deductibility) from the OECD Tax Database into account. The assumption of no MM-offset has the largest impact on costs, as it assumes that all additional costs of acquiring equity are directly translated into higher funding costs for banks. The highest optimum ratio we find by only re-calibrating the cost parameters is 25%. In this case, we employ an MM-offset of 45% (as is used in Miles), which lies within the range of estimates reported in Kashyap *et al.* (2010).

Figure 5: Optimal capital ratio

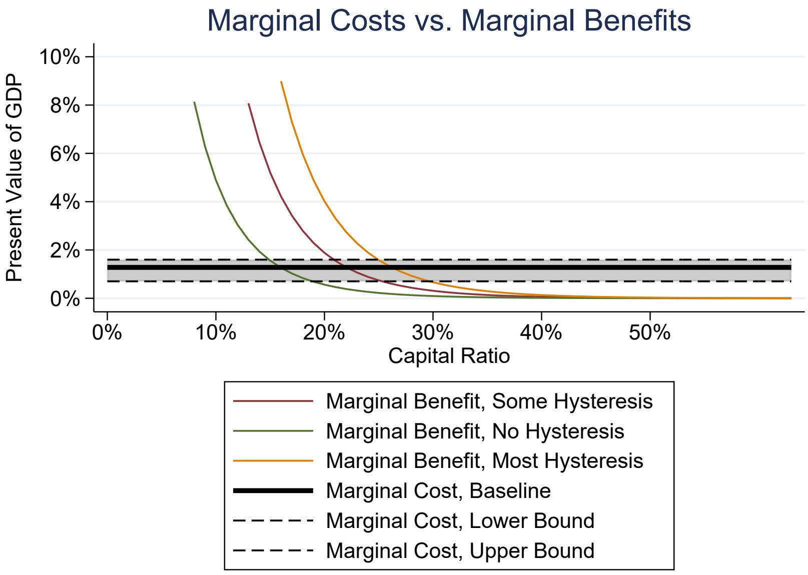


Table 6, however, demonstrates that the largest impact on the optimal ratio stems from alternative calibrations for the size of the benefits of lowering leverage. Based on our baseline cost calibration, the optimal ratio ranges from 16% to 26% when we vary the benefits calibration. We obtain the lower estimate of 16% when we only allow a banking crisis to have temporary effects on output. This assumption, however, is quite unrealistic. This is especially the case for the euro area due to the large size of the European banking sector. The estimate of 26% is found when we assume that banking crises have substantial, permanent effects on the economy.

Table 6: Optimal ratios

	Benefits		
Costs	Low, no permanent	Baseline	High, only permanent
High, no MM & national taxes	15%	20%	25%
Baseline	16%	22%	26%
Low, MM-offset 45%	18%	25%	30%

The lowest estimate we obtain occurs when we assume the largest costs (no MM-offset and including national corporate tax rates which are deductible) and only a temporary loss in output due to a banking crisis. In this case, we estimate the optimal bank ratio of 15%. The highest estimate of 30% is derived for the case when we assume the lowest cost estimate (MM-offset of 45%) and large, permanent effects from a banking crisis. Our estimated range of optimal ratios between 15% and 30% shows a somewhat larger dispersion than in Miles, where the optimal ratio varies between 16% and 20%. We suspect this is mostly driven by our alternative and more dispersed calibration of the costs of a banking crises, although our choice for an alternative parametric distribution for GDP growth may also drive part of this difference.

Although this range in values may initially seem quite large, it is driven by quite extreme calibrated values. For example, the assumption of either no permanent effect or of a large permanent effect on output of a banking crisis are both strong claims. The former assumption is arguably particularly dubious for the euro area economy, where the banking sector has a substantial presence. Nonetheless, regardless of which calibration we adopt, the range in optimal capital ratios are generally substantially higher than the minimum required CET1-ratio of 12.5% for systemic banks set by the Bank for International Settlements (BIS).

5.2 Individual countries

Given that the degree of banking sector stability differs quite substantially between euro area member states (see, e.g., Uhde & Heimeshoff, 2009 and Schoenmaker & Peek, 2014), we would expect optimal bank capital ratios to show considerable variation among member states as well. In countries with more stable financial sectors, attracting additional funding likely comes at a lower cost than countries with less stable ones (see, e.g., Arnould *et al.*, 2020 and Aymanns *et al.*, 2016). For this reason, we aim to subdivide our panel into subgroups of member states. To accomplish this, we re-estimate the marginal costs of additional bank equity for each member state. Additionally, we approximate the heterogeneity in marginal benefits by grouping countries in terms of GDP-volatility.

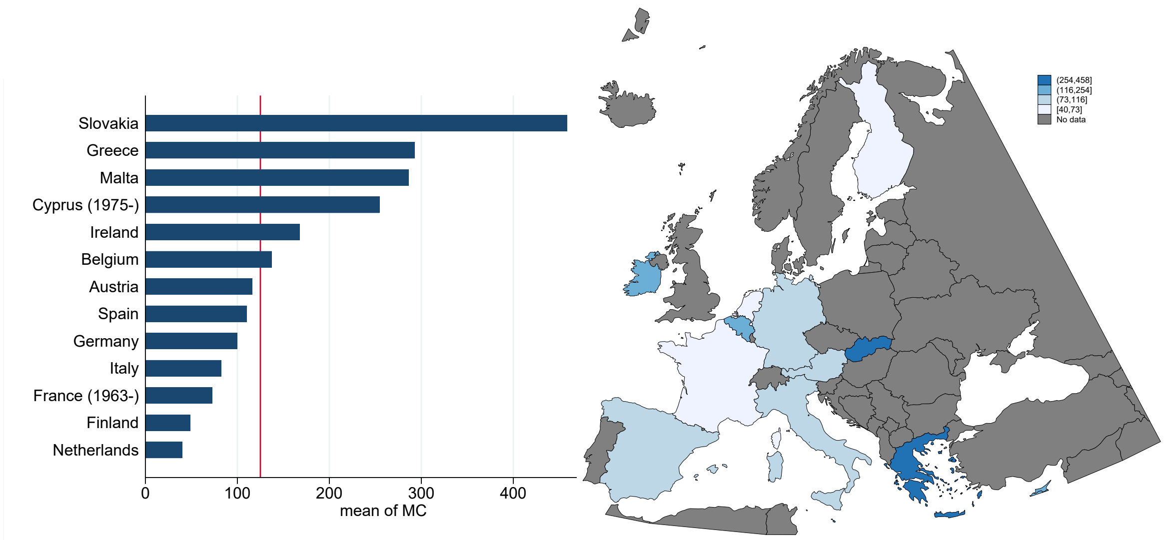
In the estimation of costs for individual member states, we use the same baseline calibration described in section 4, but re-estimate equation (6) for each country separately. In Appendix C we display the outcome of this estimation. Furthermore, we use the average leverage ratios and equity betas by country. Together we can derive the WACC for each individual country. Next, we derive the marginal costs by adjusting the conversion factor in (10) to national averages of total assets, RWA, and CET1 to Tier1 ratios. We keep the risk-free rate and market equity risk premium as average of the EMU.

Here we additionally require that a member state must have at least two banks in our sample for which there are a minimum of ten observations per bank.[28] This additional constraint leads to the loss of 3 countries from our sample: Estonia, Lithuania, and Portugal. This leaves us with 13 countries to analyze.

The bar chart 6a on the left-hand side of Figure 6 shows the estimated marginal costs of each member state for which we are able to obtain estimates. Our results indicate that the highest marginal countries are those in which banks have more difficulty to raise capital. These countries are Slovakia whose MC estimate is close to 450 bps, and Malta, Greece and Cyprus with estimates that are close to 300 bps. As Appendix C shows, for those countries we find relatively large (and potentially positive) estimates for $\hat{a}$ and/or $\hat{b}$ in equation (6); that is, banks face relatively high costs of acquiring additional equity funding. These outcomes are substantially higher than our main outcome for the panel results of 128bps, as described in Section 5.1. We obtain the lowest cost estimates for the Netherlands and Finland, both with values close to 40 bps. Both of these countries are generally considered to have more stable financial sectors.

The relatively low estimate for Italy, with an estimated cost slightly above 70bps, is surprising given that the Italian banking sector is not generally regarded as being an example of stability. As displayed in Appendix C, the estimated constant of the equity beta and relatively low coefficient on leverage for Italy resulted in this low marginal cost estimate.

Figure 6: Marginal costs by individual countries



(a) (b)

Note: The map displays a grouping based on the MC estimates for individual member states. These MC estimates are shown in the bar chart, in which the vertical red line displays the outcome for the entire panel of 128bps (see Section 4.1.2).

[28] Presenting a result for a country based on one bank with a minimum of 10 observation might be less reliable.

The map 6b on the right-hand side of Figure 6 is based on a grouping of the euro area countries based on their individual marginal cost estimates. This results in four groups. The first group consists of countries with the lowest marginal costs of not more than 73bps. The countries in this group are the Netherlands, France, and Finland. The second group contains countries with estimates that fall between 73bps and 116bps: Germany, Italy, Spain, and Austria. Belgium and Ireland are the only two countries in the third group. Their marginal cost estimates lie between 116bps and 255bps. The final group, with the highest marginal costs of above 255bps, consists of Cyprus, Malta, Greece and Slovakia.

As is the case with marginal costs, heterogeneity among countries can also affect the benefits of raising additional capital. The probability of a banking crisis, and the impact of it, may differ strongly across countries. Less stable economies may benefit more from stronger bank capitalization, given that this ensures that banks have a greater capacity to absorb shocks. At the same time, the opportunity costs of a resultant lower level of investment may also be higher in these countries.

In order to explore the possible heterogeneity among countries in the benefits of bank capital, we group member states in terms of their GDP volatility. We create 3 groups of EMU member states based on the volatility of GDP in the Maddisson dataset (Bolt, Jutta and Van Zanden, Jan Luiten, 2014) from 1950 onwards.[29] For each group we obtain an estimate of the group's cumulative distribution function in (4.2), which we then use to calculate the total benefit of a change in leverage, B_λ given in (17).

Here we are assuming that countries with higher levels of GDP volatility may benefit more from additional bank capital, as this should reduce the downside risks to the real economy. In Figure 7, we display the marginal benefit estimates for the three groups based on our baseline estimate for B_c of 60%.[30] The three groups are as follows. The countries with low GDP volatility are Belgium, France, Netherlands, Austria, and Italy. The countries with medium volatility are Ireland, Finland, Germany, Portugal, Spain, and Luxembourg). The high volatility countries are Malta, Greece, Slovenia, Slovakia, Estonia, Cyprus, Lithuania, Latvia.[31]

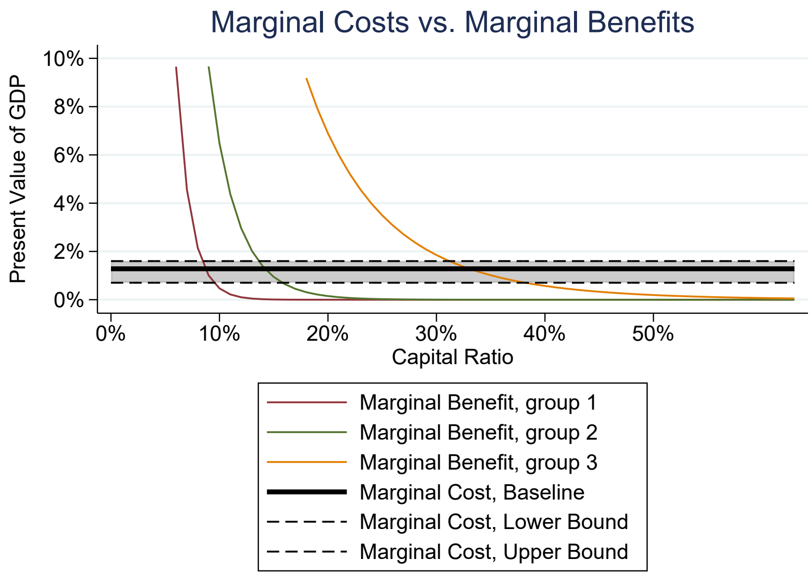
In addition to the marginal benefit curve, Figure 7 includes the marginal cost curve based

[29]We also explored two other groupings. One is based on the estimated marginal costs of individual countries. The other is based on how long each member state has been a member of the EU. The former grouping might be expected to allow us to capture the heterogeneity in marginal benefits related to the ease with which banks can attract capital. The latter grouping could similarly be expected to be useful under the presumption that countries that joined the EU early on might therefore have more developed and integrated financial markets. In terms of overall dispersion of optimal ratios, both criteria yield fairly similar results to those we obtain based on economic volatility, although for individual countries there are some changes to their optimal ratio. We also explore splitting the countries into a different number of groups: from two up to four for each of the third methods of forming the subgroups. To save space, we do not report on these findings here. They are available upon request.

[30]To save space, we do not display the results based on the lower and upper bounds of our calibration for B_c. These are available upon request.

[31]Changing the volatility levels used to define these groups has only a limited effect on our estimates.

Figure 7: Heterogeneity in marginal benefits



Note: Three groups based on the volatility of GDP from 1950 to 2016.

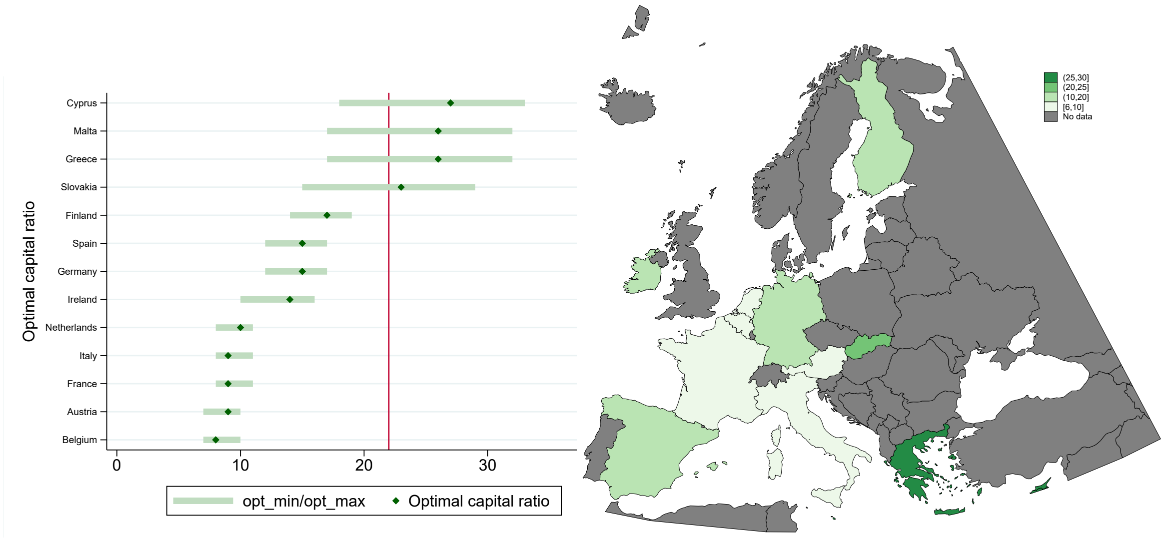
on the panel estimation of all Euro member countries (see Figure 5). We can see from the figure that the variability in the marginal benefit over the three volatility groups is considerably more pronounced than the variability induced by changing the calibration parameters in the benefits calculation. We can see that the benefits of higher bank capital are lowest for countries with low GDP volatility, and that the marginal benefit curve is relatively steep. This indicates that the benefits with respect to bank capital are relatively inelastic. This is quite different for countries with the highest GDP volatility, where we see that for these countries the marginal benefit curve shifts to the right substantially, and is flattened. This indicates that the rewards to society are greater, but also more sensitive to the level of bank capital.

We note that in our analysis we do not account for potential spillover effects among banks domestically, or for spillovers across borders. Marginal benefits may therefore be higher for banks operating internationally.

We can take our analysis one step further by estimating optimal capital ratios for individual member states. Here we match the country-specific marginal costs estimate, with the marginal benefit estimate for the group the country belongs to. For example, we compare the marginal cost we obtain for Belgium (116bps, Figure 6) with the marginal benefit for the first group with the lowest GDP volatility (group 1 of Figure 7).

On the left-hand side of Figure 8, we display the range of optimal ratios for individual countries in Panel 8a. The range in values is determined by the assumed size of the effects of a banking crisis and by the extent to which these effects are permanent. On the right-hand side in Panel 8b, we show a map with the Euro member countries divided into four groups according to the size of their optimal capital ratio.

Figure 8: Optimal capital ratio by individual countries



(a) (b)

Note: The map displays a grouping based on the optimal capital ratio for each member state. These ratios are shown in the bar chart, with the vertical red line representing our main panel outcome as presented in Section 5.1.

Both panels indicate that optimal bank capital ratios are the highest in Cyprus, Greece, Malta and Slovakia, ranging from 23% for Slovakia to 27% for Cyprus. These estimates lie above our main panel outcome of 22%. Note that the range in optimal ratios for these countries is also the largest. This is due to the fact that the assumed size of the effect on output of a banking crisis dominates the calculated size of the marginal benefit. Even though banks in these countries have higher costs of acquiring capital, these countries benefit even more from having banks with a larger shock absorbing capacity (i.e. the marginal benefits for countries in group 3 are substantially higher than the other two groups).

The lowest estimate of optimal bank capital is 8% for Belgian banks, while we find an optimum of 9% for banks in Italy, France and Austria and 10% for Dutch banks. These countries have relatively low estimated marginal costs, but also lower benefits, because the volatility of their economies is less pronounced. A note of caution is warranted, as the estimation of benefits does not take the government (and consumer and firm) debt levels into account which might lead to higher benefits of preventing a banking crisis. In countries with high government debt levels, such as Italy (around 160% of GDP in 2020), a banking crisis can hurt the economy more severe as the government faces more difficulty in potentially saving individual banks. Therefore, preventing a banking crisis can have higher benefits for the economy, pushing the optimal capital ratio upwards.

Finally, in between these two groups, with low and high marginal costs, lie banks from Ireland (14%), Germany and Spain (15%), and Finland (17%). Altogether, aside from Italy, the results seem to suggest that optimal ratios are likely inversely related to the resilience of national economies (low marginal benefits) and the ease with which banks in different member states can raise capital (low marginal costs).

6 Sensitivity

In this section, we explore the sensitivity of our baseline results for the full set of countries in our sample, as described in Section 5. The estimation of optimal capital ratios is sensitive to a number of factors. For this reason, we aim to show how our estimates are affected by different time and country selections, as well as to a number of our calibrations. We divide the sensitivity analysis into those aspects affecting the marginal cost and those affecting the marginal benefit.[32]

6.1 Cost sensitivity

In Table 7, we report the sensitivity of our marginal cost estimates to a variety of assumptions. Using the same baseline estimate for benefits as in Figure 5, we derive optimal capital ratios based on the sensitivity checks to costs. We run several variations to our baseline setting related to sample selections, calibration of parameters, and we apply a bootstrapping methodology.

First, we explore the impact of sample selection. Prior to the financial crisis of 2007/08, the banking sector was subject to less stringent regulation. This rapidly changed in the aftermath of the financial crisis and the sovereign debt crisis in the euro area, with intensified supervision and regulation by national and supranational authorities. To investigate the impact of these crisis periods, we apply two sensitivity checks. In one, we only use observations from 2007 onward. Here we want to capture the developments in banking capital since the Great Recession. In the other, we only use data after 2012, following the European sovereign debt crisis.

Based on data from the period following the GR, our marginal cost estimate increases to 187bps. As the banking sector was subject to substantial financial strain, this increase is not surprising. At the same time, financial markets may have increased monitoring resulting in higher costs of capital. As a result, the optimal capital ratio falls to 20%. Next, when we focus explicitly on the period following the European sovereign debt crisis, during which time more stringent regulation was applied, the marginal cost estimate falls to 113bps, resulting in an optimal capital ratio of 23%.

[32]To save space, we do not report all figures. These are available upon request.

The second variant we discuss is a block bootstrapping procedure for estimating equity betas. This procedure allow us to account for the uncertainty involved in the estimation of the equity betas in (5). For this estimation we run 1000 bootstraps and take the estimates from the 5th and 95th percentiles to construct a 90% confidence interval. This results in a lower bound on the marginal cost estimate of 104bps, and an upper bound of 233bps. This results in bounds on the optimal ratio for our baseline of 19% to 23%.[33]

Table 7: Optimal ratios: sensitivity

Sensitivity	**Marginal Cost**	**Optimal Ratio**
Baseline	128bps	22%
2007 Crisis	187bps	20%
2012 Crisis	113bps	23%
Bootstrap upper	239bps	19%
Bootstrap lower	113bps	23%
Core countries	92bps	24%
France not included	136bps	22%
Non-linear, two bins	97bps	24%
Assets >10bln	129bps	22%
Assets >100bln	93bps	24%
Bank financing 35%	100bps	23%
Substitution elasticity 0.7	179bps	20%
Capital elasticity 0.45	178bps	20%

Note: For each variant we obtain all other aspects and calibrations of our model from our baseline. The upper and lower bound of the bootstrapped results reflect the 95th and 5th percentiles from 1000 draws. Core countries are those EMU members that have been part of EU since its inception. Regarding the non-linear estimates, with two bins, we only report the marginal cost estimate intersecting with the marginal benefits. This is the case for the second bin, with capital ratios over 18%.

In our third variant, we estimate our model for the founding member states of the EMU (core countries). The banking sectors in these states might have had more time to adjust to the union-wide banking sector framework (see, e.g., Goddard *et al.*, 2007 for a literature overview on European banking integration).[34] With this reduced set of member states, marginal costs fall to 95bps and result in an optimal ratio of 24%. Next, because the full sample includes many branches of Credit Agricole (see Appendix A for the full set of banks), we also run an estimation for which we drop France altogether from the full sample. In this case, marginal costs rise marginally to 136bps with the optimal ratio staying unchanged at 22% compared to our baseline.

[33] The graphical representation can be found in Appendix D.

[34] The countries in this sample are Austria, Belgium, Germany, Spain, Finland, France, Ireland, Italy, The Netherlands, and Portugal.

Fourth, Arnould *et al.* (2020) investigate the potential non-linear relationship between bank solvency and funding costs for european banks, and show that higher capital levels lead to lower costs with a convex nature. To explore potential non-linearities in the estimation of marginal costs in our approach, we apply a piece-wise linear estimation technique, by creating bins of banks depending on their leverage ratios.[35] Here we use the baseline parameter settings laid out in Section 4. In the results presented here, we set the limits of the bins in such a way that they have roughly the same number of observations. That is, banks with capital ratios under 18% (bin 1) and over 18% (bin 2).[36] The results indicate that there may be some non-linearity, but only marginally, resulting in an optimal ratio of 24%. As the figures in Appendix E make clear, this does not affect the outcome of optimal capital ratios, also for other number of bins.

Fifth, in an empirical study for banks in the United States, Berger & Humphrey (1991) show that larger banks can reduce inefficiencies and benefit from economies of scale. As a result the costs of these banks should fall. To explore the impact of bank size on optimal capital ratios, as an additional potential source of non-linearity, we run our estimations for banks with assets of over 10 billion euros, and for systemic banks with over 100 billion in assets. In the former case, our estimates remain roughly unchanged. The latter, however, leads to a quite substantial fall in the marginal costs to 93bps. The optimal capital ratio therefore increases to 24%, although this value is still close to our baseline estimate. This finding suggests that larger banks may indeed reduce inefficiencies and have lower costs of acquiring additional capital.

Finally, the calibration of the production function relating the change in the cost of capital to the real economy and the share of bank financing of firms can have an substantial impact on our estimates. Therefore, we investigate the effect of a change in some of these technical parameters. Firstly, we reduce the share of bank financing Ω from 45% to 35% as the availability of alternative funding sources for firms might reduce the role of bank funding. The marginal costs fall to 100bps, leading to an optimal capital ratio of 23%. Secondly, we raise the substitution elasticity between output and capital σ from 0.5 to 0.7, in line with the estimations of Klump *et al.* (2007) for the euro area. The marginal costs increase to 179bps, resulting in an optimal buffer falling marginally to 20%. Thirdly, we increase α, the elasticity of output with respect to capital, from 0.37 to 0.45, in line with Arpaia *et al.* (2009) and Klump *et al.* (2007) who find a steadily declining labour income share. The marginal cost estimate increases to 178bps, with the resulting optimal buffer also being 20%.

In summary, Table 7 demonstrates that the baseline estimate of 22% is robust to a large set of different sample selections and calibrations. The lowest estimate of 19%, for the lower bound

[35] Admittedly, this is not a clear-cut non-linear estimation technique, because we do not know the upper and lower level of the capital ratio that defines each bin. We attempt to deal with this problem by experimenting with various cut-off points for the bins.

[36] The first bin has 713 observations, and the second 753.

of our bootstrapping procedure, is still close to our baseline estimate.

6.2 Benefit sensitivity

In Table 8, we report on the sensitivity of our optimal bank capital estimates to different calibrations or sample selections related to the marginal benefit.

First, we use the same larger set of countries used in Miles, covering the periods since 1820 to fit the AEP distribution of GDP per capita. This involves the use of the data on the 31 countries in the Maddison data set. Arguably, the larger set of countries provides more variability in the GDP shocks. However, some of the countries and much of the earlier period in the data may be less representative of the current euro area economic situation. Based on this data, the optimal ratio increases from our baseline of 22% to 26%. As an additional check we also refit the AEP distribution using only OECD countries from the Maddison dataset with data since 1820. In this case, we obtain similar optimal value as the baseline.

In a second sensitivity test, we fit the Miles distribution to the GDP data. This distribution is bi-modal with a small peak around an extreme drop in output. This results in two regions where marginal cost and benefit cross. They first cross at the lower value of roughly 12%, while the upper region is nearly at 30%. By calculating the difference between the integral of the marginal benefit and the cost function, we can work out the net benefit as a function of the level of capital. This results in an optimal value of nearly 30%.

Finally, an argument could be made that there is a problem with endogeneity in the derivation of optimal capital ratios, because it is partly determined by GDP fluctuations that took place during banking crises themselves. Therefore, we remove all observations from our GDP data set in which R&R code a banking crisis; see Reinhart & Rogoff (2009). As Table 8 shows, in this case the optimal ratio remains unchanged.

Table 8: Optimal ratios: sensitivity

Sensitivity	**Optimal Ratio**
Baseline	22%
AEP, Miles data, 1820-	26%
AEP, OECD data, 1820-	26%
Miles, EMU countries, 1950-	30%
Baseline, exclude crises R&R	22%

7 Conclusion

In policy debates, bank capital is often considered to be one of the most important instruments to safeguard the financial system and the real economy from financial shocks. Higher bank capital requirements may have a negative impact on credit supply and the economy, as rising funding costs can be translated into higher lending rates. This makes raising bank capital socially costly. If increasing bank capital is socially costly, so too is not adequately raising bank capital. Doing so ensures that banks can absorb financial shocks and reduces the likelihood of future banking crises. Insufficient capital thus poses a risk to the financial sector and aggregate economic activity.

In this paper we estimate the optimal level of capital for euro area banks, weighing the costs and benefits of additional capital. To our knowledge, we are the first to do so in an empirical study. Building on the framework of Miles *et al.* (2013) and by extending their analysis, we obtain a baseline value of 22% for optimal bank capital ratios. This estimate is fairly robust to a wide set of sensitivity analyses. Even though European banks have improved levels of capitalization since the Great Recession, and subsequent Euro crisis, we conclude that there is still room for improvement. Moreover, the minimum capital requirements set by Basel III lie well below the optimum found in this paper.

Furthermore, we find substantial heterogeneities in the optimal bank capital ratio across member states, mainly displaying higher optimal level for countries with a weaker banking sector. For individual member states, optimal ratios vary from 27% in Cyprus to 8% in Belgium. This suggests that optimal ratios are likely inversely related to the resilience of national economies and the ease with which banks in different member states can raise capital. In our study we also find some evidence for reduced costs of capital for very large banks. This does not, however, significantly affect their level of optimal capital.

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A Banks in the sample

Table A.1 displays all (listed) banks in our sample. Branches for Credit Agricole (France) are denoted by Cred. Agri. followed by the region of the branch. For a list of all listed and non-listed banks in Europe, see for exampe Schoenmaker & Véron (2016).

Table A.1: Banks by country

Belgium	Dexia SA		Cred. Agri. Paris et d Ile de France
	KBC Groep NV		Cred. Agri. Sudra
Cyprus	Bank of Cyprus Holdings PLC		Cred. Agri. Toulouse 31 SC
	Hellenic Bank PCL		Cred. Agri. Tourain Poitou
Germany	Aareal Bank AG	**Ireland**	AIB Group plc
	Comdirect Bank AG		Bank of Ireland Group PLC
	Commerzbank AG		Permanent TSB Group Holdings PLC
	Deutsche Bank AG	**Italy**	Banca Carige SpA
	Deutsche Pfandbriefbank AG		Banca Finnat Euramerica SpA
	IKB Deutsche Industriebank AG		Banca Generali SpA
	ProCredit Holding AG		Banca IFIS SpA
	Umweltbank AG		Banca Intermobiliare di Investimenti
	UniCredit Bank AG		Banca Monte dei Paschi di Siena SpA
Greece	Alpha Bank SA		Banca Piccolo Credito Valtellinese SpA
	Attica Bank SA		Banca Popolare di Sondrio ScpA
	Eurobank Ergasias		Banca Profilo SpA
	National Bank of Greece SA		Banco BPM SpA
	Piraeus Bank SA		Banco di Desio e della Brianza SpA
Estonia	LHV Group AS		Banco di Sardegna SpA
Spain	Banco Bilbao Vizcaya Argentaria SA		Bper Banca SpA
	Banco Santander SA		Credito Emiliano SpA
	Banco de Sabadell SA		Intesa Sanpaolo SpA
	Bankia SA		Mediobanca Banca di Credito Finanziar
	Bankinter SA		UniCredit SpA
	Caixabank SA		Unione di Banche Italiane SpA
	Liberbank SA	**Lithuania**	Siauliu Bankas AB
	Unicaja Banco SA	**Malta**	FIMBank plc
Finland	Aktia Bank Abp		HSBC Bank Malta PLC
	Alandsbanken Abp		Lombard Bank Malta PLC
	Evli Pankki Oyj	**The Netherlands**	ABN Amro Bank NV
	Nordea Bank Abp		Cooperatieve Rabobank UA
	Taaleri Plc		ING Groep NV
France	BNP Paribas SA		Van Lanschot Kempen NV
	Natixis SA	**Austria**	BKS Bank AG
	Societe Generale SA		Bank fuer Tirol und Vorarlberg AG
	Credit Agricole SA		Erste Group Bank AG
	Cred. Agri. Alpes Provence		Oberbank AG
	Cred. Agri. Atlantique Vendee SC		Raiffeisen Bank International AG
	Cred. Agri. d'Ille-et-Vilaine SC		Volksbank Vorarlberg e Gen
	Cred. Agri. Languedoc		Wiener Privatbank SE
	Cred. Agri. Loire Haute-Loire	**Portugal**	Banco Comercial Portugues SA
	Cred. Agri. Morbihan SC	**Slovakia**	OTP Banka Slovensko as
	Cred. Agri. Nord de France SC		Tatra Banka as
	Cred. Agri. Normandie Seine SC		Vseobecna Uverova Banka as

B Recent average risk-weighted ratios

For the banks in Appendix A, we present the risk-weighted common equity tier-1 ratio for December 2019 (end of our sample) averaged by country in Table B.1:

Table B.1: Common Equity T1 ratios by Dec 2019

Country	Mean	Country	Mean
BG	21.95	IE	15.25
CY	17.14	IT	17.03
DE	14.31	LT	14.95
EL	15.01	MT	15.87
EO	12.39	NL	18.19
ES	12.60	OE	14.39
FN	17.74	PT	12.20
FR	17.97	SK	14.95
EA	16.08		

BG=Belgium, CY=Cyprus, DE=Germany, EL=Greece, EO=Estonia, ES=Spain, FN=Finland, FR=France, IE=Ireland, IT=Italy, LT=Lithuania, MT=Malta, NL=the Netherlands, OE=Austria, PT=Portugal, SK=Slovakia, EA=euro area average.

C Country panel FE estimates

Here we report the re-estimation of equation (6) for each country in Table C.1, next to the full panel results (denoted by EA), and appends to Section 5.2.

Table C.1: Panel FE estimates by country

Countries	$\hat{a}$	$\hat{b}$	N
BG	1.773	−0.020	70
CY	1.459	−0.010	36
DE	1.121	−0.013	236
EL	1.741	0.005	88
ES	0.888	0.015	185
FN	0.572	−0.008	115
FR	0.747	0.002	214
IE	1.412	−0.009	98
IT	0.572	0.013	550
MT	1.809	0.037	87
NL	0.431	0.018	138
OE	0.750	−0.004	183
SK	3.116	−0.012	55
EA	1.034	0.000	2092

These results display the panel FE estimators, including the normalized constant $\hat{a}$. BG=Belgium, CY=Cyprus, DE=Germany, EL=Greece, EO=Estonia, ES=Spain, FN=Finland, FR=France, IE=Ireland, IT=Italy, LT=Lithuania, MT=Malta, NL=the Netherlands, OE=Austria, PT=Portugal, SK=Slovakia, EA=euro area.

D Bootstrapping results

The estimation of equity betas is subject to uncertainty, for which we aim to assess the sensitivity. This appends to the sensitivity results presented in 6. As it delivers an important part of our analysis, we check the sensitivity of the final outcomes to bootstrapping the equity betas. We apply block bootstrapping in which we reshuffle the daily residuals of equation 5 by bank and half-year. In Figure 5 we display the optimal capital ratios for the bootstrapped equity betas of our baseline model. The figure displays the 5th and 95th percentiles of 1000 bootstraps, including our baseline estimate. The optimal bank capital ratio ranges from 19% to around 23%. Given our prior on the substantial uncertainty in equity betas, this range of optimal ratios is limited.

Figure D.1: Optimal capital ratio, bootstrapped MC

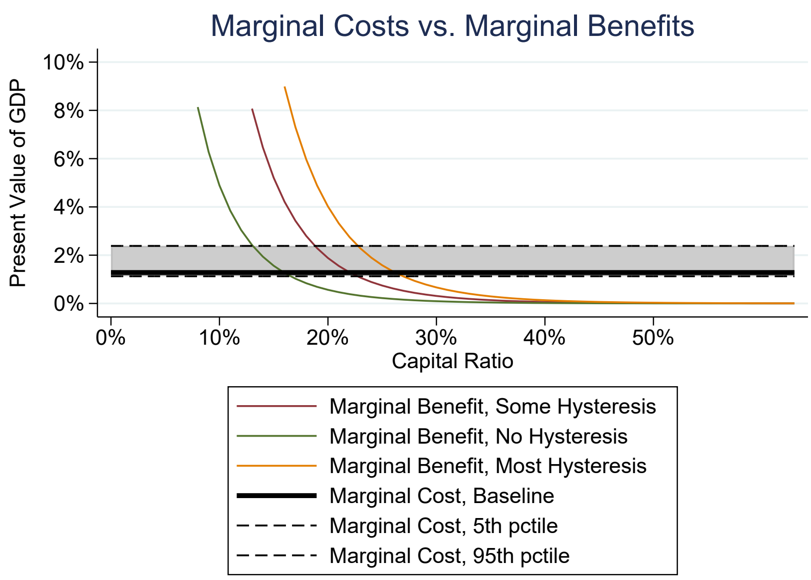


Figure D.2

The marginal cost lines (dotted) display the 90% confidence interval of block bootstraps of equity betas, with the 5th percentile as lower bound and 95th as upper bound.

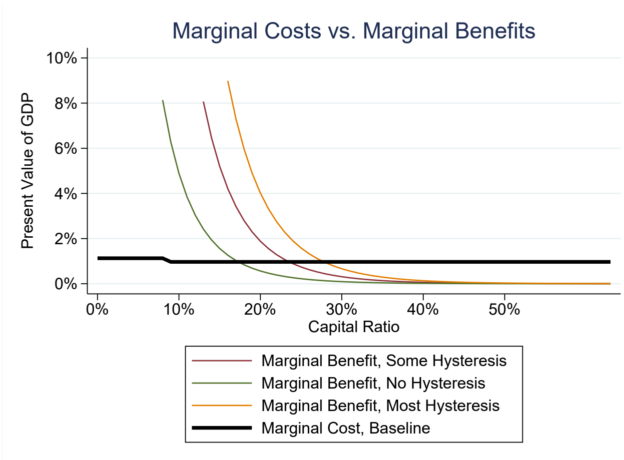
E Non-linear results

In Section 6 we reported our non-linear marginal cost estimate for two groups, with the split in the bins based on the number of observations. Here we report the figure belonging to the two bins, that is, banks with capital ratios under 18% (bin 1) and over 18% (bin 2). The results show some non-linearity, but only marginally, and not affecting the optimal ratio intensively.

We also report the non-linear estimates once we split the bins in three or four groups of fairly similar observations. The three bins are split on the risk-weighted capital ratio spectrum of 0-15%, 15-23%, and >23%. The four bins on the spectrum of 0-13%, 13-18%, 18-25%, and >25%.

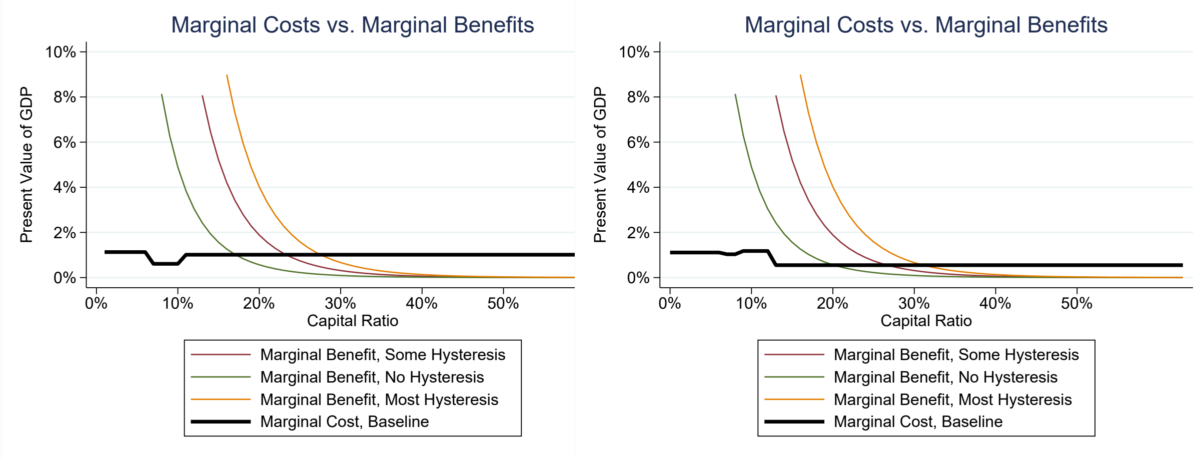
These results show some irregular non-linearities. With three bins, we see that the second bin shows a decline in the marginal costs, in line with the pattern with two bins in the main text. However, the final bin again sees some increase in marginal costs. With four bins, our estimates display fairly the same estimate for the first three bins, and a substantial drop for the fourth bin.

Figure E.1: Optimal capital ratio, two bins



Note: benefits are unchanged. We only display the baseline estimate.

Figure E.2: Optimal capital ratio, three and four bins



(a) (b)

Note: benefits are unchanged. We only display the baseline estimate. Panel (a) displays the results for three bins, and panel (b) for four bins.