Rightsizing Bank Capital: The Role of Macrofinancial Structure*

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We employ a macroeconomic cost-benefit approach to determine the appropriate tier 1 capital ratio for the banking systems of advanced economies. The macroeconomic costs of higher capital ratios are quantified using structural and semi-structural models of the Irish economy, while the macroeconomic benefits are derived using probabilistic models of financial crises and assumptions about the persistence of resulting output losses. We then examine the role of certain macrofinancial characteristics in determining the optimal level of bank capital. Incorporating these characteristics, the "rightsized" level of capital lies in a range of 12.5 to 19 percent.

JEL Codes: E5, G01, G17, G28, R39.

1. Introduction

Given their importance in the economy, banks face a number of requirements on the quantity and quality of their funding structure. Large losses in the banking system can have considerable spillover consequences for the real economy, which cannot be fully internalized by individual banks when mitigating their own risk profile. In addition, banks benefit from both explicit and implicit deposit insurance. Since capital represents the first line of defense in terms of loss

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absorption, banks are required to hold minimum levels of capital in line with existing regulations, regardless of the contribution of debt to their funding structure. In addition, they must fund themselves via tranches of capital to cater to specifically targeted balance-sheet-related risks, as well as systemic risk related to the broader environment or the systemic importance of a particular institution.

O'Brien and Wosser (2022) find that economies that are smaller, more open to trade and financial flows, more dependent on foreign direct investment (FDI), and that have more concentrated banking systems tend to have relatively higher systemic banking crisis probabilities, suffer larger systemic banking crisis-related costs, and exhibit relatively more adverse gross domestic product (GDP) growth tail risk through the financial cycle. In this paper, we examine the implications for appropriate levels of capital in the banking system of countries which display these structural characteristics. Specifically, we examine the influence of macrofinancial structural characteristics on the appropriate range of tier 1 capital[1] during periods when cyclical systemic risks are neither elevated nor subdued, including as necessary any additional bank capital needed to mitigate the effect of such structure-related systemic risks. This issue has been largely neglected in the existing literature.

Several studies have attempted to establish an appropriate capital range for particular banking systems based on the macroeconomic cost-benefit methodology that we follow in this paper (see Table 1). In the post–Global Financial Crisis (GFC) era, the Basel Committee on Banking Supervision (BCBS) study finds that the "optimal" tier 1 capital ratio range lies in the interval of 10 to 15 percent for advanced economies (see BCBS 2010).[2] However, as the approach has been refined and applied in other settings, the range found in subsequent studies is often somewhat higher.

From a methodological perspective, our approach is most similar to that of Brooke et al. (2015), who in turn follow Miles, Yang, and

[1] The tier 1 capital ratio is the ratio of a bank's core tier 1 capital, that is, its equity capital and disclosed reserves, to its total risk-weighted assets. Risk-weighted assets comprise approximately 60 to 70 percent of total assets (see Firestone, Lorenc, and Ranish 2019, p. 218).

[2] In an update to their paper (Birn et al. 2020), the BCBS acknowledges subsequent studies and concludes that optimal capital levels are likely to be higher than originally estimated.

Table 1. Estimates of Optimal Capital in Previous Studies

Study	Country	MM Offset	Optimal Bank Capital
Admati and Hellwig (2014)	—	Holds	20–30% tier 1 capital ratio
Barth and Miller (2018)	U.S.	Does not fully hold	Leverage ratio of 19% (equates to a tier 1 capital ratio of 25%)
BCBS (2010)	OECD	Holds	10–15% tier 1 capital ratio
Brooke et al. (2015)	U.K.	Does not fully hold	10–14% tier 1 capital ratio, 15–19% if resolution ineffective
Clerc et al. (2015)	Euro Area	No reference (does not hold)	Circa 10.5% tier 1 capital ratio
Cline (2016)	Ind. Countries	Does not fully hold	12–14% CET1 to RWA
Collard et al. (2017)	U.S.	Does not hold	10–14% tier 1 capital ratio
Dagher et al. (2016) (IMF)	Ind. Countries	0–75%	15–23% tier 1 capital ratio
Firestone, Lorenc, and Ranish (2019)	U.S.	Does not fully hold	13–26% tier 1 capital ratio
Junge and Kugler (2013)	Switzerland	Does not fully hold	13–17% tier 1 ratio for global systemically important banks (G-SIBs)
Miles, Yang, and Marcheggiano (2013)	U.K.	Does not fully hold (45% offset used)	16–20% CET1 to RWA
Schroth and Moyen (2017)	None	No reference	12.75–15.75% tier 1 ratio
Kragh-Sorensen (2012)	Norway	Does not fully hold	13–23% CET1 to RWA
Almenberg et al. (2017)	Sweden	Holds	10–17% CET1 to RWA

Note: The MM offset captures the extent to which a bank's weighted average cost of capital is invariant to changes in its capital structure in accordance with Modigliani and Miller (1958). RWA refers to risk-weighted assets.

Marcheggiano (2013), although we depart from their paper in some aspects of our modeling framework and in our focus on the role of macrofinancial structural characteristics. In addition, we employ two structural macroeconomic models of a small open economy (Ireland) to estimate the output-related costs of higher capital. Depending on the assumed effectiveness of the resolution regime for banks that are failing or likely to fail, Brooke et al. (2015) establish an optimal tier 1 capital range of 10–19 percent for the U.K. Abstracting from the potential benefits of the resolution regime, Miles, Yang, and Marcheggiano (2013) similarly find that much higher levels of capital than those deemed optimal by the original BCBS (2010) study were appropriate for the U.K., up to as much as 20 percent.

An important determinant of the macroeconomic cost of higher capital requirements in the literature is the extent to which the Modigliani and Miller (1958) theorem regarding the irrelevance of the capital structure to the weighted average cost of capital is expected to hold empirically for banks. Higher capital requirements can reduce economic activity if they raise banks' funding costs and, consequently, lead to higher interest rates for firms and households. Studies that have examined the macroeconomic impact of raising capital requirements typically assume that equity is more costly than debt financing, and that the increase in funding costs associated with higher capital requirements is partially or fully passed through to borrowers (BCBS 2010). However, the change in banks' weighted average cost of capital due to higher capital targets hinges on the value of the Modigliani-Miller "offset" that is applied. This offset determines the degree to which lower levels of leverage, by reducing the risk of bank failure, will also reduce banks' cost of equity and debt (Birn et al. 2020). Higher values of the offset will accordingly reduce the sensitivity of banks' funding costs to changes in the debt-equity composition of their liabilities.

Firestone, Lorenc, and Ranish (2019) consider the U.S. economy and estimate the optimal tier 1 capital ratio to be between 13 and 25 percent. In their analysis, the Modigliani-Miller offset does not fully hold, which has the effect of raising the optimal capital levels somewhat and goes some way toward explaining their relatively higher upper bound. In one of the few papers to specifically consider a smaller economy, Almenberg et al. (2017) determine the appropriate capital range for Sweden. They estimate that the optimal tier 1 capital ratio falls within a slightly different range (10–24 percent with Modigliani-Miller offset set to zero). However, this paper does not consider the specific contribution that the macrofinancial structural characteristics of Sweden contributes to their findings.

Barth and Miller (2018) examine the costs and benefits from raising the leverage ratio from 4 to 15 percent.[3] They find that, based on their benchmark specification, the optimal leverage ratio is 19 percent (equating to a tier 1 capital ratio of circa 25 percent). At those levels of capital, banks are able to absorb high losses and almost completely shield the sovereign from having to recapitalize the banking system following crisis onset.

Of particular relevance is the study conducted by Cline (2016) who, similar to this paper, examines optimal capital across a range of countries, including Ireland. Our optimal capital range (12.5 to 19 percent) is aligned with his (12 to 14 percent).[4] While the range for optimal capital ratios that we estimate is wider, this is likely attributable to our more structural approach, which tries to identify the independent and joint role of individual macrofinancial characteristics in determining these optimal levels of capital.

In line with the previous literature, we examine the resulting macroeconomic costs and benefits associated with requiring banks to raise additional capital. Following a similar methodology to the papers discussed above, we find that during periods when systemic risk is at median levels, the net marginal benefit of higher capital is zero when the tier 1 capital ratio is 16 percent. Below this point, the benefits of higher capital still outweigh the costs, whereas above this point the opposite holds. The results require a range of assumptions on key modeling parameters, such as the value of the Modigliani-Miller offset applied, the duration of crises, and the discount factor applied to future GDP losses related to systemic banking crises. Based on these assumptions, we derive a range of appropriate tier

[3] Defined as total capital divided by total exposures (i.e., inclusive of off-balance-sheet items). The leverage ratio can be converted to a tier 1 capital ratio via the application of a risk-weighted asset scaling factor. Our sample's median risk-weighted assets to total assets ratio is 60 percent. Assuming this condition holds in our generalized "benchmark" country, a tier 1 ratio of 16 percent then equates to a leverage ratio of 9.7 percent.

[4] Under the same assumptions of median risk-weighted assets to total assets of 60 percent, this equates to an optimal leverage ratio range of 7.2 to 12 percent.

1 capital ratios for normal risk environments between 12.5 to 19 percent with a benchmark level that is centered around 16 percent.

It is important to note, however, that our analysis does not address ancillary factors such as changes in the resolution framework or in approaches to risk weighting, which may influence both the steady-state and transition costs or benefits of particular capital levels. In terms of transition costs, the short-run impact of shifting to stronger capital regulations could also be significant. For example, the Macroeconomic Assessment Group (MAG 2010) finds that a 1 percentage point (pp) increase in capital ratios leads to a temporary negative deviation of GDP from its baseline of between 0.1 and 0.26 percent, with a concomitant 15 to 17 basis point increase in lending spreads. Similarly, Dorich and Zhang (2010) find that a 1 percentage point increase in capital ratios, implemented over four years, generates a fall in Canadian GDP of 0.26 percentage points eight years after implementation. In the case of Spain, Gerba and Mencia (2017) find that a 1 percentage point increase in capital leads to a drop in bank credit to firms and households by 1.1 and 1.4 percentage points, respectively, after four quarters, lowering GDP by close to 0.3 percentage points. More recently, Mendicino et al. (2020) find, using the three-dimensional model of the euro area, that higher capital requirements can carry considerable short-term costs, leading to a decline of GDP by up to 0.34 percent. Consequently, they argue that changes in required capital requirements should be implemented gradually across the euro area.

In terms of one of the main focal points of this paper, we find that net benefits of up to 3.5 percentage points of additional tier 1 capital accrue when macrofinancial structural characteristics are taken into account. This additional capital holds over the range derived from various modeling parameter assumptions mentioned above. While we consider the independent and joint impact of a number of structural macrofinancial characteristics, our results highlight the particularly important role played by country size, trade and financial openness, and FDI exposure in determining optimal capital buffers for a given country. Accordingly, countries that are smaller, more open to trade and financial flows, or have a high dependency on FDI should maintain slightly higher levels of tier 1 capital to mitigate the concomitant higher levels of systemic risk within their financial systems.

Finally, a key advantage of our analytical approach is that our results for the optimal capital ratio are readily generalizable to other countries. In particular, as we use a panel of OECD (Organisation for Economic Co-operation and Development) countries to estimate the marginal benefits of higher capital for given macrofinancial characteristics, these estimates provide an international benchmark which can be used to inform the rightsizing of capital levels across countries. On the marginal cost side, while our estimates are Irish-specific, they are consistent with the literature on the impact of higher capital ratios on steady-state output levels.

Moreover, there are aspects of our empirical approach that can provide insights for policymakers in other countries in terms of the strength of the different mechanisms through which capital-based macroprudential policy is transmitted to the real economy. We also highlight how using two macroeconomic models that feature detailed banking sectors, but that are methodologically quite different, can be used to enhance the overall robustness of the cost estimates. Alternatively, given the assumption that the marginal macroeconomic cost of higher capital is constant, policymakers could also combine local estimates of these costs with our results for marginal benefits to derive an optimal capital range for their banking system.

The remainder of the paper is structured as follows. Section 2 outlines our methodology for estimating the macroeconomic costs and benefits of additional capital. Section 3 presents our benchmark estimate of optimal capital and then quantifies the role of macrofinancial structural characteristics in shifting this optimal level. Section 4 addresses the robustness of our results and Section 5 concludes.

2. Estimating the Costs and Benefits of Higher Capital

We adopt and modify the "top-down" optimal capital approach set out in the existing literature. This methodology determines the marginal macroeconomic costs and benefits, in GDP terms, that are associated with additional bank capital. In this framework the marginal benefit of higher capital relates to the reduction in the probability of a systemic banking crisis as capital levels increase. The lower probability of a crisis in turn reduces the potential GDP losses that arise when systemic banking crises emerge. The marginal costs of additional capital relate to the potential for higher capital requirements to increase bank lending rates, and consequently to damp consumption, investment, and aggregate output growth.

Combining the marginal benefit with the marginal cost yields the net marginal benefit of additional bank capital:

$$NetMargBen = (\Delta CrisisProb * CrisisCost) - \Delta CapitalCost, \quad (1)$$

which remains positive up until the point at which the costs associated with a given level of capital exceed the benefits. The level of capital achieved at that point is the estimate of the appropriate level of capital for a given banking system.

In order to address our main research question—the role of macrofinancial structural characteristics in determining appropriate levels of bank capital—we focus primarily on how these factors can influence the marginal benefit component of Equation (1). Specifically, we examine how these characteristics can influence the probability of systemic banking crises and thus their expected cost in output terms. Our approach to estimating marginal costs employs structural and semi-structural models of the Irish economy, which could be considered the prototypical small, open advanced economy. Accordingly, the key aspects of our modeling framework can be adapted to examine optimal capital regulation in other small, open economies.

2.1 Marginal Benefits of Higher Capital

The first step in our analytical approach is to estimate systemic banking crisis probabilities for each country over time. Following O'Brien and Wosser (2018), we use a pooled logit model that estimates systemic banking crisis probabilities for 27 OECD countries.[5] Crisis probabilities are determined over a forecasting horizon of up to two years, conditional on a set of contemporaneous indicators found in the literature to have robust predictive properties, which we augment with the level of tier 1 bank capital in each country. The

[5] The logit model has become the de facto standard in the literature. See Demirgüç-Kunt and Detragiache (1997), Davis and Karim (2008), Eichler and Sobański (2012), and Lo Duca and Peltonen (2013).

model estimates the following regression specification using biannual data from 1980 to 2021:

$$Log\left(\frac{Pr(Crisis_{it}|Z_{it})}{Pr(NoCrisis_{it}|Z_{it}))}\right) = \alpha + \beta Z_{it} + \epsilon_{it}. \qquad (2)$$

The dependent variable is a binary variable that takes a value of one in crisis periods and zero otherwise. To determine crisis and non-crisis periods in our sample we use data from Lo Duca et al. (2017) for European countries and Laeven and Valencia (2013) for non-European countries. Based on the definitions in Laeven and Valencia (2013) and Lo Duca et al. (2017), systemic banking crises are those that result in the failure of one or more banks, exhibit some degree of bank-to-bank contagion, require particular government-backed support programs for the banking sector, and result in spillovers from banking system losses to the real economy. In the benchmark O'Brien and Wosser (2018), vector Z_{it} comprises eight leading indicator variables: (i) the first-difference of the short-term real interest rate, (ii) the credit-to-GDP ratio, (iii) a house price index and (iv) its deviation from its long-run trend, (v) losses on equity markets, (vi) unemployment rate, (vii) a financial conditions index, and (viii) the extent of household leverage relative to GDP. To this specification we add the tier 1 capital ratio in the banking system for each country in our sample. All variables are lagged by one period. The list of our sample countries is provided in Table 2, while variable definitions, data sources, and summary statistics are shown in Table 3.

Our data are pooled across all countries, with standard errors clustered by country. We do not use a fixed-effects model, so that countries which never experienced a banking crisis may be included during model estimation. Following this, we add dummy variables capturing structural characteristics to the model, allowing for the potential role of macrofinancial structural characteristics to be identified.

To estimate the marginal effect of higher capital on crisis probability, we hold the remaining explanatory variables at their sample median levels to reflect time periods when systemic risk levels are neither elevated nor subdued. We then estimate crisis probabilities for each percentage point increment of the tier 1 capital ratio over a range from 5 to 30 percent. The fitted crisis probabilities across this

Table 2. Countries, Crises, and Macrofinancial Structure

Country	Crisis Years		Source	Small Country	Fin. Open	Trade Open	CBS (R.E.)	CBS (WB)	CBS (Mkt. Sect.)	FDI Dep. Country
	Start	End								
Argentina	1980:Q1	1980:Q4	LV (2013)							
	1989:Q1	1989:Q4	LV (2013)							
Australia	—	—	LV (2013)		X					
Austria	2007:Q4	2014:Q1	ECB (2016)			X	X	X		
Belgium	2007:Q4	Ongoing	ECB (2016)		X	X		X	X	X
Brazil	1990:Q1	1990:Q4	LV (2013)							
	1994:Q1	1994:Q4								
Canada	—	—	LV (2013)				X			
China	1998:Q1	1998:Q4	LV (2013)							
Denmark	1987:Q1	1995:Q1	ECB (2016)	X	X		X			
	2008:Q1	2013:Q4								
Finland	1991:Q3	1996:Q4	ECB (2016)	X	X			X	X	
France	1991:Q2	1995:Q1	ECB (2016)		X				X	
	2008:Q2	2009:Q4								
Germany	2001:Q1	2003:Q4	ECB (2016)		X					
	2007:Q3	2013:Q2								
Greece	2010:Q2	Ongoing	ECB (2016)	X						
Hungary	1991:Q1	1995:Q4	ECB (2016)	X		X				X
	2008:Q3	2010:Q3								
Ireland	2008:Q3	2013:Q4	ECB (2016)	X	X	X	X	X	X	X
Italy	1991:Q3	1997:Q4	ECB (2016)							
	2011:Q3	2013:Q4								

(*continued*)

Table 2. (Continued)

Country	Crisis Years		Source	Small Country	Fin. Open	Trade Open	CBS (R.E.)	CBS (WB)	CBS (Mkt. Sect.)	FDI Dep. Country
	Start	End								
Japan	1997:Q3	1997:Q4	LV (2013)							
Luxembourg	2008:Q1	2010:Q4	ECB (2016)	X	X	X		X		X
Netherlands	2008:Q1	2013:Q2	ECB (2016)		X	X	X	X	X	
New Zealand	—	—	LV (2013)	X				X		
Norway	1991:Q1	1991:Q4	LV (2013)	X				X		
Poland	1981:Q1	1994:Q4	ECB (2016)			X	X			
Portugal	1983:Q1	1985:Q1	ECB (2016)	X	X				X	X
	2008:Q4	Ongoing								
Spain	1980:Q1	1985:Q3	ECB (2016)		X		X			X
	2009:Q1	2013:Q4								
Sweden	1991:Q1	1997:Q2	ECB (2016)		X	X	X	X		
	2008:Q3	2010:Q4								
Switzerland	2008:Q1	2008:Q4	LV (2013)		X	X				X
United Kingdom	1991:Q3	1994:Q1	ECB (2016)		X					X
	2007:Q3	2010:Q1								
United States	1988:Q1	1988:Q4	LV (2013)				X			
	2007:Q4	2011:Q4								

Note: This table presents information identifying the name and number of countries in the panel. The abbreviations LV (2013) and ECB (2016) refer to the Laeven and Valencia (2013) and the Lo Duca et al. (2017) crises databases, respectively. Crisis start and end dates are based on the ECB crisis data set as documented in Lo Duca et al. (2017) and on that of Laeven and Valencia (2013) for non-EU countries. Countries are designated as small if they fall into the lower median of countries in the underlying EWS database based on sample average rankings of a country's contribution to world GDP. Trade openness measures exports plus imports to GDP ratio. Financial openness measures the upper median of countries based upon the ratio of external claims of the banking system (inward and outward) relative to GDP. FDI dependency measures the ratio of foreign direct investment to GDP according to a CIA World Factobook survey (2018). "CBS" refers to different measures of concentration in the banking system. World Bank (WB) concentration measures the proportion of total banking system assets held by the largest three retail banks in a country. Bank concentration by market segment measures market segment concentration by NACE code (based on Herfindahl-Hirschmann methodology; see ECB statistical data warehouse). Concentration by real estate (R.E.) measures the proportion of bank assets that are real estate related with underlying bank balance sheet source data provided by Bloomberg and aggregated at the country level.

Table 3. Variable Description and Summary Statistics

Variable Name	Summary Statistics				Description	Obs.	Countries	Coverage	Source
	Mean	S.D.	Min.	Max					
Real Short-Term Interest Rates	0.053	0.058	–0.01	0.53	Real 3m money mkt rate	3,560	27	1980:Q1–2021:Q2	OECD
Losses Only S&P 500 Index	–0.014	0.04	–0.26	0.00	S&P losses only in a quarter	4,676	27	1980:Q1–2021:Q2	Yahoo Finance Historical Data
% Deviation of House Price Index from Trend	–0.91	0.11	–0.48	2.38	Trend fitted using Hamilton (4,8) filter	3,550	17	1981:Q4–2021:Q2	BIS—Long Property Series
% Deviation of Household Credit Growth from Trend	0.036	5.63	–100.45	30.22	Trend fitted using Hamilton (4,8) filter	2,780	27	1981:Q2–2021:Q2	BIS—Total Credit Statistics
% Deviation of Unemployment Rate from Trend	–.06	1.4	–10.00	6.73	Trend fitted using Hamilton (4,8) filter	3,228	25	1980:Q4–2021:Q2	OECD
Credit-to-GDP Ratio	135.48	64.63	9.4	455.3	Total credit extended to GDP	4,249	27	1980:Q1–2018:Q3	BIS—Total Credit Statistics
Financial Stability Index	0.12	0.10	0.00	0.84	Country-level index of financial stress (CLIFS)	2,750	17	2000:Q1–2021:Q2	ECB—Statistical Data Warehouse
House Price Index	155.75	101.52	21.29	564.96	House Price Index (1995=100)	3,727	17	1980:Q1–2021:Q2	BIS—Long Property Series

(*continued*)

Table 3. (Continued)

Variable Name	Summary Statistics				Description	Obs.	Countries	Coverage	Source
	Mean	S.D.	Min.	Max					
GDP World Share	2.40	4.07	0.42	22.27	Contribution to world GDP share	4,202	27	1980:Q1–2021:Q2	IMF—IFS Database
Trade Openness	75.14	54.35	11.54	423.99	Ratio of exports plus imports as a percentage of GDP	3,816	27	1980:H1–2021:H1	IMF—IFS Database
Financial Openness	10.65	47.17	0.01	466.33	External claims inward and outward as a percentage of GDP	2,348	27	1980:H1–2021:H1	IMF—IFS Database
FDI Dependency	49.58	62.27	0.58	391.11	Stock of FDI to GDP ratio	1,225	27	1980:H1–2021:H1	IMF—IFS Database
Tier 1 Capital Ratio	0.11	.04	.01	.25	Tier 1 capital as a proportion of risk-weighted assets	1,450	15	2000:H1–2020:H2	Bloomberg
Bank Concentration I	66.47	20.02	20.19	100.00	Share of total banking assets held by three largest banks	2,252	26	2000:H1–2020:H2	World Bank
Bank Concentration II	2,318.01	520.43	1,365.41	3,588.03	HHI Index of concentration	682	11	2000:H1–2020:H2	BIS
Bank Concentration III	53.39	11.28	21.87	74.27	Share of R/E exposure of banking sys.	744	11	2000:H1–2020:H2	Bloomberg

Note: This table presents information on the variables in the panel. The EWS panel is held at quarterly frequency whereas bank balance sheet data are only available. EWS data are collapsed according to the frequency available for analysis. The bank crisis data are taken from the ECB's crisis database (Lo Duca et al. 2017) for EU countries and from Laeven and Valencia (2013) for non-EU countries.

Table 4. Crisis Probability and Tier 1 Capital

	(1)
Constant	0.489 (3.473)
Real Short-Term Int. Rates	–141.558*** (35.074)
Losses Only S&P 500	–8.352** (3.960)
House Prices (%d)	0.846 (4.429)
Unemployment (%d)	–0.121 (0.139)
Household Credit Growth (%d)	0.159 (0.136)
Credit-to-GDP Ratio	0.005 (0.005)
Fin. Stability Index	–13.821** (5.483)
House Price Index	0.001 (0.016)
Tier 1 Capital Ratio	–54.561*** (9.051)
Observations	1,021
Pseudo R^2	0.348

Note: This table shows the effects of including tier 1 capital in the baseline EWS panel logit model with random effects. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic banking crisis begins, and is zero otherwise. Variables denoted by (%d) represent the deviation of the variable from its underlying trend. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

range allow the marginal contribution of each additional 1 percentage point of tier 1 capital to be estimated. Fitted systemic banking crisis probabilities are determined according to the following equation:

$$Pr\left(Crisis_{it} = \frac{e^{Z_{it}\beta}}{1 + e^{Z_{it}\beta.}}\right). \tag{3}$$

An example of the regression output from one of the underlying logit models is presented in Table 4. In this model, tier 1 capital is negative and statistically significant at the 1 percent level, indicating that the given level of tier 1 capital reduces the likelihood of a systemic banking crisis emerging in the subsequent two years when "normal" or median risk conditions prevail. However, there are diminishing marginal benefits as tier 1 capital increases, which suggests that there is an optimal level beyond which the costs of additional capital requirements outweigh the benefits.

This finding that tier 1 capital has a negative and statistically significant effect on crisis likelihood is robust to alternative model specifications. Table 5 presents the results of a robustness test for the inclusion of tier 1 capital in the logit model using the algorithm outlined in Young and Holsteen (2017). This procedure examines all possible combinations of the variables in the logit model together with the tier 1 ratio. In total, 254 models are considered. In all cases, the coefficient on tier 1 capital is negative and significant. The lower panel of the table shows the effect that the exclusion of each of the control variables has on the coefficient on tier 1 capital. For example, in all models that exclude real short-term interest rates, the coefficient on tier 1 capital is 5.4 percent larger than its mean value when all variables are included. Overall, we interpret these results as providing strong evidence of a systematic negative correlation between bank capitalization and crisis likelihood.

From Equation (1), there are two components to the calculation of the marginal benefits of capital comprising the probability of systemic crises and the expected cost of crises. In our analysis we use a common measure of the cost of crises derived from the crisis episodes in our sample. In particular, we estimate costs as the difference between actual GDP in the five years following the onset of the crisis and a pre-crisis linear projection of GDP over the same period, and express this difference as a percentage of the projected values.[6] The results suggest that, on average, crises reduce GDP by 7.17 percent relative to pre-crisis trend. This is in line with prior studies, as shown in Table 6.

The final elements to consider when estimating the marginal benefit of higher bank capital are (i) the permanence or transience of the shock to GDP arising from crises, (ii) if the crisis costs are transitory, how long do they persist, and (iii) the appropriate discount rate to be used to evaluate the present value of losses.

[6] Calculated using an exponentially weighted moving average of the GDP series up to the quarter where the crisis is deemed to have commenced.

Table 5. Logit Model Robustness and Tier 1 Capital

Model Robustness: Tier 1 Capital			
Dependent Var.	Prob. Sys. Crisis		
Robust Var.	Tier 1 Capital		
Control Variables	8		
No. Models	254		
No. Observations	1,023		
Model Robustness Statistics		**Significance Testing (%)**	
Mean Coefficient	–0.346	Sign Stability	100
Sampling Std. Error	0.113	Significance Rate	100
Modeling Std. Error	0.024	Positive	0
Total Std. Error	0.116	Positive and Significant	0
		Negative	100
		Negative and Significant	100
Model Influence			
Marg. Effect of Variable		**%Δ from Mean Coeff.**	
Unemployment (%d)	0.025	7.3	
Real Short-Term Rate	–0.019	5.4	
Credit-to-GDP Ratio	–0.016	4.7	
House Price Index	–0.010	2.9	
Losses Only S&P 500	–0.008	2.3	
Fin. Stability Index	–0.007	2.0	
HH Credit Growth (%d)	–0.006	1.6	
House Prices (%d)	0.001	–0.1	
Constant	–0.326		
R-Squared	0.643		

Note: This table presents robustness results related to the inclusion of tier 1 capital in the benchmark EWS logit model using the Young and Holsteen (2017) algorithm. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic crisis begins, and is zero otherwise. The remaining variables are as defined in Table 2. All possible combinations of these variables that include tier 1 capital are examined (254 models).

If the GDP loss from a systemic banking crisis is permanent, the present value (PV) of the loss can be calculated using the formula for a perpetuity, with the PV of the loss (C = 7.17 percent) determined via the discount factor r according to

$$PV(Crisis_{it}) = \frac{C}{r}. \tag{4}$$

Table 6. Prior Studies of Crises and Output Loss

Study	Peak Loss (% GDP)	Long-Run Impact (% GDP)
Barrell et al. (2010)	6	3
Cecchetti, Kohler, and Upper (2009)	9	—
Cerra and Saxena (2008)	8	7
IMF (2009)	10	10
BCBS (2010)	9	6
Romer and Romer (2015)	4	3
Brooke et al. (2015)	5	4

In contrast, if the costs of crises are assumed to be transitory, then the duration over which they persist t will also be incorporated in the computation of losses (again with C = 7.17 percent):

$$PV(Crisis_{it}) = C\left(\frac{1-(1+r)^{-t}}{r}\right). \tag{5}$$

Overall, our estimate of the marginal benefit of higher bank capital is the reduction in crisis probability at each level of the tier 1 capital ratio multiplied by the expected crisis cost as calculated above.

2.2 Marginal Costs of Higher Capital

Imposing additional capital requirements on the banking sector may raise banks' funding costs and ultimately lead to higher interest rates on lending to firms and households. The macroeconomic cost of higher capital is the lower growth in consumption, investment, and GDP that results from the increase in interest rates relative to the scenario in which capital requirements remain unchanged. To illustrate how such capital shocks are transmitted to the economy and to quantify their macrofinancial impact, we use two detailed macroeconomic models of the Irish economy—COSMO and Eire-Mod.

The transmission mechanism of an increase in capital requirements to the real economy is broadly similar in both models. There are several channels through which banks can raise their risk-weighted capital ratios: through retained earnings, via deleveraging, by shifting the risk profile of their lending portfolios, or by issuing new equity. Both COSMO and EireMod assume that banks generate higher capital ratios through raising retained earnings. This assumption is consistent with the "pecking order theory" (see Myers and Majluf 1984) according to which banks prefer to exhaust internal funds first due to having to pay a premium on external finance. It is also consistent with other studies that use macroeconomic models to assess the costs of higher capital requirements (BCBS 2010) and with the empirical evidence on the behavior of banks' capital ratios since the Global Financial Crisis (Cohen and Scatigna 2016). Deleveraging does occur endogenously in COSMO and EireMod as households and firms demand less credit in response to higher lending rates.

To quantify the impact of higher capital requirements, we simulate a scenario in both COSMO and EireMod in which banks are required to increase their capital ratios by 1 percentage point. Following the literature on optimal levels of capital, our analysis focuses on the long-run or "steady-state" impact of higher requirements and abstracts from transition costs.[7]

2.3 COSMO

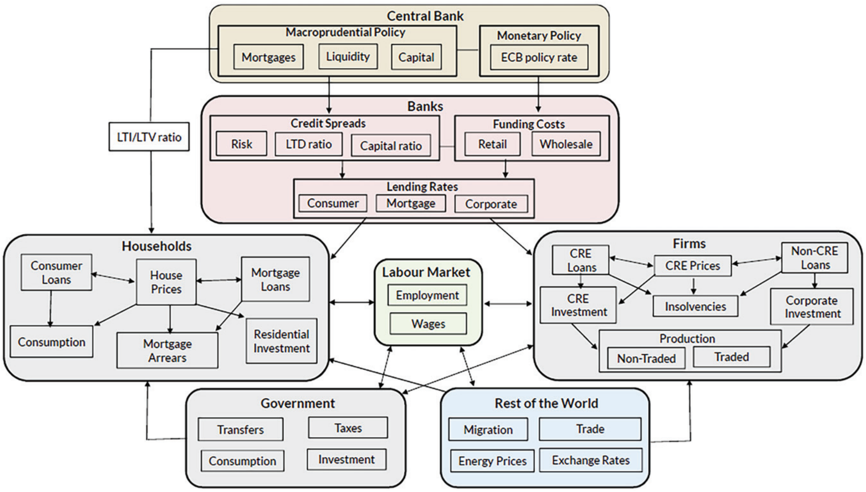
COSMO is a medium-scale estimated semi-structural model of the Irish economy. At its core it comprises three sectors: a traded sector that depends on world demand and Ireland's export prices relative to competitors; a nontraded sector that is primarily driven by domestic economic conditions; and a government sector that grows in line with the rest of the economy in the absence of exogenous policy changes.[8]

The model incorporates a wide range of linkages between the central bank, retail banks, households, and firms. A key feature of the model is that it includes several borrower- and lender-based macroprudential instruments. The central bank can set limits on loan-to-income (LTI) and loan-to-value (LTV) ratios on household

[7] If banks are required to increase capital ratios relatively quickly, they may choose to adjust loan volumes rather than interest rates. This may generate substantial short-run economic costs (Bridges et al. 2014; Aiyar, Calomiris, and Wieladek 2016).

[8] See Bergin et al. (2017), Conefrey, O'Reilly, and Walsh (2018), and McInerney (2020) for details on different aspects of COSMO.

Figure 1. Macrofinancial and Macroprudential Linkages in COSMO



Source: Authors' own schematic representation of the COSMO model.

mortgage borrowing. Given the focus of our study, it can also impose additional capital requirements or buffers on banks by raising their target capital ratio. These macroprudential and macrofinancial linkages are illustrated in Figure 1, where the transmission paths of macroprudential and monetary shocks are represented by the solid arrows.

COSMO assumes a monopolistically competitive banking sector in which banks set lending rates as a variable spread over deposit and wholesale funding costs. These lending rates form supply curves for the respective types of credit in the model: mortgages, consumer credit, commercial real estate (CRE) lending, and other (non-CRE) corporate credit. Lending spreads are a function of policy and risk factors, and it is through the spread that lender-based macroprudential instruments operate. When the central bank raises capital requirements, banks respond by raising lending spreads so as to generate the necessary increase in retained earnings to meet the new target capital ratio.

Higher lending rates increase the user cost of capital for firms and households and reduce the demand for all types of credit. The

Table 7. Impact of a 1 pp Increase in Banks' Capital Ratio in COSMO

Variable	Long-Run Impact (%)
Lending Rates (bps)	+11
Credit	–0.61
Total Investment	–0.28
Residential Investment	–0.64
CRE Investment	–0.51
House Prices	–0.42
Consumption	–0.06
GDP	–0.05
"Nontraded" Output	–0.12
Total Employment	–0.06

Note: Estimates are percent deviations from baseline except for lending rates, which are basis point deviations.

contraction in credit depresses house prices. This reduces household consumption through the housing wealth effect and residential investment due to the fall in the profitability of housing construction. The combination of higher mortgage rates and lower house prices pushes up the rate of household mortgage arrears. As lending to households is now riskier, banks raise lending spreads on loans to this sector.

Similarly, higher borrowing costs reduce corporate investment while the fall in CRE prices reduces investment in CRE. The fall in CRE prices reduces the value of collateral used for corporate borrowing, leading to a fall in both CRE and non-CRE corporate lending. Lower collateral values also affect firms' ability to roll over existing credit lines and obtain working capital. This increases the rate of corporate insolvency, which—as a driver of the risk component of the corporate lending rate—further raises firms' user cost of capital. The cumulative fall in investment leads to lower capital stocks and accordingly reduces the productive capacity of each sector in the economy in the long run.

To assess the macroeconomic cost of higher capital requirements, we simulate a 1 percentage point increase in banks' capital ratios in COSMO. The impact on key variables is reported in Table 7. To generate the retained earnings necessary to meet the new target for the capital ratio, banks raise the weighted average lending rate by 11 basis points (bps) relative to the baseline scenario in which capital requirements do not change.[9] The increase in the cost of borrowing reduces the demand for credit, with the weighted average stock of credit falling by 0.6 percent.[10]

The increase in lending rates raises the user cost of capital for both firms and households. In response, total investment falls by approximately 0.3 percent. CRE and residential investment, which are more interest rate-sensitive than other types of investment, fall by 0.5 percent and 0.6 percent, respectively. The increase in the user cost of housing capital reduces the demand for housing, leading to a fall in house prices relative to baseline of 0.4 percent. Household consumption falls by 0.06 percent due to the negative wealth effect arising from lower house prices.

Overall, the long-run macroeconomic impact of a 1 percentage point increase in capital requirements in COSMO is to reduce GDP by 0.05 percent and employment by 0.06 percent. However, the impact on the more bank-dependent, domestically oriented sectors of the economy is larger, with the output of the nontraded sector falling by 0.12 percent relative to the baseline.[11]

2.4 EireMod

EireMod is a dynamic stochastic general equilibrium (DSGE) model of the Irish economy. At its core it comprises two sectors: a tradable-good sector, which consists of firms producing consumption and investment goods for the domestic market and a tradable goods sector producing export goods. The tradable goods sector uses intermediate imported goods as input and employs foreign capital as a factor of production. The core structure of the model has been extended by Lozej, Onorante, and Rannenberg (2023) to include a realistic

[9] The weighted average rise in lending rates comprises an increase of 10, 11, and 19 bps in corporate, mortgage, and consumer lending rates, respectively.

[10] This comprises a fall of 0.5, 0.4, 0.7, and 0.8 percent in the stock of mortgage, (non-CRE) corporate, CRE, and consumer credit, respectively.

[11] The traded, nontraded, and government sectors in COSMO are defined using the Irish Central Statistics Office's (CSO) Supply and Use Input-Output tables. The nontraded sector includes those sectors in which less than 50 percent of total final uses is exported and those sectors in which less than 50 percent of total final uses is used as government consumption.

financial sector, so that credit is intermediated by banks subject to a minimum capital requirement.

In the model, an implicit government guarantee on deposits creates an incentive for banks to increase leverage. As discussed below, this creates a break with the Modigliani-Miller proposition. As banks face a trade-off between increasing their leverage and incurring regulatory penalties if a shock hits their balance sheet, they optimally set their capital ratio above the regulatory minimum. All else equal, a marginal increase in the capital requirement forces the bank to deleverage, decreasing the bank's profitability. Monopolistically competitive banks respond to the decline in profitability by increasing the lending rate. In the long run, the lending rate will increase enough to keep the return on equity unaltered.

The model features a central role of the banking system in credit intermediation, by assuming that at each point in time, a constant share of both productive capital and the housing stock is intermediated through bank loans. An increase in the lending rate will therefore directly affect investment in productive capital and the demand for housing, which, in turn, affect investment in the construction sector. In the long run, capital will be lower, limiting production possibilities in the economy. Overall, the long-run macroeconomic impact of a 1 percentage point increase in capital requirements in EireMod is to increase average lending rates by 10 basis points and to reduce GDP by about 0.04 percent.[12]

2.5 The Modigliani-Miller Offset

The Modigliani-Miller theorem (Modigliani and Miller 1958) comprises two propositions. The first states that in a perfectly competitive and frictionless economy the value of a firm is independent of how it is financed, while the second postulates that, given that the first proposition holds, the cost of equity for a leveraged firm increases linearly with the debt-to-equity ratio. The implication of the theorem is that the relative returns on debt and equity adjust in response to a change in the capital structure so that the weighted average cost of capital (WACC) remains constant. For example, an

[12] A more detailed decomposition of these results is available from the authors.

Table 8. Estimates of the Modigliani-Miller Offset

Study	Sample	Offset (%)
Toader (2015)	European Banks	42
ECB (2011)	International Banks	41–73
Yang and Tsatsaronis (2012)	International Banks	10
Junge and Kugler (2013)	Swiss Banks	36
Miles, Yang, and Marcheggiano (2013)	U.K. Banks	45–90
Brooke et al. (2015)	U.K. Banks	53
Kashyap, Stein, and Hanson (2010)	U.S. Banks	36–64
Cline (2015)	U.S. Banks	45
Clark, Jones, and Malmquist (2018)	U.S. Banks	25–100
Barth and Miller (2018)	U.S. Banks	0

increase in capital (reduction in leverage) reduces the volatility of the return on equity and therefore lowers its required return.

However, there are two main distortions that prevent the Modigliani-Miller theorem from holding empirically in relation to banks. The first is the tax treatment of debt—banks' interest payments on debt can be used to reduce their tax liabilities. The second relates to the implicit or explicit public guarantees on bank debt, mainly deposits. This acts as a subsidy to banks that reduces the cost of debt relative to equity, which does not enjoy such guarantees.

Accordingly, the key question from an empirical perspective is whether the required return on equity falls as the volatility of the return falls due to higher capital ratios (or lower leverage). The most common approach to testing the Modigliani-Miller theorem uses the Hamada (1972) framework that combines the theorem with the capital asset pricing model (CAPM). Essentially, this involves estimating the relationship between a bank's leverage and its equity beta.[13] Assuming that the beta of a bank's debt is zero, this gives a relationship between the beta (or riskiness) of a bank's assets and its leverage (Miles, Yang, and Marcheggiano 2013).[14]

As Table 8 shows, the empirical evidence on the Modigliani-Miller theorem is mixed. The estimated values for the offset from the

[13] A bank's equity beta measures the covariance between the return on the bank's equity and that of the overall market.

[14] Assuming a debt beta of zero implies that debt has bank-specific default risk but no systematic market risk.

Table 9. Impact of a 1 pp Increase in Banks' Capital Ratio

Study	Country	Lending Rates (bps)	GDP (%)	Offset (%)
COSMO	Ireland	11	–0.05	0
EireMod	Ireland	10	–0.04	0
Mikkelsen and Pedersen (2017)	Denmark	10	–0.2	0
BCBS (2010)	OECD	9 to 19	–0.02 to –0.35	0
Almenberg et al. (2017)	Sweden	16	–0.09	0
Brooke et al. (2015)	U.K.	5 to 10	–0.01 to –0.05	50 to 0
Cline (2016)	U.S.	6	–0.08	50
Federal Reserve Bank of Minneapolis (2017)	U.S.	5.7	–0.06	50
Firestone, Lorenc, and Ranish (2019)	U.S.	3.4 to 6.9	–0.04 to –0.08	50 to 0

literature range from zero to a full offset, with a median value of close to 50 percent. There is some evidence that the offset is close to full for large or too-big-to-fail banks but significantly lower for small- and medium-sized banks (Clark, Jones, and Malmquist 2018) and some evidence that it is time-varying (Kashyap, Stein, and Hanson 2010).

Given the considerable heterogeneity in estimates of the offset, together with the absence of specific estimates for Irish banks, it is not clear which value for the offset should be applied to the increase in lending rates. The median estimate for the offset from Table 8 is close to 50 percent. However, in many studies that examine the macroeconomic impact of higher capital requirements, the rate at which the increase in lending rate is "offset" by a fall in the required return on equity is simply assumed. As our baseline, we assume that the offset is zero, but we consider alternative values in Section 3.1. Moreover, it is important to note that, as both COSMO and EireMod are linear models, any value for the offset can be applied ex post by scaling the fall in output due to higher capital requirements by that value.

2.6 Comparing Cost Estimates with Other Studies

Table 9 compares the impact of a 1 percentage point increase on lending rates and GDP in COSMO and EireMod with estimates for other countries. Similar to our approach, some of these studies such as BCBS (2010) and Mikkelsen and Pedersen (2017) use macroeconomic models that include a banking sector to quantify the impact of higher capital requirements on both lending rates and GDP and which allow for feedback from the real economy to the banking sector. The remaining studies broadly adopt a two-step approach. They first use a basic loan pricing model and information on the relative cost of debt and equity to calculate how lending spreads may increase in response to higher capital requirements. They then feed this information into either a simple production function as an increase in the cost of capital (Brooke et al. 2015; Cline 2016) or as an increase in bond spreads facing nonfinancial firms in a macro model (Almenberg et al. 2017; Federal Reserve Bank of Minneapolis 2017; Firestone, Lorenc, and Ranish 2019).

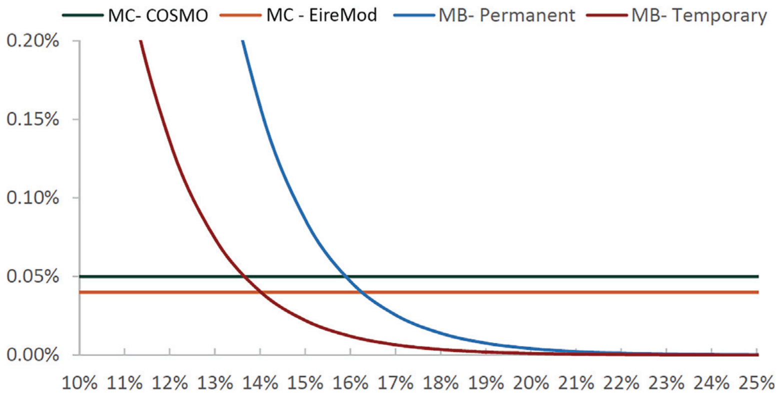
All of the approaches yield broadly similar results to those from COSMO and EireMod in terms of the long-run increase in lending spreads and fall in output relative to a baseline. The study by the Basel Committee on Banking Supervision (BCBS 2010) is perhaps the most comprehensive, as it covers 13 countries and uses a variety of models. It finds that a 1 percentage point increase in capital requirements raises lending rates by between 9 and 19 basis points and reduces output relative to baseline between 0.02 and 0.35 percent of GDP. However, our results are closest to those of the Bank of England (Brooke et al. 2015). They find that a similar increase in capital requirements raises lending rates by between 5 and 10 basis points and reduces output relative to baseline by between 0.01 and 0.05 percent, depending on the value of the Modigliani-Miller offset applied. As the results from COSMO and EireMod assume the Modigliani-Miller offset is zero, they closely match the upper bound in Brooke et al. (2015).

The similarity of our cost estimates to those from other studies reflects a consistency in the approach to modeling these costs across countries. The models employed by these studies have similar transmission mechanisms from the shock to capital to the increase in lending rates and through to the reduction in the interest rate-sensitive components of aggregate demand. In particular, in the case of those models that explicitly incorporate a banking sector, the primary channel through which banks achieve the higher capital target is by accumulated retained earnings from raising lending rates. In this respect, our framework for quantifying the macroeconomic cost of increasing capital requirements can be readily applied to other countries.

While our cost estimates are consistent with the literature, there are two potential caveats to these estimates that should be mentioned relating to the use of macroeconomic models of the Irish economy to generate these estimates. First, the models' equations are estimated or calibrated over a sample period that includes episodes of severe macrofinancial and macrofiscal volatility in the aftermath of the 2007–08 financial crisis. Isolating and quantifying the economic impact of higher capital requirements is therefore complicated by the concurrent shocks to banks' balance sheets, financial market liquidity, and sovereign creditworthiness that buffeted the real economy and banking system over that period. In addition, the introduction of comprehensive macroprudential regulations over the last decade in Ireland has significantly changed how banks respond to real and financial shocks. These factors can therefore complicate the identification of capital shocks when using Irish data.

Second, the outsized presence of multinational enterprises (MNEs) in the Irish economy distorts the relationship between conventionally used measures of aggregate output, such as GDP, and macroeconomic conditions in the domestic economy. The activities of MNEs in Ireland are outward-focused and have limited spillovers to the local economy. Moreover, as they are not typically dependent on domestic banks for financing, investment by MNEs in their Irish operations is generally insensitive to any increase in retail lending rates arising from higher capital requirements for Irish banks (Desai, Foley, and Hines 2004; Lawless, O'Connell, and O'Toole 2014). These factors result in a relatively low (semi-) elasticity of aggregate output (GDP) with respect to interest rates in the macroeconomic models we use, and explain why our estimates of the macroeconomic impact of capital shocks are at the lower bound of the literature. However, our analysis does also highlight how when we focus on the impact of shocks to bank capital on the output of domestically focused sectors, our results are close to the mean found in the literature. These additional results can therefore provide useful information for interpreting our estimates relative to those found in studies of similar sized economies.

Figure 2. Benchmark Rightsized Tier 1 Capital Ratio



Note: The figure plots the marginal benefits of additional tier 1 capital when systemic banking crises have temporary (MB-Temporary) or permanent (MB-Permanent) effects, and the marginal costs of additional capital as simulated by a DSGE (MC-EireMod) and semi-structural (MC-COSMO) model. The marginal benefits relate to a risk environment in which EWS variables are at their median.

3. Rightsizing Tier 1 Capital Ratios

3.1 Benchmark Model

Using the estimates discussed above, we plot the resulting marginal benefit and marginal cost curves consistent with given levels of tier 1 capital in Figure 2. We show the marginal benefits curves for the cases in which systemic crises are assumed to have either permanent or temporary effects. In the latter scenario, the economic impact of a crisis is assumed to dissipate after five years. The slope of these curves capture the extent to which the marginal gain in terms of lower crisis likelihood from additional capital diminishes as the tier 1 capital ratio increases. The point at which the marginal cost and benefit curves intersect corresponds to the level of capital beyond which net benefits of higher capital become negative, and thus this level can be interpreted as the "optimal" or "rightsized" level for the economy.

Figure 2 clearly illustrates how assumptions regarding the nature of economic scarring effects from financial crises can significantly influence the optimal capital ratio. If the policymaker assumes that crises have a transitory effect on the economy only, the appropriate level of capital for an economy is approximately 14 percent. In contrast, if these effects are assumed to be permanent, the appropriate level of capital rises to 16 percent. From a macroprudential and risk management perspective, policymakers would likely adopt a conservative approach to the calibration of capital buffers and thus we adopt the latter as our "benchmark" model of optimal capital. This represents the baseline case against which alternative parameterizations of the marginal benefit and marginal cost curves can be compared. This benchmark model includes all eight early warning system (EWS) variables, set to their median values, and the tier 1 capital ratio. It assumes that crises reduce GDP by 7.17 percent relative to the pre-crisis trend and these output losses are discounted using a discount rate of 3 percent. Finally, it assumes that banks' weighted average cost of capital rises in proportion to the increase in capital so that the Modigliani-Miller offset is zero.

To highlight how the appropriate tier 1 capital ratio varies according to particular calibrations of the model, we consider alternative values for each of the key input parameters. A summary of alternative model calibrations is presented in panel A of Table 12. For example, assuming crises negatively affect GDP growth over a 10-year horizon results in an optimal tier 1 capital ratio of 13.5 percent (Scenario 2). Table 12 also shows the impact that different values of the Modigliani-Miller offset has on the optimal level. Setting the offset to a value of 50 percent, as some studies have assumed, results in a 1 percentage point increase in the appropriate capital level (Scenario 5). While the relatively small incremental increase in optimal capital that results from a halving of the macroeconomic costs of capital may seem surprising, it is important to note that the slope of the marginal benefit at that point mainly determines this change. As discussed above, the change in the slope of the marginal benefit curve is primarily a function of how the probability of experiencing a systemic crisis falls as the tier 1 capital ratio of the banking system increases. Thus, if the marginal benefit curve is relatively steep at the benchmark, this indicates that small changes in capital levels have a relatively large effect on mitigating the likelihood of lost output, or the expected output loss, due to a crisis. Accordingly, a given change in the marginal cost of higher capital will result in a smaller increase in optimal capital than if the marginal benefit curve were flatter.

Overall, this sensitivity analysis suggests that, based on plausible alternative parameterizations of the marginal cost and marginal benefit curves, optimal tier 1 capital levels can range between 12.5 and 19 percent, with our benchmark or baseline calibration indicating a level of 16 percent. Having established this benchmark estimate for an appropriate tier 1 capital ratio for advanced economies, we now focus on the role that macrofinancial structural characteristics may play in influencing that ratio.

3.2 The Role of Macrofinancial Characteristics

Our choice of structural characteristics is informed by O'Brien and Wosser (2022), who find that economic size, the extent of trade and financial openness, the dependency on inward foreign direct investment (FDI), and the degree of market and sectoral exposure concentration in the banking system are important structural factors determining systemic risk. We now employ the same set of variables in our framework to assess how they affect the optimal or rightsized level of capital for the economy. The definitions of these variables, along with data sources and summary statistics, are reported in Table 3.

We first consider the role played by macrofinancial structural variables in amplifying or mitigating financial crisis likelihood. To classify an economy as having a particular macrofinancial structure, we construct dummy variables that indicate whether the economy is the top or bottom tertile of the cross-country distribution of the variable. For example, a country is categorized as being "small" if its contribution to global GDP is in the bottom tertile of countries in our sample. In the case of trade openness, we classify a country as being "trade open" if its ratio of exports and imports to GDP is in the top tertile across countries. In terms of financial openness, we focus on a de facto measure of financial globalization as captured by the ratio of inward and outward external claims to the total assets of the country's banking system. A country is thus defined as being "financially open" if this ratio is in the top tertile in our sample.

We measure bank concentration using three variants: (i) a market exposures concentration index (based on a Herfindahl-Hirschmann

Index (HHI) of market-sector exposures), (ii) the share of total banking system assets held by the three largest banks in a country, and (iii) the extent to which a banking system has exposures to real estate in particular. Our final structural variable measures the extent to which the country may be FDI dependent as indicated by the ratio of the stock of FDI to GDP.

The results of including these macrofinancial variables in our benchmark model with tier 1 capital are presented in columns 1–7 in Table 10, with the results relating to the structural dummy variables shown in the bottom panel. We find that only the small (at the 10 percent level) trade and financial openness variables have an independent effect on crisis likelihood for a given level of tier 1 capital. While not shown here, it is worth noting that the FDI dependency variable and two of the banking concentration measures are statistically significant if the capital variable is excluded or if these variables are included in continuous rather than discrete (dummy variable) form.[15] Thus, these variables may be systematically associated with higher probabilities of crises, but either these risks are offset by higher levels of capital or the direct relationship is essentially linear.

We now examine the interactions between the dummy variables given that countries in our sample may exhibit multiple macrofinancial structural characteristics concurrently. For example, countries may be small and highly open to trade, or they may be financially open and also have concentrated banking systems. To assess how combinations of different characteristics may amplify or mitigate the effect of each characteristic on systemic risk, we include the interaction of different combinations of macrofinancial variables in the benchmark logit model. The results of these regressions are reported in columns 8–10 in Table 10, where only statistically significant interactions are reported for expository reasons. We find that being a small country tends to amplify the impact of other macrofinancial characteristics on systemic risk. In particular, systemic risk tends to be higher in countries that are both small and also open to trade, financially open, and dependent on FDI.

[15] These results are available on request from the authors.

Table 10. Crisis Probability and Macrofinancial Structure

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	–0.635	0.622	–1.195	2.023	1.438	1.724	1.784	–1.780	–2.542	1.447
	(1.987)	(1.987)	(1.748)	(4.003)	(2.774)	(3.900)	(3.790)	(2.562)	(2.818)	(4.063)
Real Short-Term	303.889***	226.663***	277.919***	270.206***	258.736***	271.202***	279.548***	277.553***	282.989***	276.429***
Int. Rates	(116.285)	(75.315)	(94.199)	(98.968)	(85.719)	(96.705)	(83.620)	(92.790)	(99.256)	(105.146)
Losses Only	–30.031**	–26.460***	–25.493***	–26.979**	–25.468***	–25.919**	–27.576***	–28.456***	–26.357***	–28.586***
S&P 500	(11.976)	(10.005)	(9.100)	(10.757)	(9.191)	(10.204)	(10.161)	(10.395)	(9.560)	(11.000)
House Prices	9.947**	12.838***	12.333***	10.659***	8.931*	9.701***	8.143*	13.935***	12.463***	11.459***
(%d)	(4.333)	(4.295)	(4.106)	(3.258)	(4.765)	(3.102)	(4.664)	(4.515)	(4.359)	(2.998)
Unemployment	–0.374*	–0.521**	–0.586*	–0.391*	–0.302	–0.325*	–0.272	–0.430***	–0.424***	–0.319**
(%d)	(0.205)	(0.217)	(0.312)	(0.231)	(0.214)	(0.179)	(0.182)	(0.130)	(0.164)	(0.135)
HH Credit	0.272**	0.234**	0.270**	0.229**	0.221***	0.234**	0.229**	0.248**	0.281**	0.234**
Growth (%d)	(0.133)	(0.096)	(0.117)	(0.090)	(0.086)	(0.097)	(0.102)	(0.118)	(0.139)	(0.106)
Credit-to-GDP	0.004	–0.009	–0.009	–0.007	–0.001	–0.002	0.008	–0.001	0.003	–0.002
Ratio	(0.007)	(0.009)	(0.010)	(0.012)	(0.010)	(0.009)	(0.022)	(0.010)	(0.010)	(0.009)
Fin. Stability	–19.943**	–19.146**	–17.468**	–16.426***	–14.970**	–15.444***	–15.356***	–16.596***	–15.595***	–16.269***
Index	(8.852)	(7.577)	(7.033)	(6.140)	(6.567)	(5.586)	(5.325)	(5.781)	(5.532)	(5.959)
House Price	–0.002	–0.001	0.016	–0.013	–0.015	–0.013	–0.025	0.009	0.017	–0.013
Index	(0.015)	(0.013)	(0.015)	(0.033)	(0.022)	(0.031)	(0.024)	(0.018)	(0.021)	(0.033)
Tier 1 Capital	–55.914***	–55.315***	–61.195***	–50.983***	–49.889***	–54.288***	–51.821***	–59.001***	–67.710***	–53.461***
Ratio	(17.973)	(12.227)	(16.540)	(12.106)	(11.909)	(12.660)	(11.204)	(16.685)	(21.902)	(12.774)

(*continued*)

Table 10. (Continued)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Small Country	2.098*									
	(1.280)									
Trade Openness		3.339***								
		(1.023)								
Fin. Openness			3.646***							
			(1.401)							
FDI Dependent				2.438						
				(1.691)						
CBS I: HHI					0.747					
					(1.762)					
CBS II: Three-Bank Share						1.606				
						(1.476)				
CBS III: Real Estate							−0.698			
							(2.567)			
Small*TradeOpen								4.122***		
								(1.194)		
Small*Fin.Open									3.900***	
									(1.417)	
Small*FDI										3.198***
										(1.065)
Observations	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021
Pseudo R^2	0.381	0.403	0.403	0.374	0.359	0.366	0.358	0.431	0.419	0.393

Note: This table shows the effects of including macrofinancial structural characteristic variables in the EWS panel logit model with random effects. The dependent variable is a crisis dummy variable that takes a value of one in the quarter in which a systemic banking crisis begins, and is zero otherwise. Variables denoted by (%d) represent the deviation of the variable from its underlying trend. “CBS” refers to the different measures of concentrated banking systems. All variables are lagged by one period. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

The marginal effects of these macrofinancial characteristics on the probability of experiencing a systemic financial crisis are presented in Table 11. We find that, conditional on the early warning indicators in the benchmark model, the marginal effect of being a small country is statistically significant (at the 10 percent level) and increases the probability of experiencing a crisis by 0.7 percentage points. Countries that are classified as "trade open" or "financially open" are over 1 percentage point more likely to experience crises. Focusing on the statistically significant interaction terms, crisis probabilities are 1.2 percentage points higher in countries that are both small and trade open, and 1.1 percentage points higher in countries that are both small and financially open. Finally, we find that the marginal effect of being small and FDI dependent has a similar impact on crisis likelihood (1.1 percentage point increase) as being small and either trade or financially open.

To quantify how optimal capital varies in countries with these types of macrofinancial structure, we first compute the marginal benefits of additional tier 1 capital incorporating the impact of these macrofinancial characteristics on the likelihood of financial crises. Figure 3 illustrates how the optimal level of capital changes for countries that are small and those that are trade open when crises are assumed to have either permanent or temporary effects on output. The marginal benefit curves from the benchmark models that exclude structural characteristics are shown for comparison. The top panel of Figure 3 shows that for small countries, the optimal level of capital increases by 1 percentage point relative to the benchmark in both scenarios for crisis-related output losses. The bottom panel of Figure 3 shows the impact of being "trade open" on the optimal level of capital. While small countries are typically also those that are most open to trade, we find that the impact of the latter on the appropriate level of capital is 50 basis points higher than the former in our baseline case that assumes that crises have permanent effects on output. However, in the case that the effects of financial crises are transitory, the small country and trade open characteristics have a similar impact on optimal levels of capital.[16]

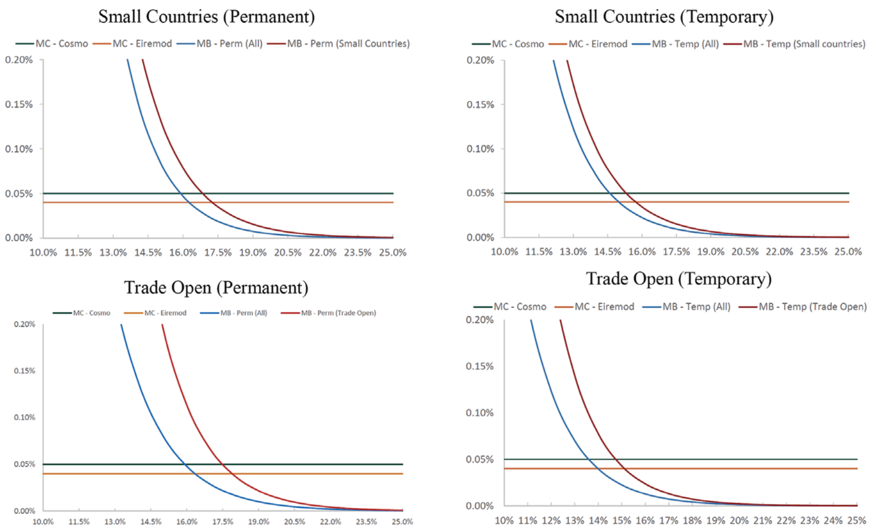
[16] It is important to note that the relative scale of the marginal effects associated with structural variables, vis-à-vis each other, does not necessarily translate

Table 11. Marginal Effects of Macrofinancial Characteristics on Crisis Probabilities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Small Country	0.007*									
	(0.004)									
Trade Openness		0.010***								
		(0.004)								
Fin. Openness			0.011**							
			(0.005)							
CBS I: HHI				0.003						
				(0.004)						
CBS II: Three-Bank Share					0.005					
					(0.007)					
CBS III: Real Estate						0.002				
						(0.004)				
FDI Dependent							0.008			
							(0.006)			
Small*TradeOpen								0.012***		
								(0.003)		
Small*Fin.Open									0.011***	
									(0.004)	
Small*FDI										0.011***
										(0.002)
Observations	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021	1,021

Note: This table shows the marginal effects of macrofinancial structural characteristics variables on crisis likelihood. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

Figure 3. Impact of Structural Characteristics on Rightsized Capital Ratios



Note: Impact of the "small country" and "trade open" characteristics on optimal capital ratios when systemic crises are assumed to have either permanent or temporary effects. The marginal benefit curves for all countries are plotted for comparison.

The loadings on the benchmark capital ratio that are attributable to each of the other macrofinancial characteristics are shown in panel B of Table 12. To keep the presentation tractable, we focus on the case where financial crises have permanent effects on output. For completeness, we also include the loadings based on individual characteristics, including those for FDI dependency and banking concentrations. As these coefficients are not statistically significant, any inference based on their values is subject to the associated caveats.

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into a similar scale of optimal capital adjustments. The inclusion of various structural variables in regressions is associated with variation in the coefficients of the other EWS variables, depending upon which structural variable (or combination thereof) is included. Thus the trajectory of the marginal benefit curve, and its intersection point with the marginal cost curve, is altered, depending upon the structural variable involved. Whereas the optimal capital point is influenced by the marginal effect of the structural variable upon crisis probability, fitted values for the latter are also affected by the variation in the other coefficients.

However, the point estimates may be indicative of the magnitude of capital loadings that could be appropriate in countries that exhibit these characteristics. In these cases, the additional capital that is appropriate given higher levels of systemic risk ranges from 1 percentage point in countries with banking systems that are highly concentrated in either the share of assets held by the largest three or in their exposure to the real estate sector, to 2 percentage points in countries that are FDI dependent.

Table 12 shows that the largest increase in optimal capital relative to the benchmark comes from being both small and dependent on FDI, with an additional 3.5 percentage points of tier 1 capital required to mitigate the systemic risks associated with these characteristics. In countries that are small and open to trade, or small and financially open, additional capital of approximately 1.25 to 1.5 percentage points above the benchmark level may be appropriate. To our knowledge, these are the first estimates of how macrofinancial characteristics can independently or jointly raise the level of tier 1 capital that is optimal for a country's banking system.

In summary, the results in Table 12 show that estimates of appropriate levels of the tier 1 capital ratio in the banking system of advanced economies when cyclical systemic risk is at its median level can, depending on the particular calibration, range from 12.5 to 19 percent with a benchmark estimate of 16 percent. However, when various structural macrofinancial characteristics are considered, that range and benchmark could be up to 3.5 percentage points higher. From a financial stability perspective, therefore, our analysis suggests that it may be prudent for macroprudential authorities in countries that aim to incorporate systemic risk factors in their calibration of required capital buffers to also consider the structural macrofinancial dimension to these risks.

3.3 Capital Ratios, Risk Weights, and Cyclical Risks

While our framework is primarily designed to assess appropriate capital ratios in the steady state, policymakers would also likely require an analytical assessment of how rightsized levels of capital vary due to risk weights and to cyclical risks. In terms of the former, we can derive the implicit average risk weights applied to bank

Table 12. Model Calibration and Effect of Economic Structure on Optimal Capital

A. Sensitivity of Benchmark Tier 1 Ratio of 15% to Alternative Parameterization						
Parameterization Scenario	**MM Offset (%)**	**Discount Factor**	**Perm. Crisis Effects**	**Temp. Crisis Effects**	**Duration (Years)**	**Optimal T1 Capital (%)**
Benchmark	0	3	Y	N	—	16.00
Scenario 1	0	3	N	Y	5	12.50
Scenario 2	0	3	N	Y	10	13.50
Scenario 3	25	3	Y	N	—	16.50
Scenario 4	75	3	Y	N	—	18.00
Scenario 5	50	3	Y	N	—	17.00
Scenario 6	50	3	N	Y	5	13.75
Scenario 7	50	3	N	Y	10	14.75
Scenario 8	50	5	Y	N	—	16.25
Scenario 9	50	5	N	Y	5	13.75
Scenario 10	50	5	N	Y	10	14.50
Scenario 11	50	1	Y	N	—	19.00
Scenario 12	50	1	N	Y	5	14.00
Scenario 13	50	1	N	Y	10	15.00

(continued)

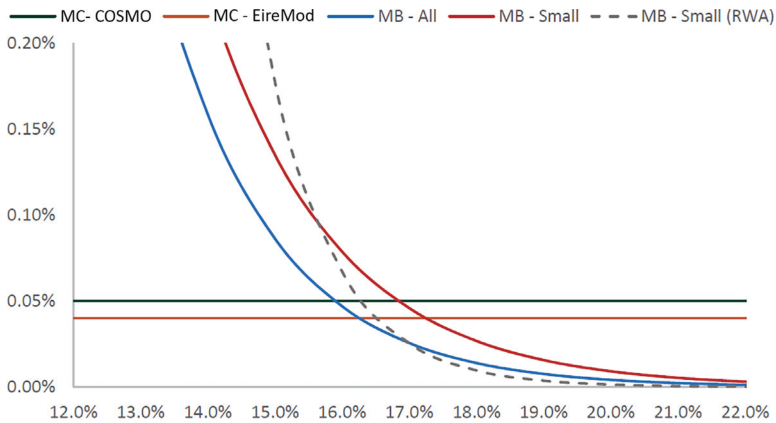
Table 12. (Continued)

B. Impact of Structural Characteristics Loadings on Benchmark Tier 1 Ratio of 16%

Structural Variable	Definition	ΔOptimal Ratio (pp)
Small Economy	Based on contribution of bottom tertile of countries in sample to world GDP	+1.00
Trade Openness	Countries in top tertile of share of exports plus imports in GDP	+1.50
Financial Openness	Countries with ratio of banking system external claims to GDP in top tertile	+1.00
FDI Dependent†	Countries with ratio of FDI to GDP in top tertile	+2.00
CBS I†	Countries in top tertile of shares of total banking system assets held by three largest retail banks	+1.00
CBS II†	Countries in top tertile of concentrated market-sector exposures measured by HHI	+1.25
CBS III†	Countries in top tertile of concentrated real estate market exposures	+1.00
Small and Trade Open	Based on cohort of countries that are both small and trade open	+1.25
Small and Fin. Open	Based on cohort of countries that are both small and financially open	+1.50
Small and FDI Dependent	Based on cohort of countries that are both small and FDI dependent	+3.50

Note: EWS variables in the benchmark scenario are set at their sample median. "CBS" refers to the different measures of a concentrated banking system. † denotes variables with coefficient point estimates that are not statistically significant in the structural dummy variable regressions.

Figure 4. Impact of Risk-Weighted Assets on Structural Capital Delta



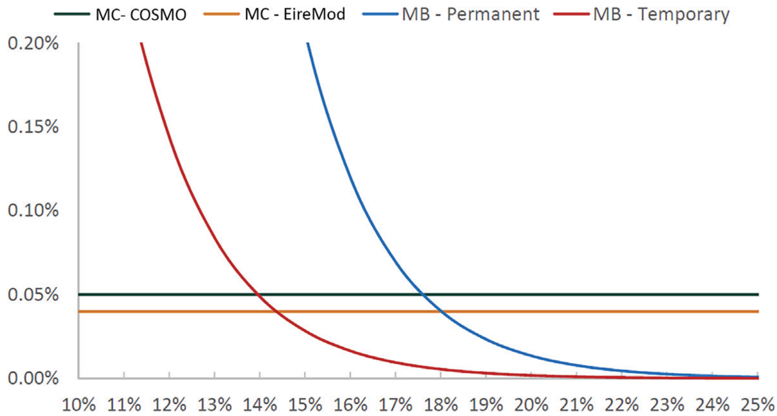
Note: The figure plots the marginal benefits of additional tier 1 capital for all countries, for small countries, and for small countries incorporating risk weights. The marginal benefit curves assume that systemic banking crises have permanent effects on output.

assets by country and over time.[17] This allows us to examine the capital implications implied by higher risk weights, in addition to the capital implications of different structural macrofinancial characteristics considered above. For exposition purposes, we focus only on the "small" structural characteristic in the case that crises have permanent effects on output. Figure 4 illustrates how the incorporation of risk weights changes both the slope and position of the marginal benefit curve. Importantly, it shows that, although higher risk weights reduce the structure-related capital gap, they do not eliminate it.

In terms of cyclical risks, our analysis has focused on appropriate levels of capital when risks are held at median levels. To address the issue of how rightsized capital ratios change when risks are elevated, we evaluate the marginal benefits of additional capital when each leading crisis indicator is at a "stressed" level. Note that as the macroeconomic models we use to estimate the marginal costs of

[17] For example, where tier 1 capital to total assets are reported alongside tier 1 capital to risk-weighted asset ratios such as in BCBS (2010), the risk-weighted assets and the average risk weights may be determined. See also footnote 1.

Figure 5. Rightsized Capital in an Elevated Risk Environment



Note: The figure plots the marginal benefits of additional tier 1 capital when EWS variables are at their 75th percentile for cases in which banking crises have temporary (MB-Temporary) and permanent (MB-Permanent) effects. The marginal costs of additional capital are simulated using a DSGE (MC-EireMod) and semi-structural (MC-COSMO) model and relate to average macroeconomic costs over the cycle.

additional capital are linear, these costs do not vary over the cycle. To keep the discussion concise, we focus on the benchmark capital models and thus abstract from the impact of macrofinancial structure. Figure 5 illustrates how the rightsized level of capital changes when all early warning indicators reflect a stressed value represented by the 75th percentile. We find that the rightsized levels increase by approximately 2 percentage points to 18 percent when systemic crises have permanently harmful effects, and by 1 percentage point to circa 14.5 when crises are assumed to have temporary effects on output. With the caveat that our framework is more suitable for assessing long-run capital requirements, these results suggest that accounting for an elevated risk environment can materially affect the calibration of appropriate macroprudential buffers.

4. Robustness Checks

We assess the robustness of our results across several dimensions. To ensure that our results are not driven by a single crisis episode or country, we drop each crisis observation sequentially and reestimate the logistic model. These changes in the composition of our sample do not affect our results. We also estimate the model over different time periods and similarly find that our primary findings are broadly unchanged.

More fundamentally, we adjust the classification scheme for defining dummy variable according to each macrofinancial structural characteristic. Instead of assigning a particular characteristic to a country depending on whether they are above or below the top or bottom tertile value of the macrofinancial variable, we consider different thresholds such as quartiles and quintiles. We do find that some results are sensitive to these changes. The reclassification mainly affects bank concentration indicators with the coefficients on the HHI and market-sector exposure variables changing sign when the thresholds change.

As O'Brien and Wosser (2022) show however, when these structural characteristics are included in the estimation in continuous instead of discrete form, they are shown to be positively and significantly correlated with higher crisis likelihood. Moreover, when the dummy variables are more narrowly defined based on quartiles or quintiles, it becomes more difficult to distinguish between country cohorts sharing multiple characteristics, and thus the underlying structural characteristic become more difficult to identify. Accordingly, we argue that, while a more granular classification would be preferable a priori, our approach based on classifying countries according to whether they are above or below the top or bottom tertile of a particular variable is apposite given the relatively small number of country-financial crisis episodes that is available.

5. Conclusions

The analysis in this paper suggests that when the prevailing systemic risk environment is neither elevated nor subdued, the appropriate tier 1 capital range for the banking systems of advanced economies can plausibly lie in a range between 12.5 and 19 percent, with our benchmark specification indicating an optimal value of approximately 16 percent.

Additionally, we show that a country's macrofinancial structural characteristics can materially influence the appropriate level of capital by an additional 3.5 percentage points. The characteristics we find to be most important in determining steady-state capital ratios include whether a country is "small" in terms of its contribution to global GDP, the extent to which it is "open" to trade and capital flows, and the degree to which it is FDI dependent.

The range we identify is relatively broad but is consistent with prior literature, especially with those studies that use panel data similar to that used here. Our results, particularly in terms of the marginal benefits of higher capital for given macrofinancial characteristics, could therefore help inform the calibration of optimal capital ratios across different banking systems. Further, the analytical framework we outline in this paper is sufficiently flexible to allow policymakers to derive a country-specific range for appropriate levels of bank capital by combining local estimates of the marginal macroeconomic costs of higher capital requirements, which are assumed to be constant, with our results for the marginal benefits (which are nonlinear).

To further narrow the optimal capital range, additional analysis is warranted. On a country-by-country basis, a bottom-up approach toward "rightsizing" banking system capital should also be considered given that prior research has shown that the results achieved in top-down studies, such as we have adopted, can yield results indicating a higher capital range than suggested by a bottom-up approach. However, our results do point to the relevant additional capital that macroprudential policymakers could consider when framing an approach to capital buffers in small open advanced economies.

While our finding that the assessment of appropriate levels of capital should incorporate structure-related factors is novel, it should be noted that these recommendations relate to a "long-run" perspective and refer specifically to normal or median systemic risk levels. In particular, the transitional costs associated with shifting to higher levels of capital could be relatively large depending on how the introduction of additional capital requirements is sequenced. When making specific policy decisions regarding the calibration of these ratios, macroprudential authorities would also need to evaluate the impact of prevailing economic and systemic risk conditions, as well as any associated transition costs to the steady state (or normal times), on their rightsized level.

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