OPTIMAL BANK CAPITAL*

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This article reports estimates of the long-run costs and benefits of having banks fund more of their assets with loss-absorbing capital, or equity. We model how shifts in funding affect required rates of return and how costs are influenced by the tax system. We draw a clear distinction between costs to individual institutions (private costs) and overall economic (or social) costs. We find that the amount of equity capital that is likely to be desirable for banks to use is *very* much larger than banks have used in recent years and also higher than targets agreed under the Basel III framework.

This article reports estimates of the long-run costs and benefits of having banks fund more of their assets with loss-absorbing capital – by which we mean equity – rather than debt. The benefits come because a larger buffer of truly loss-absorbing capital reduces the chance of banking crises which, as both past history and recent events show, generate substantial economic costs. The offset to any such benefits comes in the form of potentially higher costs of intermediation of saving through the banking system; the cost of funding bank lending might rise as equity replaces debt and such costs can be expected to be reflected in a higher interest rate charged to those who borrow from banks. That in turn would tend to reduce the level of investment with potentially long-lasting effects on the level of economic activity. Calibrating the size of these costs and benefits is important but far from straightforward.

Setting capital requirements is a major policy issue for regulators – and ultimately governments – across the world. The recently agreed Basel III framework will see banks come to use more equity capital to finance their assets than was required under previous sets of rules. This has triggered warnings from some about the cost of requiring banks to use more equity; see, for example, Institute for International Finance (2010) and Pandit (2010). But measuring those costs requires careful consideration of a wide range of issues about how shifts in funding affect required rates of return and on how costs are influenced by the tax system; it also requires a clear distinction to be drawn between costs to individual institutions (private costs) and overall economic (or social) costs. And without a calculation of the benefits from having banks use more equity (or capital) and less debt, no estimate of costs – however accurate – can tell us what the optimal level of bank capital is.

In calculating cost and benefits of having banks use more equity and less debt it is important to take account of a range of factors including:

(*i*)   The extent to which the required return on debt and equity changes as funding structure changes.
(*ii*) The extent to which changes in the average cost of bank funding brought about by shifts in the mix of funding reflect the tax treatment of debt and equity and the offsetting impact from any extra tax revenue received by government.
(*iii*) The extent to which the chances of banking problems decline as equity buffers rise – which depends greatly upon the distribution of shocks that affect the value of bank assets.
(*iv*) The scale of the economic costs generated by banking sector problems.

Few studies try to take account of all these factors (one notable exception being Admati *et al.* (2010)); yet failure to do so means that conclusions about the appropriate level of bank capital are not likely to be reliable.[1] This article tries to take account of these factors and presents estimates of the optimal amount of bank equity capital.

We conclude that even proportionally large increases in bank capital are likely to result in a small long-run impact on the borrowing costs faced by bank customers. Even if the amount of bank capital doubles our estimates suggest that the average cost of bank funding will increase by only around 10–40 basis points (bps) (a doubling in capital from current levels would still mean that most banks were financing more than 90% of their assets with debt.) But substantially higher capital requirements could create very large benefits by reducing the probability of systemic banking crises. We use data from shocks to incomes from a wide range of countries over a period of almost 200 years to assess the resilience of a banking system to these shocks and how equity capital protects against them. In the light of the estimates of costs and benefits we conclude that the amount of equity funding that is likely to be desirable for banks to use is *very* much larger than banks have had in recent years[2] and higher than minimum targets agreed under the Basel III framework. The Basel III agreements will put capital requirements for the largest banks at just under 10% of risk weighted assets (RWAs). Our results suggest the optimal amount of capital is likely to be around twice as great.

The plan of this article is this: Section 1 presents an overview of the issues; in Section 2 we estimate the economic cost of banks using more equity (or capital). In Section 3 we assess the benefits of banks becoming more highly capitalised. In Section 4 we bring the analysis of costs and benefits together to generate estimates of the optimal levels of bank capital. Section 5 concludes.

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[1] The Basel Committee did undertake several impact studies of its new framework, published in December 2010. This included a macroeconomic assessment of the impact of higher capital (Bank for International Settlements (BIS) 2010*a*, *b*) But these estimates did not take into account the first two of the factors listed here (in large part this may be because these studies were designed to guide a judgement about minimum acceptable levels of capital rather than optimal capital). The calculations reported in the Bank of England Financial Stability Report (June 2010) do allow for some of the factors mentioned here; that analysis makes a serious effort to measure the benefits of banks holding more capital, on which we build upon in this article.
[2] But not much different from levels that were normal for most of the past 150 years.

1. Capital Requirements and Regulatory Reform

In the financial crisis that began in 2007, and which reached an extreme point in the Autumn of 2008, many highly leveraged banks found that their sources of funding dried up as fears over the scale of losses – relative to their capital – made potential lenders pull away from extending credit. The economic damage done by the fallout from this banking crisis has been enormous; the recession that hit many developed economies in the wake of the financial crisis was exceptionally severe and the scale of government support to banks has been large and it was needed when fiscal deficits were already ballooning.

Such has been the scale of the damage from the banking crisis that there have been numerous proposals – some now partially implemented – for reforms of banking regulation and the structure of the banking system. Proposals for banking reform broadly fall into two groups. The first group requires banks to use more equity funding (or capital) and to hold more liquid assets to withstand severe macroeconomic shocks. The second group of proposals are often referred to as forms of '*narrow banking*'. These proposals aim to protect essential banking functions and control (and possibly eliminate) systemic risk within the financial sector by restricting the activities of banks. But, in an important sense, proposals of both types can be seen to lie on a continuous spectrum. For example, 'mutual fund banking' as advocated by Kotlikoff (2010) is equivalent to having banks be completely equity funded (operate with a 100% capital ratio); while a pure 'utility bank' of the sort advocated by Kay (2009) can be seen as equivalent to a bank with a 100% liquidity ratio.

Measuring the cost and benefits of banks having very different balance sheets from what had become normal in the run up to the crisis is therefore central to evaluating different regulatory reforms.

The argument that balance sheets with very much higher levels of equity funding, and less debt, would mean that banks' funding costs would be much higher is widely believed. There are at least two powerful reasons, however, for being sceptical about it. First, we make a simple historical point. In the UK and in the US economic performance was not obviously far worse, and spreads between reference rates of interest and the rates charged on bank loans were not obviously higher, when banks made very much greater use of equity funding. This is *prima facie* evidence that much higher levels of bank capital do not cripple development, or seriously hinder the financing of investment. Conversely, there is little evidence that investment or the average (or potential) growth rate of the economy picked up as leverage moved sharply higher in recent decades. Figure 1 shows a long-run series for UK bank leverage (total assets relative to equity) and GDP growth. There is no clear link. Between 1880 and 1960 bank leverage was – on average – about half the level of recent decades. Bank leverage has been on an upwards trend for 100 years; the average growth of the economy has shown no obvious trend.

Furthermore, it is not obvious that spreads on bank lending were significantly higher when banks had higher capital levels. Bank of England data show that spreads over reference rates on the stock of lending to households and companies since 2000 have averaged close to 2%. Evidence indicates that the spread over Bank Rate of much bank lending at various times in the twentieth century was consistently below 2% – though as
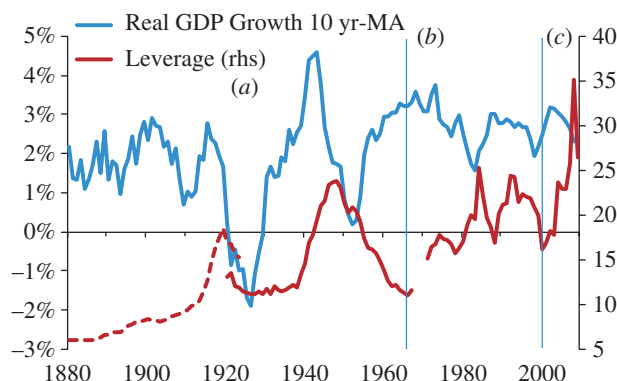
Fig. 1. *UK Banks Leverage and Real GDP Growth* (10 year moving average)
Source. United Kingdom: Sheppard, D (1971), The growth and role of UK financial institutions 1880–1962, Methuen, London; Billings, M and Capie, F (2007), 'Capital in British banking', 1920–1970, Business History, Vol 49(2), pages 139–162; BBA, ONS published accounts and Bank calculations. (*a*) UK data on leverage use total assets over equity and reserves on a time-varying sample of banks, representing the majority of the UK banking system, in terms of assets. Prior to 1970 published accounts understated the true level of banks' capital because they did not include hidden reserves. The solid line adjusts for this. 2009 observation is from H1. (*b*) Change in UK accounting standards. (*c*) International Financial Reporting Standards (IFRS) were adopted for the end-2005 accounts. The end-2004 accounts were also restated on an IFRS basis. The switch from UK GAAP to IFRS reduced the capital ratio of the UK banks in the sample by approximately 1 percentage point in 2004.

Figure 1 shows bank leverage was generally very much lower. The Banker (1971) reports:[3]

> ...traditionally bank advances are made at rates of interest very close to the Bank rate – at the most customers might be asked to pay 2 percent above Bank rate, with the bulk of funds being placed at somewhat less than this.

Over a decade earlier the Radcliffe (1959) Report stated:

> Most customers pay 1 percent over Bank rate subject to a minimum of 5 percent; exceptionally credit-worthy private borrowers pay only 0.5 percent above Bank rate.

Almost thirty years before, the Macmillan (1931) Report on UK banking noted that:

> The general position, with occasional deviations, is that ... the rate of interest charged on loans and overdrafts is ½ a per cent to 1 per cent above Bank rate.

Going back even further, Homer and Sylla (1991) report that in 1890, 1895 and 1900 English country towns banks charged average rates of respectively 5.1%, 4% and 4.5% on overdrafts. UK Bank rate averaged 4.5%, 2% and 3.9% in those years, so the average spread was about 1%.

The absence of any clear link between the cost of bank loans and the leverage of banks is also evident in the US. Figure 2 shows a measure of the spread charged by US banks on business loans over the yield on Treasury Bills. The Figure shows that the

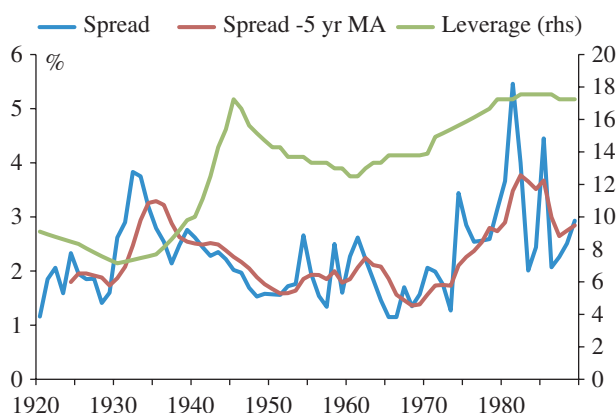[3] The Banker, October 1971, volume 121, no 548.

Fig. 2. *Leverage and Spreads of Average Business Loan Rates Charged by US Commercial Banks Over 3-month Treasury Bills*
Source. Homer and Sylla (1991).

significant increase in leverage of the US banking sector over the twentieth century was not accompanied by a decrease in lending spreads, indeed the two series are mildly *positively* correlated so that as banks used less equity to finance lending the spread between the rate charged on bank loans to companies and a reference rate actually increased. Of course such a crude analysis does not take into account changes in banks' asset quality or in the average maturity of loans or changes in the degree of competition. Nevertheless this evidence provides little support for claims that higher capital requirements imply a significantly higher cost of borrowing for firms.

The second reason for being sceptical that there is a strong positive link between banks using more equity and having a higher cost of funds is that the most straightforward and logically consistent model of the *overall* impact of higher equity capital (and less debt) on the total cost of finance of a company implies that the effect is zero. The Modigliani–Miller (MM) theorem implies that as more equity capital is used the volatility of the return on that equity falls and the safety of the debt rises, so that the required rate of return on both sources of funds falls. It does so in such a way that the weighted average cost of finance is unchanged (Modigliani and Miller, 1958). It is absolutely *not* self-evident that requiring banks to use more equity and less debt has to substantially increase their costs of funds and mean that they need to charge substantially more on loans to service the providers of their funds.

There are certainly reasons why the MM result is unlikely to hold exactly and, in the next Section, we consider them and assess their relevance for measuring the social cost of having banks use more equity to finance lending. But it would be a bad mistake to simply assume that the reduced volatility of the returns on bank equity deriving from lower bank leverage has no effect on its cost at all. Indeed recent empirical research for the US suggests that the MM theorem might not be a bad approximation even for banks. Kashyap *et al.* (2010) find that the long-run steady-state impact on bank loan rates from increases in external equity finance is modest, in the range of 25–45 basis points for a ten percentage point increase in the ratio of capital to bank assets (which would roughly halve leverage).

One of the aims of this article is to try to test empirically the extent to which the MM offsets operate for banks – cushioning the impact of higher capital requirements on their cost of funds – and to explore the sensitivities of optimal capital rules to different assumptions.

This article also quantifies the benefits of having banks finance more of their assets with loss-absorbing equity, thus reducing the chances of financial crises. Reinhart and Rogoff (2009) show that financial crises are often associated with reductions in GDP of 10% or more, a substantial proportion of which looks permanent. This suggests that the benefits of avoiding financial crises are substantial. A key question is how the probability of crisis falls as more capital is held by banks.

We show that the social cost of higher capital requirements is likely to be small, while the social benefit of having higher capital requirements is likely to be substantial.

2. How Costly is Equity?

The MM theorem states that, without distortions, changes in a company's capital structure do not affect its funding cost. There are several reasons why the theorem is not likely to hold exactly for banks, though to jump to the conclusion that the basic mechanism underlying the theorem – that equity is more risky the higher is leverage – is irrelevant would certainly be a mistake. The key question is to what extent there is an offset to the impact upon a bank's overall cost of funds of using more equity because the risk of that equity is reduced and so the return it needs to offer is lowered. Some of the reasons that this offset will be less than full are well known and apply to both banks and non-financial companies. The most obvious one is the tax treatment of debt and equity. Companies can deduct interest payments but not dividends, as a cost to set against their corporation tax payments (though this effect can be offset – possibly completely – if returns to shareholders in the form of dividends and capital gains are taxed less heavily at the personal level than are interest receipts).

Econometric evidence suggests that tax distortions have a significant influence on financial structure (Auerbach, 2002; Graham, 2003; Cheng and Green, 2008). For example, Weichenrieder and Klautke (2008) conclude that a 10-point increase in the corporate income tax rate increases the debt–asset ratio by 1.4–4.6 percentage points; Desai *et al.* (2004) estimate the impact on the debt–asset ratio at 2.6 percentage points.

Stricter capital requirements will mean banks are less able to exploit any favourable tax treatment of debt. But the extra corporation tax payments are not lost to the economy and the value of any extra tax revenue to the government offsets any extra costs to banks. Indeed the extra tax receipts could, in principle, be used to neutralise the impact on the wider economy of any increase in banks' funding costs. So it is not clear that in estimating the wider economic cost of having banks use more equity, and less debt, we should include the cost to banks of paying higher taxes. We will show what difference this makes below.

Another friction or distortion that may create a cost to banks of using less debt stems from (under-priced) state insurance. Deposit insurance – unless it is charged at an actuarially fair rate – may give banks an incentive to substitute equity finance with

deposit finance.[4] If governments insure banks' non-deposit debt liabilities (either implicitly or explicitly), the cost of that funding will also fall relative to equity.[5] With non-deposit debt, such insurance is usually not explicit so it is less clear that there is an incentive for banks to lever up by using wholesale (un-insured) debt. Nor does the existence of insurance – either explicit or implicit and on some or all of the debt liabilities of a bank – nullify the mechanism underlying the MM result. The essence of MM is this: higher leverage makes equity more risky, so if leverage is brought down the required return on equity financing is likely to fall. That is true even if debt financing is completely safe – for example because of deposit insurance or other government guarantees. In fact the simplest textbook proofs of the MM theorem often *assume* that debt is completely safe.

Because of the existence of these distortions – potential tax advantages for issuing debt and under-priced (implicit and explicit) guarantees for debt – it should not be surprising if the MM irrelevance theorem does not hold to the full extent. There are also agency arguments as to why banks might find it advantageous to use debt; see Calomiris and Kahn (1991) and, for an example of a model relying on those agency effects, see Gertler *et al.* (2010). The basic idea behind the agency arguments is that the management of banks is better disciplined by the prospect of debt funding being withdrawn than by the presence of shareholders that suffer first losses from any mismanagement of funds. But whether this sort of discipline requires such high leverage as has been typical for banks (with debt representing 95% or more of funds) is not at all clear. Indeed the empirical evidence for these agency effects is rather limited.

In the next subsection, we use data on UK banks to assess to what degree the MM theorem holds.

2.1. *To What Extent Does MM Hold for Banks?*

Kashyap *et al.* (2010) use data on US banks and find evidence of a positive relationship between a bank's equity risk and its leverage. They conclude that an increase in equity financing will not affect the cost of bank funding significantly, aside from tax factors. In this subsection, we use data on UK banks to assess the nature of the link between bank leverage and the cost of bank equity.

In the widely used Capital Asset Pricing Model (CAPM), the equity risk of a firm is reflected in its beta (β_{equity}) which depends upon the correlation between the rate of return of a firm's stock and that of the market as a whole. The CAPM also implies that the risks of bank assets (β_{asset}) can be decomposed into risks born by equity holders (β_{equity}) and by debt holders (β_{debt}) as follows:

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[4] But this point does not mean there are net economic costs in making banks use more equity because the extra private costs banks face if they use more equity are offset by lower costs of state-provided insurance.
[5] Haldane (2010) analyses differences between rating agencies' 'standalone' and 'support' credit ratings for banks. The former is a measure of banks' intrinsic financial strength while the latter reflects the agencies' judgement of government support to banks. The widening difference between these ratings for UK banks during the period 2007–9 indicated that ratings agencies were factoring in government support of banks. Haldane (2010) estimates that this public support for the five largest UK banks, through lower borrowing costs, comprised a subsidy of £50 billion annually over the period 2007–9.

$$\beta_{asset} = \beta_{equity} \frac{E}{D+E} + \beta_{debt} \frac{D}{D+E} \qquad (1)$$

D is the debt of the bank; E is its equity. Assuming $\beta_{debt} = 0$, i.e. that the debt is roughly riskless,[6] (1) implies:

$$\beta_{equity} = \frac{D+E}{E} \beta_{asset} \qquad (2)$$

$(D + E)/E$ is the ratio of total assets to equity – that is leverage. Equation (2) – which shows the link between the CAPM and the MM theorem – states that if the beta of bank debt is zero the risk premium on equity should decline linearly with leverage. When a bank doubles its capital ratio (or halves its leverage) – holding the riskiness of the bank's assets unchanged – the same risks are now spread over an equity cushion that is twice as large. Each unit of equity should only bear half as much risk as before, i.e. equity beta, (β_{equity}), should fall by half. The CAPM would then imply that the risk premium on that equity – the excess return over a safe rate – should also fall by one half. We test to what extent this is true for UK banks.

   We first estimate equity betas using publically traded daily stock market returns of UK banks, together with the returns for the FTSE 100 index, from 1992 to 2010. The banks in our sample are Lloyds TSB (subsequently Lloyds Banking Group), RBS, Barclays, HSBC, Bank of Scotland, Halifax (and subsequently HBOS). For each bank, we obtain its equity beta by regressing its daily stock returns on the daily FTSE returns over discrete periods of six months. Figure 3 shows the average of the equity betas across banks for the period 1997–2010.

   We regress these estimates of individual banks' semi-annual equity betas on the banks' (start of period) leverage ratio. We want to explore the link between beta and a measure of leverage that is affected by regulatory rules on bank capital. Ideally we would measure leverage as assets relative to the measure of loss-absorbing capital for which regulators set requirements. Under the Basel III agreements the ultimate form of loss-absorbing capital is Common Equity Tier 1 (CET1) capital, which is essentially equity. But it is not possible to get a time series of that measure of capital. So for the regressions we instead define leverage as a bank's total assets over its Tier 1 capital. Tier 1 capital includes equity and some hybrid instruments which have more limited loss-absorbing capacity. It is likely that Tier 1 Capital and the purer measure of loss-absorbing capital defined under Basel III as CET1 move closely together so that results we get from any link between the required rate of return on equity and leverage defined using Tier 1 Capital are informative about how the required rate of return would move with changes in the amount of truly loss absorbing capital. (CET1 was about 60% of Basel II Tier 1 equity in 2009, see footnote 11. But what matters is the impact of a given proportionate change in leverage).

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[6] The deposit liabilities of banks are close to riskless because of deposit insurance. The assumption of zero risk is less obviously appropriate for non-deposit debt. But note that what we mean by riskless in the context of the CAPM is not that the default probability of debt is zero but the weaker condition that any fluctuation in the value of debt is not correlated with general market movements.

The regression we estimate is:

$$\beta_{it} = \mathbf{X}'_{it}\boldsymbol{b} + \varepsilon_{it},$$
$$\varepsilon_{it} = \alpha_i + \mu_{it}, \tag{3}$$

where, for every bank $i = 1, \ldots, J$ at time $t = 1, \ldots, T$, β_{it} is the estimated semi-annual equity beta, $\mathbf{X}_{it}$ is a vector of regressors which include (lagged) *leverage* and year dummies and **b** is a vector of parameters.[7] α_i is a bank-specific effect and μ_{it} is an idiosyncratic disturbance. Equation (2) shows that the coefficient on leverage is an estimate of the asset beta (We also report results from estimating a log specification below.)

Our data set contains observations for a panel of banks at a semi-annual frequency from H1 1997 to H1 2010.[8] We use semi-annual estimates of beta since with semi annual published accounts leverage is only measured at that frequency. We show three estimates for the model: a pooled OLS estimate and two versions which allow for bank specific effects – the fixed effects (FEs) and random effects (REs) estimators. In choosing between the two estimators which allow for bank specific influences on beta the issue is whether the individual effects, α_i, are correlated with other regressors. The FE estimator is consistent even if bank specific effects are correlated with the regressors $\mathbf{X}_{it}$. The RE estimator is consistent if the α_i are distributed independently from $\mathbf{X}_{it}$, in which case it is to be preferred because it is more efficient.

The data on both beta (Figure 3) and on leverage show some signs of an upwards trend over the estimation period. If both series are non-stationary (I(1)) then there is a danger that a levels regression generates a spurious link. We performed Fisher-type unit root test for panels on both beta and leverage. Fisher-type unit root tests are based on augmented Dickey–Fuller tests and can be applied to an unbalanced panel. The null hypothesis is that all panels contain unit roots and the alternative hypothesis is that at least one panel is stationary. An augmented Dickey–Fuller (ADF) regression including 1 lag and time trend and removing the cross-sectional mean[9] – shows that we can reject the null at 0.25% significance level for beta and 1% for leverage. These results seem to suggest that the two series are likely to be trend stationary. Moreover, similar results obtained even when we exclude a time trend in the ADF regression (the null is rejected at 0.1% for beta and 5% for leverage.) Since

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[7] It is difficult to assess the impact of changes in the risks of bank assets over time. Including time dummies in the regressions should allow for factors that impact the average riskiness of bank assets in general from year to year. That would still leave the impact of shifts in risks of assets that are specific to each bank. We think these might be reflected in a range of factors: the likelihood of incurring losses on its assets as reflected in the provision for potential losses; on the ease of selling assets without suffering sharp drop in their values; and on their overall profitability. We attempt to control for these risks by including the loan loss reserve ratio, the liquid assets ratio and ROA in the regression. But in fact these variables did not appear significant in our regressions. So in the following discussion, we focus on the results using just leverage and year dummies as regressors.

[8] Halifax merged with Bank of Scotland in 2001 to create HBOS. We treat the merged bank HBOS as a continuation of Halifax and Bank of Scotland stops existing after the merger. This leads to an unbalanced panel. An unbalanced panel is not a problem for our panel estimation so long as the sample selection process does not in itself lead to errors being correlated with regressors. Loosely speaking, the missing values are for random reasons rather than systemic ones.

[9] We compute for each time period the mean of the series beta and leverage across panels and subtracts this mean from the series before apply the unit root test. Levin *et al.* (2002) suggest this procedure to mitigate the impact of cross-sectional dependence.
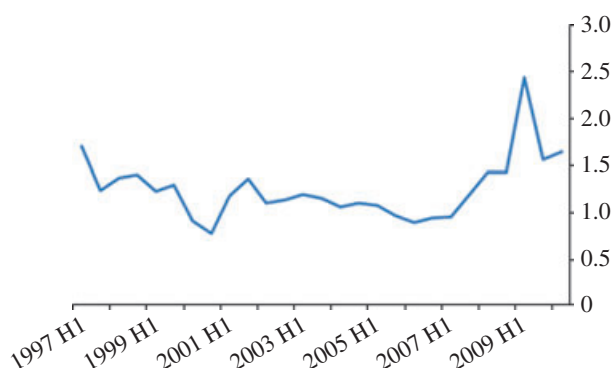
Fig. 3. *Average Beta Across Major UK Banks* 1997–2010

both series appear to be stationary after removing the cross-sectional mean, it is a reason to favour the within groups (FE) estimator which is based on a regression on the mean-differenced data.

Based on the stationary tests, we estimate the relationship between leverage and equity beta as in (3) – that is as a levels regression. We include year dummies (time effects) in all specifications so that will pick up the influence of common effects on beta across banks over time. However since the Fisher-type panel unit root tests do not guarantee that all panels are stationary, we will also estimate the link between beta and leverage using a differences specifications to check for the robustness of results.

Table 1 shows the regression results using levels data for betas and leverage. In all cases, standard errors are adjusted for clustering on banks. The pooled OLS estimation gives very similar results to the RE model with the coefficient on leverage being around

Table 1

Bank Equity Beta and Leverage: Pooled OLS, Fixed and Random Effect

	OLS	FE	RE
Leverage	0.025	0.031	0.025
	(4.22)	(3.49)	(5.35)
Const.	1.238	1.072	1.237
	(3.99)	(3.72)	(5.55)
R^2_overall	0.671	0.664	0.671
R^2_between		0.634	0.670
R^2_within		0.658	0.654
F-test or Wald test	13.3	7.54	122
Prob>F	0.00	0.00	0.00
Year effect	Yes	Yes	Yes

Note: Where bank specific effects are included the reported constant is the average of such estimated effects. A Wooldridge (2002) F-test for autocorrelation in residuals shows that $F(1, 4) = 0.028$ and $Prob > F = 0.876$. We cannot reject the null that there is no first-order autocorrelation in residuals. Regression of bank equity beta on leverage, measured as total assets/tier 1 capital. All specifications include year effects. In all three regressions, standard errors are robust to clustering effects at the bank level. Coefficient t statistics are in parenthesis. A Hausman test is used to compare FE and RE estimators. The null hypothesis is that the differences in coefficients are not systemic. Chi-square (12) = 2.84 with p-value = 0.99.

0.025. In the FE regression, changes in leverage have a somewhat bigger impact on equity beta with the coefficient around 0.03. These results suggest that the asset beta of banks is low – only around 0.03. This might seem extremely low but it is not at all implausible. Most bank assets are fixed income claims (loans of various types) and so might be expected to have a very low beta. And an asset beta of only around 0.03 generates an equity beta that is close to 1 given that for much of our sample the leverage of banks was around 30.

Given that the FE estimator is consistent both under the null and the alternative hypotheses, we take those as our central estimate – though the difference is not large (a Hausman test is used to compare FE and RE estimators. At standard levels we cannot reject the null hypothesis that the differences in coefficients are not significant ($\chi^2(12) = 2.84$ with p-value = 0.99)).

Table 2 shows the regression results where we difference the data – regressing the change in beta on the change in leverage. The coefficient estimates of the link between leverage and beta are now larger: around 0.06 compared to 0.03 with the levels specification. But in all cases the impact of leverage upon beta are highly significant.

The levels equations explain around two-thirds of the variability in betas. But the results do not conform to (2) since the constant in the levels version of the regressions is positive and significant. This suggests the conditions implied by the joint hypothesis of full MM effects and the CAPM do not hold. We can confirm this by using the coefficient estimates to assess how a change in leverage will affect the average cost of bank funds.

We express banks' average cost of funding (typically referred to in corporate finance theory as the weighted average cost of capital, WACC) as the weighted sum of the cost of its equity and the cost of its debt. Here we assume that debt has a zero beta ($\beta_{debt} = 0$), so that the cost of debt should be similar to the risk free rate (R_f). We regard this as a conservative assumption in assessing how the cost of bank funds varies with leverage, one which is designed not to understate the increase in funding costs

Table 2

Bank Equity Beta and Leverage: OLS FE and RE (First Differences)

	OLS	FE	RE
Leverage	0.06	0.06	0.06
	(5.00)	(4.99)	(5.00)
Const.	0.281	0.277	0.281
	(1.77)	(1.90)	(1.77)
R^2_overall	0.255	0.255	0.255
R^2_between		0.860	0.863
R^2_within		0.251	0.251
F-test or Wald test	2.94	2.74	35.3
Prob > F	0.002	0.003	0.0004
Year effect	Yes	Yes	Yes

Note: A Wooldridge (2002) F-test for autocorrelation in residuals shows that $F(1, 5) = 0.751$ and Prob > F = 0.426. We cannot reject the null that there is no first-order autocorrelation in residuals. Regression of bank equity beta on leverage, measured as total assets/tier 1 capital. Both variables are in their first differences. All specifications include year effects. In all three regressions, standard errors are robust to clustering effects at the bank level. Coefficient t-stat. are in parenthesis.

that lower leverage might bring. By simply assuming away any beneficial impact on the cost of debt from its being made safer as leverage falls we are neutralising one of the routes through which the MM effects might work. Making this assumption the WACC may be written as:

$$WACC = R_{equity} \frac{E}{D+E} + R_f \left(1 - \frac{E}{D+E}\right). \tag{4}$$

The CAPM states that the required return on equity, R_{equity}, can be written as a function of the equity market risk premium (R_p) and the (bank specific) equity beta:

$$R_{equity} = R_f + \beta_{equity} R_p. \tag{5}$$

Using the coefficients from the FEs levels regression between leverage and β_{equity} and (4) and (5), we get:

$$R_{equity} = R_f + (\hat{a} + \hat{b}\ \text{leverage}) R_p. \tag{6}$$

where $\hat{a}$ is a constant and $\hat{b}$ is the coefficient on leverage from the beta regressions. Since $\hat{b}$ is estimated to be positive, (6) implies that the higher the leverage of a bank the greater is the required return on its equity.

Total assets of the major UK banks averaged about £6.6 trillion between 2006 and 2009; risk-weighted assets (RWAs) were about £2.6 trillion (or 40% of total assets).[10] The average leverage of our banks over that period – that is total assets over capital (which for the purposes of the regressions we have taken to be Tier 1 capital) – is 30. Since CET1 might be only around 60% of Tier 1 capital then leverage defined as assets to CET1 would have been substantially higher – perhaps averaging around 50.[11]

We take 5% as the level of the nominal safe rate; if $\beta_{debt} = 0$ this is also the cost of banks raising debt. Five per cent is roughly the average Bank Rate over the 10-year period 1999–2009. It is somewhat higher than the average rate paid on retail deposits of UK banks but lower than the typical yields on bank bonds over this period. The key thing in assessing the impact of a change in capital (or leverage) on banks' cost of funds is the equity risk premium because it is only the *difference* between the cost of debt and the required rate of return of equity that matters. So our assumption that the nominal safe rate is 5% is not in any way crucial. We make the 5% assumption about the safe rate so as to be able to assess whether the required rate of return on bank equity that our model generates is plausible. We use a market risk premium of 5% as our base case. This 5% figure is slightly lower than the average excess return of equities over

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[10] For the banks in our sample RWAs were a slightly lower proportion of total assets than for all UK banks (36% against 40%).

[11] According to Table 3 in the BIS Quantitative Impact Study (QIS, BIS (2010c)), the Basel II T1 ratio was 10.5%, and the gross CET1 ratio relative to Basel II risk weights was 11.1%, for the QIS sample of large banks (Group 1 banks) at the end of 2009. According to Table 4, 'net CET1' – which we take as reflecting truly loss-absorbing equity – is 41.3% less than gross CET1. Finally, Table 4 suggests that there is an additional effect of changes in risk weights of 7.3% that is counted towards the redefinition of equity. Taking all this together, we infer: (net) CET1 = (11.1/10.5) × [(1 − 0.413)/(1 + 0.073)] × Basel II T1 = 58% × Basel II T1. We use a conversion of 60% in this article. We used the same source to infer the translation of Basel II RWAs into Basel III RWAs. According to Table 6 in BIS (2010c), RWAs increased by 23% from Basel II to Basel III for the QIS sample of large banks (Group 1 banks) at the end of 2009. We use a conversion of 25% in this article.

government bonds or bills in the UK and the US which for the last 100 years is nearer to 6%. Five per cent is about the average estimate of the equity risk premium of a large sample of economists; see Welch (2001). We show below the implications of using a 7.5% risk premium.

Assuming a nominal risk free rate of 5% and a market equity risk premium of 5%, and substituting our FE estimates of $\hat{a}$ and $\hat{b}$ from Table 1 into (6), suggests that at leverage of 30 investors require a return on equity of: $5\% + (1.07 + 0.03 \times 30) \times 5\% = 14.85\%$.

This is a plausible estimate of the required rate of return on bank equity with the sorts of leverage seen in recent years since many banks and bank analysts have quoted a target return on equity of about 15%.[12]

At leverage of 30 $E/(D + E)$ is 1/30 and $D/(D + E)$ is 29/30 so the weighted cost of capital would then be: $(1/30)14.85\% + (29/30)5\% = 5.33\%$.

If leverage falls by half (from 30 to 15 on an assets to Tier1 definition or from 50 to 25 when measured as assets to CET1), our regression results (Table 1, FE estimates) suggests a fall in the required return on equity to 12.6%, ie, $5\% + (1.07 + 0.03 \times 15) \times 5\%$.

If MM did not hold at all, then changes in leverage would have no impact on the required return on equity. By comparing changes in the WACC based on our regression results to those based on the assumption that there is no MM effect, we can get a sense of the extent to which the theorem holds.

Based on a risk free rate of 5% and a market equity risk premium of 5%, at a leverage of 30 our estimate of the required return on equity is 14.85%, and the average cost of bank funds is 5.33%. If leverage halves to 15, our estimates would suggest that the required return on equity would fall to 12.6% and the WACC under this scenario would rise to 5.51% (i.e. $(1/15)12.6\% + (14/15)5\%$). If MM did not hold at all, the required return on equity would have stayed at 14.85% and the WACC would have risen to 5.66%, (i.e. $(1/15)14.85\% + (14/15)5\%$).

We estimate bank WACC rises by 18 bps (5.51%–5.33%); with no MM offset this rise would be 33 bps (5.66%–5.33%). So the rise in WACC is about 55% of what it would be if there was no MM effect (18/33). Put another way, the M-M offset is about 45% as large as it would be if MM held exactly. Note that this calculation of the degree to which MM holds would have been very similar had we defined leverage as assets to CET1 capital, provided that CET1 has consistently moved in line with Tier 1 capital.[13]

If we use the RE estimate of the link between leverage and beta based on the differences specifications of Table 2 the rise in the cost of funding as leverage falls is estimated to be smaller because the estimated link between beta and leverage is stronger in Table 2. Using the coefficient estimate from the differences regression of

[12] For example, *The Financial Times* of 19 September 2011 quoted a figure of 14.5% for the target rate of return set by Lloyds bank for its equity.

[13] Using the factor of 60% to convert T1 into CET1, a leverage ratio of A/T1 of 30 corresponds to a leverage ratio of A/CET1 of 50, and a leverage ratio A/T1 of 15 corresponds to a leverage ratio of A/CET1 of 25. The WACC at a leverage ratio of A/T1 = 30 is therefore just the same as the WACC at a leverage ratio of A/CET1 = 50. This has implications for the marginal cost of increasing the ratio of capital to RWAs. RWAs under Basel III are just under 25% greater than RWAs under Basel II. A one percentage point change in the Basel II ratio of T1/RWA is equivalent to a $(CET1/60\%)/(RWA \times 1.25) = 0.5$ percentage point change in the Basel III ratio of CET1/RWA. So increasing the Basel III ratio of CET1/RWA by 1pp is about twice as costly as increasing the Basel II ratio of T1/RWA.

0.06, (and assuming that the required rate of return on equity at leverage of 30 is 14.85%) we find that a having in leverage would reduce the required equity return to 10.4%. That implies that the size of the MM offset is about 90% as large as it would be under full MM (since in this case the rise in the average cost of funds as leverage is halved is about 3 bps; it would be 33 bps if there were no relation between leverage and the required return on equity and zero under full MM.).

The results reported in Tables 1 and 2 are based on regressing beta on leverage – a natural specification given (2). But (2) could just as well be estimated in log form. Table 3 shows the log version of (2) where we regress log beta on log leverage. With a full MM effect we would expect the coefficient on log leverage to be 1 – so a doubling in leverage doubles risk. The coefficient estimates in Table 3 are all highly significant but less than 1. The results from the log specification suggest the MM effect is about 70% of what it would be if the MM theorem held precisely.[14] This is rather larger than the estimate based on the levels specification, which was that the MM effect was about 45% of the full effect, but it is a bit smaller than the estimate based on differenced data.

Notice that we have assumed no change in the required rate of return on debt as leverage changes. This is a conservative assumption and potentially understates MM effects. For subordinated wholesale debt which is not covered by deposit insurance, a reduction in leverage is likely to reduce the required return on debt – though perhaps only very marginally. But notice also that, thus far, we have not factored in the impact of the tax deductibility of interest payments.

An alternative way to gauge the extent to which the MM effect holds (setting aside tax effects for the moment) is to test more directly the relationship between the required return on bank equity and bank leverage. This has the advantage of not assuming the CAPM holds. But it is difficult to measure the required return on equity. Ideally, we would like to have expected earnings data for each of the banks in the sample, but we are unable to find a time series of such data. We instead experimented using the realised actual earnings over share price (E/P) as a proxy for required

Table 3

Bank Equity Beta and Leverage (Log Specification)

	OLS	FE	RE
Leverage	0.602	0.692	0.602
	(6.58)	(3.76)	(6.81)
Const.	−1.405	−1.693	−1.405
	(−4.45)	(−2.69)	(−4.35)
R^2_overall	0.62	0.66	0.67
R^2_between		0.54	0.61
R^2_within		0.64	0.636
F or Wald test	13.7	11.3	202
Prob > F	0	0	0

Note: Regression of the log of bank equity beta on log leverage, measured as total assets/tier 1 capital. Year effects included. Standard errors are robust to clustering effects at the bank level. Coefficient t-statistic in parenthesis

[14] The FE specification generates a point estimate of 0.692 (with a standard error of 0.18). So the rise in risk is about 70% as great as the MM theory would suggest.

returns and we regress this on leverage. The regression using the earning yield as a proxy for the required return on equity suggests that the impact on the required return on equity of changing leverage is about as big as if MM held exactly (assuming riskless debt). The beta regressions suggest that the MM theorem effect is somewhere between 45% and 90% as large as it would be if MM held exactly (depending on whether we use levels regressions (45%), differenced regressions (90%) or a log specification (70%)).

In the above calculation we have ignored tax. Arguably *if* banks pay more tax as leverage falls the value of the extra tax revenue to the government pretty much exactly offsets the loss to banks. So from the point of view of measuring true economic costs it should be ignored. While having sympathy for that argument we will also show below the impact of treating tax costs as if they were true costs. In this calculation we will ignore any offset from the lower taxation of equity returns to holders of shares; this will generate an upper bound of the estimate of the extra cost of banks using more equity and less debt. We will also use as our base case the lowest of the estimates of the MM offsets from higher leverage, assuming that such offsets are about 45% of what they would be if MM held exactly.

2.2. *Translating Changes in Bank Funding Costs into Changes in Output for the Wider Economy*

To estimate the economic cost of higher capital requirements, we calibrate the impact of higher funding costs for banks on output. We assume any rise in funding costs is passed on one-for-one by banks to their customers. The impact of higher lending costs on GDP could be assessed using a structured macroeconomic model that incorporates banks (see, for example, BIS (2010*a*) and Barrell *et al.* (2009). We follow the strategy used in the Bank of England Financial Stability Review (June 2010), which is more transparent and focuses on the key transmission channels between banks' cost of funding, firms' cost of capital, investment, and GDP. We assume that output (Y) is produced with capital (K) and labour (L) in a way described by a standard production function. Shifts in the cost of borrowing to finance investment alter the equilibrium capital stock and it is the impact of that upon steady state output that gives the long-run cost of higher bank capital requirements.

For a production function with constant elasticity of substitution, $Y = f(K, L)$ the responsiveness of output to cost of capital can be written as follows using the chain rule:

$$\frac{\mathrm{d}Y}{\mathrm{d}P_k}\frac{P_k}{Y} = \left(\frac{\mathrm{d}Y}{\mathrm{d}K}\frac{K}{Y}\right)\left(\frac{\mathrm{d}K}{\mathrm{d}P}\frac{P}{K}\right)\left(\frac{\mathrm{d}P}{\mathrm{d}P_K}\frac{P_K}{P}\right) \tag{7}$$

$$= \alpha\sigma\frac{1}{\alpha - 1}. \tag{8}$$

The first term in brackets on the right hand side of (7) is the elasticity of output with respect to capital, denoted α. The second term is the responsiveness of capital to changes in the relative price of capital to labour P, ($P = P_K/P_L$). This is the elasticity of

substitution between capital and labour (σ). The last term is the elasticity of relative price with respect to the cost of capital, which we can show is $1/(1 - \alpha)$.[15]

Equation (8) says that if the firms' cost of capital increases by 1%, output falls by $\sigma \times \alpha/(1 - \alpha)\%$. The share of income that flows to capital, α, is about one third. We set the elasticity of substitution between capital and labour at 0.5, as suggested by Smith (2008) and Barnes *et al.* (2008). This implies that a 1% increase in firms' cost of capital could lead to a reduction in output of 0.25%.

In the previous Section, we estimated that if capital relative to assets doubles – meaning that leverage defined using Tier 1 capital falls from around 30 to 15.[16] – banks' cost of funding increases by around 18 bps (assuming the lowest estimated MM effect) That figure is based on the estimates in Table 1 (FE regression); it assumes an equity risk premium of 5% and a safe rate of 5%; it also excludes tax effects (In the next Section we consider the impact of varying all those assumptions.). Assume that banks pass on an increase in funding cost of 18 bp so lending rates go up one-for-one. In the UK bank lending typically represents less than 1/3 of firms' total financing. (In the US, the figure would be lower – in some European countries, it would be slightly higher). Using a 1/3 reliance on bank loans, firms' overall cost of capital is likely to rise by about a third of 18 bp, so by about 6 bps. Assuming the cost of capital for firms is around 10% (which with a safe rate of 5% and an equity risk premium of 5% is the cost of equity for a firm with a unit beta), this 6 bps increase translates into a 0.6% increase in the cost of capital for firms in proportional terms. This suggests that output might fall by about 0.15% or 15 bps (that is $0.6 \times \sigma \times \alpha/(\alpha - 1)$). This would be a permanent fall in output. Using an annual discount rate of 2.5%,[17] this would mean a fall in the present value of all future output of about 6% or 600 bps (i.e. 0.15%/2.5%). That is, a capital ratio increase which would halve leverage leads to a permanent fall in GDP whose present value is equal to 6% of current annual output. This is the way in which we estimate the cost of higher capital requirements, whose magnitude needs to be weighed against the benefits of lower leverage from a reduced risk of banking crises. Clearly the calculation of the

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[15] Total income can be written as $Y = P_L L + P_K K$, where we assume factors are paid their marginal product so that P_L is wage and P_K is the cost of capital. The cost of capital equals the marginal product of capital, i.e. $P_K = \mathrm{d}Y/\mathrm{d}K = Y_K$, so we can rewrite the equation as $P_L L = Y - Y_K K$. Total differentiation of this equation yields: $L\mathrm{d}P_L = Y_K\mathrm{d}K - Y_K\mathrm{d}K - K\mathrm{d}P_K = -K\mathrm{d}P_K$. This can be rewritten as

$$\mathrm{d}P_L/P_L = -\frac{\mathrm{d}P_K}{P_K}\left(\frac{P_K K}{P_L L}\right) = -\frac{\mathrm{d}P_K}{P_K}\left(\frac{\alpha}{1 - \alpha}\right),$$

given the shares of income that flows to capital and labour are α and $1 - \alpha$ respectively. Then using the definition of relative price $P = P_K/P_L$, we can get

$$\frac{\mathrm{d}P}{P} = -\frac{\mathrm{d}P_K}{P_K} - \frac{\mathrm{d}P_L}{P_L} = \frac{\mathrm{d}P_K}{P_K}\left(\frac{1}{1 - \alpha}\right),$$

that is

$$\frac{\mathrm{d}P}{\mathrm{d}P_K}\frac{P_K}{P} = \frac{1}{1 - \alpha}.$$

[16] Or on a leverage ratio defined as CET1 to assets it falls from around 50 to 25.

[17] The discount rate 2.5% is a real social discount rate, which is different from the assumed nominal rate of 5% that banks offer on debt. This gap between 2.5% and 5% also reflects the difference between the time preference of agents and the government (or a social planner). A 2.5% real discount rate is arguably quite high; Stern in his work on climate change makes a case for a much lower number. We illustrate the impact of using different discount rates below.

costs of higher bank capital has many moving parts, so before turning to the benefits of banks having more capital we consider the sensitivity of costs to alternative assumptions.

2.3. *Alternative Scenarios*

Estimates of the economic cost, in terms of lower output, of higher capital requirements on banks depend on several things: the magnitude of the market-wide equity risk premium; whether or not tax factors affect the impact upon non-financial firms of banks having to use more equity; the extent of any MM offset so that the required return on bank equity falls with lower leverage; the importance of bank lending in firms total finance; the elasticity of substitution between labour and capital; and the choice of discount rate. In Tables 4 and 5 we report estimates of the impact upon banks' cost of funds, and of the present value of lost output, under different assumptions about some of these key factors. The economic cost is the present value of all lost GDP out to infinity expressed as a percentage of current annual GDP.

We consider the following cases: a scenario in which it is assumed that there are no MM effects and the required return on bank equity is invariant to leverage; we also assume that if banks pay more tax this is a real economic cost;[18] we allow for a 45% MM offset to banks' cost of equity; we do not count any extra tax that banks pay as an economic cost (one can think of this as the government using more tax receipts from banks to offset the impact upon companies of banks charging higher loan rates – for example through a reduction in corporation tax that is overall revenue neutral); a bigger MM offset of 75% (as suggested by the log specification).

Table 4

Economic Impact of Halving Leverage* – Basis Points

	Tax effect, no. M-M	Tax effect, 45% M-M	Base case: no. tax effect, 45% M-M	No tax effect and 75% M-M
Change in banks WACC	38.0	22.5	17.9	7.7
Change in PNFC† WACC	12.7	7.5	6.0	2.6
Fall in long run GDP	31.7	18.8	14.9	6.4
Present value of GDP lost	1,268	751	596	256

Note: * From 30 to 15 based on assets relative to Tier 1 capital; or from 50 to 25 based on assets to CET1; † Private Non-Financial Corporations.

Table 5

Sensitivity of Base Case Estimates to Changes in Various Assumptions – Basis Points

	Base case (no. tax effect and 45% MM)	Higher discount rate (@ 5%)	Lower share of banks in PNFC finance (@ 16%)	Higher equity risk premium (@ 7.5%)
Change in banks WACC	17.9	17.9	17.9	26.8
Change in PNFC WACC	6.0	6.0	2.9	8.9
Fall in long run GDP	14.9	14.9	7.1	22.3
Present value of GDP lost	596	298	286	894

[18] And is not offset by providers of funds to banks paying less tax because dividends and capital gains might be taxed at lower rates than receipts of interest.

The impact of a doubling in capital (halving in leverage) is to increase the average cost of bank funds by about 38 bps when there is no MM offset and we assume that all of the impact of the extra tax paid by banks is included as an economic cost. That would reduce the present value of the flow of annual GDP by 13% of current annual output (1,268 basis points); it would mean the level of GDP was permanently about one third of a percent lower. If we allow a 45% MM offset the impact on bank cost of funds falls to about 22 bps and the effect on GDP falls to under 0.2% (generating a present value loss of about 7.5% of annual GDP). Of that impact on WACC just under 5 bps is a tax effect; the effect of higher capital on WACC without tax is slightly under 18 bps, generating a hit to GDP of about 0.15% (creating a present value loss of just under 6%). If the MM effect is bigger (75%) the rise in WACC falls to around 8 bps and the fall in long run level of GDP is just over 6 bps.

Table 5 shows the impact of varying other assumptions relevant to the impact upon GDP of higher bank funding costs. Here we use the base case assumptions (column 3 of Table 4) on MM and tax effects. If we double the discount rate (from 2.5% to 5%) the present value of lost output is halved. If instead of assuming that non-financial companies finance 33% of investment with bank loans we set that rate at 16% (closer to the recent average in the UK) the impact of higher capital upon GDP is also roughly halved. But raising the overall market equity risk premium from 5% to 7.5% rather substantially raises the cost of higher bank capital – which is about 50% higher than in the base case.

These estimates illustrate that under reasonable assumptions even doubling the amount of bank capital has a relatively modest impact upon the average cost of bank funds – ranging from just under 40 bps to under 10 bps. If we allowed the cost of debt raised by banks to fall with leverage, the estimated cost of higher capital would be even smaller. One reason why the cost of bank debt may not be responsive to changes in leverage may be its implicit insurance by the government. We do not attempt to make any explicit calculation of the value of such insurance but its existence only reinforces the argument for higher capital requirements to be imposed on banks.

3. Quantifying the Benefits of Higher Capital Requirements

Higher capital makes banks better able to cope with variability in the value of their assets without triggering fears of (and actual) insolvency. This should lead to a more robust banking sector and a lower frequency of banking crises. The benefit of having higher capital levels can be measured as the expected cost of a financial crisis that has been avoided. The marginal benefit of having banks fund more of their assets using equity is the reduction in the probability of a banking crisis that using more equity brings multiplied by the expected cost of a banking crisis. In this Section, we try to calibrate how much the chances of banking crises are reduced as bank capital ratios rise and how costly such crises typically are. Both those things are hard to judge.

3.1. *Probability of Crisis and Bank Capital*

We think of a banking crisis – at least of the sort that higher capital can counter – as a situation where many banks come close to insolvency. That is where the fall in the value of their assets is close to being as large as (or is greater than) the amount of

loss-absorbing equity capital they have. The type of fluctuations in asset values that would generate such a situation are generalised falls in the value of bank assets – things not specific to a particular bank. The key assumption we make is that generalised falls in the value of bank assets are driven by changes in the level of incomes in the economy. More specifically we will assume that losses arise if income levels fall. This assumption is consistent with the evidence from periods when banks have suffered substantial losses on the value of their assets. We review that evidence in Appendix B and use it to calibrate the link between falls in incomes in the economy and declines in the value of bank assets. Our calibration is conservative, in the sense that the sensitivity we assume between falls in incomes in the economy and declines in the value of bank assets is at the low end of what recent experience suggests. The evidence suggests that in recessions that are associated with banking crises the proportionate fall in the value of (un-weighted) bank assets is often equal to the decline in GDP. We assume that the fall in bank assets for a given fall in incomes is only about half as large as that.

We proceed by modelling the process that drives incomes. Given the assumed link between those fluctuations and the value of bank assets we can calculate the probability distribution of asset values and find the probabilities that asset values fall by more than the level of bank equity. That is the probability of a banking crisis. From that it is a simple calculation to see how the probability of insolvency changes, for given assets, as bank equity rises. The product of that change in the probability in insolvency and the cost of insolvency is the marginal benefit of banks using more equity.

The key parts of the mechanism can be illustrated with three equations. Denote the probability of a bank's insolvency by p, losses on bank assets by L, bank equity by K (for capital), percentage changes in income levels in the economy by Y, and the cost of banking crises (insolvency) by C. The relationships that govern the marginal benefit of having banks use more equity (denoted MB) are these:

$$p = \text{prob}(L > K) \tag{9}$$

$$L = \begin{cases} f(Y) > 0 & \text{if} \quad Y < 0 \quad \text{with } f'(Y) < 0 \\ 0 & \text{if} \quad Y \geq 0 \end{cases} \tag{10}$$

$$MB = (dp/dK) \times C \tag{11}$$

For any given level of K there is a value of Y, denoted Y^*, such that if falls in incomes are greater than this level then L exceeds K. This means that $Y^* < 0$ and $f(Y^*) = K$. The probability of a crisis for a given level of capital is $\text{prob}(Y < Y^*)$. If we model the probability distribution of changes in incomes then given a model of the link between changes in income and asset values (that is the $f(Y)$ function) we can calculate that level of Y^* and the probability that $Y < Y^*$. Clearly $dY^*/dK < 0$ and so $dp/dK < 0$.

The crucial assumption is that bank asset values are driven by the incomes of those who have borrowed from banks. A large part of banks' assets are debt contracts whose value depends on the ability of borrowers to honour interest and principal repayments from their income and savings. There is likely to be a close link between the value of bank assets (in aggregate) and a country's national income (GDP). The more international are banks the less tight will be the link between movements in domestic

incomes and the value of bank assets. A few UK banks do have a great many foreign assets. It is also the case that sharp recessions – the ones where bank capital really matters – are often synchronised across countries.

Our basic assumption is that losses in the value of assets are linked to *permanent* falls in GDP.[19] Specifically we will assume that the percentage fall in the value of RWAs moves in line with any permanent fall in the level of per capita GDP. In aggregate our sample of big UK banks have had total assets that are almost three times RWAs on the Basel II definitions. The Basel III measures of RWA are greater than the Basel II measures by a little under 25%; see BIS (2010c, Table 6). On a Basel III definition of RWA the total assets of major UK banks are probably closer to 2.25 times RWA. So on a Basel III RWA definition the typical risk weight is about 45%. We assume that a bank sees a fall in the value of each of its assets that is equal to any permanent fall in per capita GDP (in per cent) multiplied by the risk weight of that asset. If per capita GDP permanently falls by 1% an asset worth £1 and with a risk weight of 0.45 would see its value fall by 0.45%, so it would be worth 99.55p. If GDP fell by 10% in a year (a very large fall), and using the average risk weight of 0.45, the fall in assets would be 4.5% – so assets would be worth 95.5% of their start of year value. A bank with leverage less than 22.2 (1/0.045) would have enough capital to absorb this loss.

In terms of the notation used above – and now interpreting Y as the percentage change in per capita GDP – we are assuming a specific functional form for equation (10), namely:

$$L = |Y| * \text{RWA} \quad \text{if} \quad Y < 0$$

$$L = 0 \qquad \text{if} \quad Y > 0,$$

which implies that bankruptcy occurs if $Y < -K/\text{RWA}$.

One way to think about this assumption – that RWAs fall by the same as a fall in average incomes – is to see assets with a positive risk weight as ones where the ability of the borrower to repay the loan is less than certain and depends on their income. More specifically, assume that an asset with a risk weight of 0 is always repaid but that an asset with the average risk weight (relative to all those which are judged risky) has a repayment profile which is eroded in line with falls in average incomes in the economy. So an average risky asset is one which, so long as average incomes do not fall, is repaid in full; but if income falls $x\%$ the value of interest and capital repayments also falls by $x\%$. This would imply that risky agents who have borrowed from banks and find that their incomes fall cannot devote more of their lower incomes to debt repayment.

This way of looking at the assumption we make of the link between falls in incomes and in the value of RWAs helps in interpretation but it does not in itself throw much light on its consistency with the evidence. So in Appendix B we describe the evidence on the relative size of recent falls in banks' assets and falls in GDP. We find that in

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[19] Our empirical model of changes in GDP is a random walk with drift and a stochastic term which has a mixed distribution. This model implies that changes in GDP are permanent and that there is a unit root in GDP. Evidence on whether there is a unit root in GDP is not entirely conclusive though many papers do find support for the unit root hypothesis; see the influential original contribution of Nelson and Plosser (1982) and later work by Campbell and Mankiw (1995), Perron (1988), Banerjee *et al.* (1992). Fleissig and Strauss (1999) find some evidence for trend stationarity using panel unit root tests.

recessions that are associated with banking crises the fall in the value of (un-weighted) bank assets is often equal to the decline in GDP. It is very likely that the proportionate fall in RWAs is greater than the decline in total assets because risky assets are more exposed to falls in incomes. In recent years Basel III measures of RWA would probably have been a bit under 1/2 of total assets for large UK banks.[20] So if – as some evidence seems to suggest – declines in total assets are of roughly the same order as declines in GDP, then the proportionate fall in RWA should be expected to be greater – perhaps twice as great.[21] This is why we consider our assumption of an equal percentage fall in RWAs and GDP as a conservative one for calibrating the exposure of bank assets to economy wide shocks.

Based on this assumption, we use an assumed probability distribution for changes in annual GDP to calculate the probability of a banking crisis in any given year for different levels of bank capital. We note that it is far from self-evident that using one year as the appropriate time interval is correct. What we are assuming is that within a year banks find it hard to raise their level of capital so that if a shock arises within a year which generates losses greater than capital at the start of the year then this will cause a banking crisis.

We are taking falls in incomes as the fundamental driver of losses on bank assets. We are treating this as an exogenous factor. So ideally we need to model those shocks to incomes that are not themselves influenced by banking problems. This is not straightforward since some of the historical fluctuations in incomes will have been influenced by banking problems. We use a dataset of income fluctuations which we believe means that this feedback (from initial shocks in incomes that are influenced and exacerbated by the banking problems they may generate) is likely to be absent or insignificant in the great majority of observations. We think that our way of modelling GDP largely reflects shocks that cause bank asset values to fluctuate – rather than shocks that emanate from banks and cause movements in incomes.[22] What we do is to calibrate a model of shocks to incomes (per capita GDP) using data from a large group of countries over a nearly two hundred year period. For many of these countries, and for much of the period, banks were much less important than they have subsequently become and most of the biggest movements in GDP reflect wars and political turmoil that are likely to be substantially independent from banking conditions. (In estimating optimal bank capital we will not however assume that banks need to be able to with-stand extreme events like wars.)

Historical data on changes in GDP strongly suggests that the frequency of such large negative shocks is very much greater than would be implied by an estimated normal distribution, a distribution which most of the time matches the GDP data well. A much

[20] Basel III RWA are about 25% larger than Basel II RWA. They are therefore a larger share of total assets than are RWA under Basel II, as well as better reflecting the relative risk of assets. That is why we think our results on optimal bank capital relative to RWA should be interpreted in terms of Basel III RWA.

[21] Consider an extreme example where there are two types of assets: those that are risky and those that are completely safe. If RWAs are 45% of total assets then if total assets are 100, those exposed to risk are worth 45. By assumption all the falls are concentrated in the risky assets. If total assets fall in line with falls with GDP then the value of risky assets needs to fall by about 2.2% for each 1% fall in GDP (i.e. by 1/0.45%).

[22] Even so it is likely that some of the historical variability in GDP reflects the impact of banking problems. To the extent this is true it increases the benefits of having banks hold more equity because that will result in a somewhat lower variance of GDP. In ignoring this feedback we are therefore likely to underestimate the size of optimal bank capital.

better way to match the distribution of risks that end up affecting GDP is to assume that most of the time risks – or shocks – follow a normal distribution but once every few decades a shock comes that is very large and which is not a draw from a normal distribution. This assumption – that GDP changes are normal but with the added chance that there are low probability quite extreme outcomes – is one made by Robert Barro (2006) in a series of important studies of rare events that hit economies.

Figure 4 shows a slight generalisation of the Barro (2006) model calibrated to match historical experience going back almost 200 years. The data are for the change in GDP per capita for a sample of 31 countries and starts, in some cases, in 1821 and comes up to 2008. We do not include observations from 2009 and 2010 when GDP in most countries was severely affected by the global banking crisis which began in the wake of the failure of Lehman Brothers in September 2008. We have almost 4,500 observations of annual GDP growth across the sample of countries; see Appendix A for more details and also Miles *et al.* (2005). Here we assume that the first difference of the log of per capita GDP (Y) follows a random walk with a drift and two random components

$$(Y_t) = \gamma + u_{t-1} + v_{t-1}.$$

The parameter γ captures average productivity growth. The first random component, u_t is the shock in normal times, i.e. it reflects the typical level of economic volatility. This shock follows an independently and normally distributed process $u \sim N(0, \sigma^2)$.

The other random component v_t is zero in normal times but with given probabilities it takes on significant values. There is a small chance (probability p) that v_t takes on a very large negative value, equal to $-b$. The parameter b represents the scale of the asymmetric shock; there is no chance of an equally large positive shock. There is a second type of shock, which is symmetric, and whose scale is denoted by c. This shock has a higher probability of occurring (probability $q > p$) and it is smaller, though still large relative to the volatility of the normally distributed shock. Formally, the random component v_t can be written as following
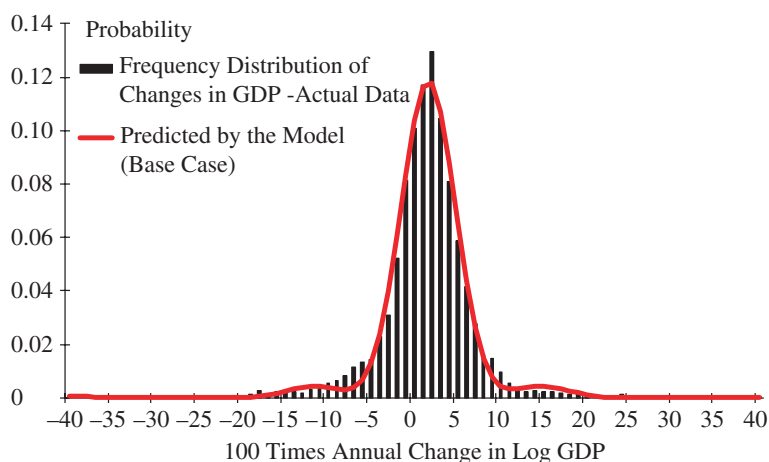

Fig. 4. *Annual GDP Growth: Comparing the Economic Model with Data* (1821–2008)

$$v_t = \begin{cases} 0 \text{ with probability } (1 - p - q) \\ -b \text{ with probability } p \\ +c \text{ with probability } q/2 \\ -c \text{ with probability } q/2. \end{cases}$$

Note that our model is one where shocks that hit incomes are permanent – we are not estimating a process where there are temporary shocks to GDP. We believe this is a model better suited to calibrating shocks to income that hit the value of bank assets; temporary shocks to incomes would be much less likely to affect the value of bank assets.

We choose the six parameters (γ, σ^2, b, c, p, q) to roughly match these four moments – mean, variance, skewness and kurtosis – based on 4,472 observations of historical annual real GDP growth; but we also want to match as best we can the chances of extreme events based on the frequency of big changes in the GDP data going back 200 years. Table 6 presents the chosen parameters for the model.

For given values of the parameters we can calculate the mean, variance, skewness, and kurtosis of the income process, as shown in Table 7. The implied expected

Table 6

Key Parameters

SD of GDP growth in normal times (σ)	3.1%
Average productivity growth (γ)	2.1%
Annual probability of extreme negative shock (p)	0.7%
Scale of extreme negative shock ($-b$)	−35%
Annual probability of less extreme, symmetric shock (q)	7.0%
Scale of less extreme, symmetric shock (c)	±12.5%

Table 7

Actual and Predicted Growth in GDP Per Capita (Data From 1821–2008)

	Actual data	Model prediction
Mean (%)	1.81	1.80
SD(%)	5.7	5.9%
Skewness	−2.40	−2.65
Excess Kurtosis	39.0	20.0
Observations	4472	
Percent of observations less than		
−20%	0.4	0.7
−15%	1.2	1.1
−10%	2.5	2.9
−5%	7.0	5.0
−2%	13.8	12.7
0%	27.1	27.1
Percent of observations more than		
0%	72.8	72.9
+2%	51.1	50.9
+5%	19.5	19.5
+10%	3.6	3.7
+15%	1.3	1.9
+20%	0.4	0.2

per-capita GDP growth (in logs) is 1.8% with an overall standard deviation of annual growth of 5.9%, a negative skew of − 2.65% and excess kurtosis of about 20.

The changes in annual GDP for a large sample of countries over long periods have two significant characteristics: changes in annual GDP do not follow a normal distribution (they have much bigger chances of extreme movements) and the chances of big falls are much greater than the chances of big rises (there is clear downwards skew). Table 7 shows our estimated distribution reflects this very well. Table 8 shows the frequencies with which GDP fell by various amounts in one year.

Table 8 suggests that occasions when generalised falls in real incomes might be 5% or more occur roughly once every 15 years. Falls in excess of 10% might be about once every 40 year events. Declines of 15% or more are roughly once every 80 year events. The final row in the Table shows the chances of falls in GDP based on a normal distribution which has mean and variance equal to the empirical distribution. The difference between that and the actual frequency is striking. For example, with the normality assumption, a decline of 15% GDP or more is a one-in-600-years event, compared to an historic frequency of about once every 80 years. Self-evidently a normal distribution greatly understates the probability of tail events – the very events we are interested in when assessing the appropriate levels of bank capital.

Table 8 suggests that *if* RWAs fall in line with falls in per capita GDP then banks would need far more capital than has been typical in recent years to be truly robust. For example, the probability that banks' RWAs fall in value by 15% or more is 1.2%. It follows that banks should have loss-absorbing capital of at least 15% of RWAs (which might correspond to about 7% of total assets using Basel III risk weights) to weather such an event.

We define a generalised banking crisis as a situation where the loss in the value of bank assets is as large as their equity capital. In many ways this is a conservative criterion as the early failure of less-capitalised institutions would be likely to freeze funding markets well before the sector as a whole falls into negative equity. We have also assumed that the percentage fall in asset values is equal to the risk weight multiplied by the fall in GDP. Appendix B suggests that this is likely to be a conservative assessment of bank losses.

3.2. *Expected Cost of Crisis and Bank Capital*

The expected cost of a crisis is equal to the product of the probability of a crisis and the loss given a crisis. To assess the impact of a financial crisis, one needs to make some assumptions about the size of its initial effect on incomes (GDP) and their persistence. We make the same assumptions as in the Bank of England's Financial Stability Report (June 2010), this is that if a banking crisis occurs, GDP falls initially by 10% and three-

Table 8

Frequency Distribution of Annual Falls in GDP

Annual GDP fall	>20%	>15%	>10%	>5%	>2%	>0%
Observed frequency (%)	0.40	1.21	2.48	6.95	13.8	27.10
Frequency implied by normal distribution(%)	0.006	0.16	1.90	11.58	25.17	37.50

quarters of this reduction lasts for just five years whilst one quarter is permanent. Based on that assumption, and a discount rate of 2.5%, the present value gain of permanently reducing the likelihood of a systematic crisis in any one year by one percentage point is around 55% of current annual GDP.[23] The initial impact of a 10% fall in GDP is in line with the IMF estimate of the typical cost of a financial crisis. It also accords with the recent experience of the UK: the level of UK GDP in the first half of 2010 was around 10% below what it would have been if growth from 2007 H1 had been equal to the long-run UK average.

The estimate of the cost of crisis is, of course, sensitive to our assumptions about the impact of the financial shock and its persistence. If we assumed no permanent effects on GDP, the benefits of higher capital requirements would then fall to about 20% of GDP per percentage point reduction in the likelihood of crises. The cost of bank crises would be very much greater if we assumed that all the damage done was permanent. In some ways that would be the natural assumption to make since it is consistent with the assumed process for GDP we have used, which is a random walk. We are effectively making the assumption that most shocks which have historically hit countries (the great majority of which are not banking crises) have permanent effects but that bank crises generate big shocks to output, not all of which are permanent. We make this assumption to avoid the charge of pushing the results towards generating very high optimal capital.

4. Calibrating Optimal Capital

Using the estimates for the social costs and benefits of higher capital requirements, we can assess what is a socially-optimal level of capital for the banking sector; that is the level of capital where the extra benefit of having more capital just falls to the extra costs of having more capital.

The marginal benefit of additional units of equity capital is the reduction in the expected cost of future financial crises. We measure capital relative to RWAs and we assume that any losses on RWA is in proportion to any fall in per capita GDP. We have defined a crisis as a situation where bank equity is wiped out. This means that the loss on assets – the value of which we assume is RWA multiplied by the percentage decline in per capita GDP – exceeds equity capital. If we express capital relative to RWA then a crisis happens when the percentage fall in per capita GDP exceeds that ratio. So if capital is 15% of RWA a decline in per capita GDP of 15% causes a banking crisis. Given the assumed distribution of shocks to bank asset values, the benefit of greater equity

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[23] The expected loss in output per crisis, LPC, can then be computed as

$$\text{LPC} = \left(\frac{3}{4} \frac{1 - \delta^5}{1 - \delta} + \frac{1}{4} \frac{1}{1 - \delta} \right) \times 10\%$$

where δ is the discount factor. Using a discount rate of 2.5% (which implies a discount factor of 0.975), this amounts to a cumulated discounted cost of about 140% of GDP per crisis, and 1.4% of GDP per percentage point reduction in the likelihood of this crisis. As higher capital requirements would not only reduce the likelihood of a single crisis but of all future crises, the expected benefit of higher capital requirements would be

$$1\% \text{ LPC } \frac{1}{1 - \delta}$$

per percentage point reduction in the probability of crises, or about 55% of GDP. A similar approach is used in Haldane (2010).
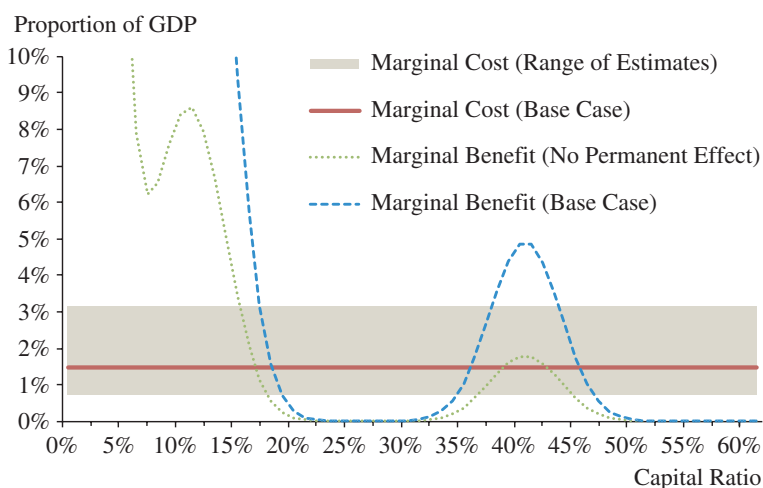
Proportion of GDP

Fig. 5. *Expected Marginal Costs and Benefits of More Capital*

capital in reducing the chances of a banking crisis tends to decline with additional capital. But since it looks like there are very occasionally extremely negative shocks to asset values, the benefit of extra capital does not fall monotonically. The costs of having banks finance more of their assets with equity is, given our assumptions, linear. So the marginal cost (for a given set of assumptions on the equity risk premium, the extent to which MM holds and the degree to which investment is assumed to be financed from bank lending) is constant. Both costs and benefits are measured as the expected present value of all changes to the future levels of GDP.

In Figure 5 we show two estimates of the marginal benefits of extra capital: in the higher line we assume that a quarter of the fall in output associated with a financial crisis is permanently lost; in the lower line we assume that five years after a banking crisis the level of GDP returns to where it would have been had there been no crisis.

On the horizontal axis in this Figure we show the ratio of capital to RWAs. In calibrating the model we need to be clear about what we mean by capital and RWAs. We have consistently said that capital needs to be pure, loss-absorbing capital. We think of this as common equity. So the regulatory concept nearest to it would seem to be the Basel III concept of CET1. In measuring the cost of requiring more equity relative to RWA we need to translate a change in that capital ratio to a rise in banks' weighted average cost of funds.[24]

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[24] It is useful to explain how we estimate the cost of higher capital ratios (in terms of lost GDP) by reference to the figures in Table 4. That table showed that on the base case assumptions halving leverage – reducing assets to Tier 1 capital from 30 to 15 – costs 596 bp of lost GDP, in present value terms. Basel II RWA were, for big UK banks, about 40% of total assets, so assets to Basel II RWA (which we denote A/RWA2) was around 250%. We assume that CET1 is around 0.6 a large as Tier 1 capital and that RWA under Basel III are around 1.25 as large as under Basel II. Using those assumptions the shift in leverage from 30 to 15 is a change in the Basel III capital ratio (ie CET1 to Basel III RWA) from:

$$0.6/30 \times [A/(RWA2 \times 1.25)] \text{ to } 0.6/15 \times [A/(RWA2 \times 1.25)]$$

Since A/RWA2 is around 2.5 this is a change from 4.0% to about 8.0%. So to convert into a cost per unit of capital to RWA we need to use: 596 bp/4.064 = 149 bp. This is what we use for the base case. Lower and higher cost scenarios are similarly scaled.

The different sets of assumptions for the cost of higher capital requirements are as in Tables 4 and 5. The highest cost scenario (the top of the band for costs) is one where there are no MM offsets and additional tax payments from banks to the government are simply a loss to society. Our base case (the solid marked line within the band of costs) assumes a 45% MM offset (the lowest estimated MM offset) and that the Government uses any additional tax receipts to neutralise the negative impact on corporate investment from banks paying more tax. The lowest-cost scenario is the bottom of the band for costs and this is based on the assumption that banks provide 16% of business finances, rather than the 33% assumed in the base case.

Figure 5 shows very clearly the implication of assuming that there is a small probability of a huge negative shock to incomes and bank asset values – it means that there is a benefit in having extremely high levels of capital (of the order of 45% of RWAs) to allow banks to survive such a shock. But there is a great deal of uncertainty about what the true probability of very big negative shocks to economies is and how bad those shocks really are. But even if one ignored the chances of those extreme shocks – and ignored the rise in marginal benefits of equity capital at very high levels that we see in Figure 5 – one would still find that the point at which benefits of more capital fell below costs was not until capital was 16% to 20% or so of RWAs. (The slight upward blip in the marginal benefit curve at around 10% is because of the impact of the less severe, and symmetric, shock to GDP that is also reflected in the hump in the probability distribution for GDP growth at around -10% shown in Figure 4.)

Taking the difference in the integrals of the marginal benefit and cost functions gives us the overall net benefit of setting capital at different levels. Figures 6 and 7 show that the net benefit lines are maximised at different levels of capital depending on which combination of assumptions on cost and benefits calculations we use.

In Table 9 we report the optimal level of bank capital implied by each combination of cost and benefit estimates. It is remarkable to note that using the low estimate for the marginal cost of higher capital suggests an optimal capital ratio of nearly 50% of RWAs – which might mean a capital to total assets ratio of around 20% and leverage of about 5.
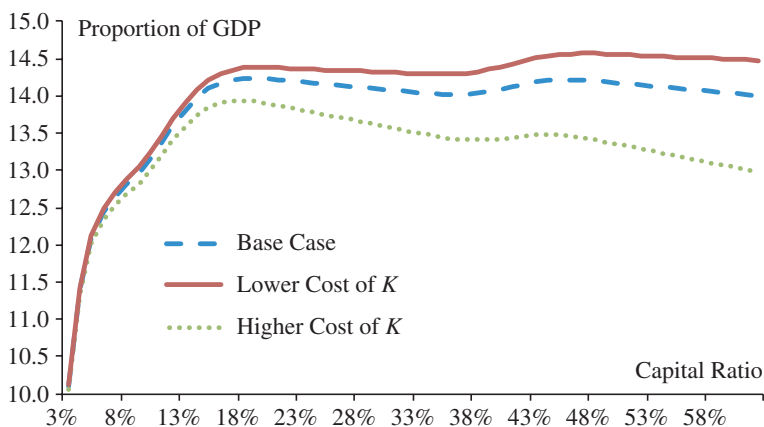

Fig. 6. *Net Benefit Of Holding Capital Assuming Financial Crises Have Some Permanent Effect on GDP Growth*
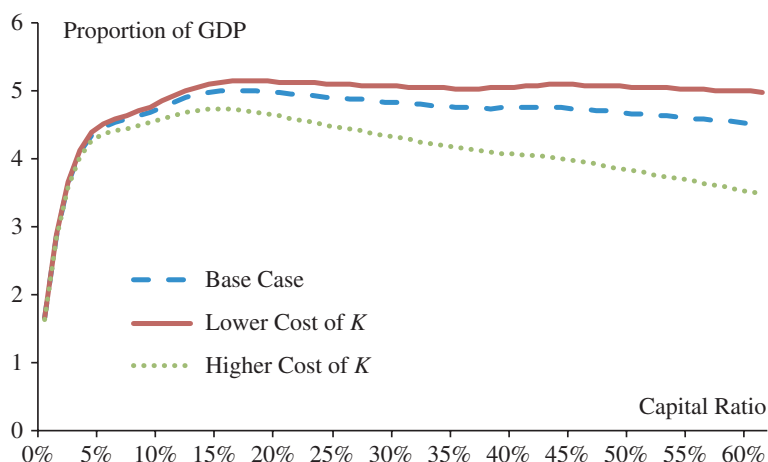
Fig. 7. *Net Benefit of Holding Capital Assuming Financial Crises Have No Permanent Effect on GDP Growth*

Table 9

Optimal Capital Ratios Considering Full Distribution of Bad Events

	Crises have some permanent effects on GDP growth	Crises have no permanent effects on GDP growth
Base cost of capital	19%	17%
Lower cost capital	47%	18%
Higher cost capital	18%	16%

This would be about five times as much capital – and one fifth the leverage – of banks now. But as noted above that result is hugely influenced by our assumption that there is a non-negligible probability of a fall in GDP and RWAs of the order of 35% or so. Historically that kind of fall in incomes is associated with wars or major political turmoil. It could be argued that bank capital levels should not be set at a level to provide protection against such extreme events. If we set those extreme events to one side the implied optimal levels of capital for the low estimate of capital costs is very much smaller. In Table 10 we report the locally optimal ratios when we ignore the cases of catastrophic falls in incomes. These are the maximum points closest to the vertical axis in Figure 6 and 7 (which in most cases are also the global maxima – though as noted this is not true for the low cost case). In the central case our estimate of optimal capital – assuming some permanent impact of a crisis on GDP – is 19% of RWAs. Table 10 shows that once we ignore very bad outcomes all the optimal capital ratios estimated are within the 16%–20% range. It is clear from the net benefit estimates shown in Figures 6 and 7 that the optimal capital ratios are not likely to be below 15%, but could well be in excess of 20%; the graphs of net benefits are relatively flat to the right of the maximum points, but start to decline sharply at ratios beneath 15%. The reason the net benefits curves look relatively flat beyond 20% capital is that the extent to which the expected marginal cost of more capital exceeds the marginal benefit is

Table 10

Optimal Capital Ratios Ignoring the Most Extreme Bad Events

	Crises have some permanent effects on GDP growth	Crises have no permanent effects on GDP growth
Base cost of capital	19%	17%
Lower cost capital	20%	18%
Higher cost capital	18%	16%

small relative to the huge excess of benefits over costs of raising capital from low levels up to around 20%.

The latest Basel agreement takes some significant steps in the direction our results suggest. It does so by redefining capital to be truly loss-absorbing and setting the (ultimate) minimum target for common equity capital at 7% of RWAs. Nevertheless our analysis suggests clearly that a far more ambitious reform would ultimately be desirable – a capital ratio which is at least twice as large as that agreed upon in Basel would take the banking sector much closer to an optimal position.

In this article our concept of capital is one of truly loss-absorbing capital (which we think should really be seen as equity), and we assume that RWAs correctly reflect the riskiness of banks' exposures; and we have calibrated the model to reflect Basel III definitions of loss absorbing capital and RWAs.[25] If we assume that the Basel III definitions of capital and RWAs are closer to the 'truth' (i.e. a better reflection of truly loss absorbing capital and a better reflection of true risk) than the Basel I/II definitions, the article says more about Basel III than about Basel I/II ratios.[26] So when we estimate that ultimately loss-absorbing capital should be 16%–20% of RWA (as implied by Table 10) then we are saying that truly loss-absorbing capital should be 16%–20% of the best measure of RWA. Basel III makes equity – i.e. *truly* loss-absorbing capital – at least 7% of RWA. With various 'add ons' that will come closer to what our estimates suggest is optimal, though it is likely to remain substantially below it. That is why we conclude that Basel III sets levels well below what the results suggest is optimal.

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[25] Our read on the evidence, summarised in Appendix B, is that assuming that RWA fall in value by the same percent as any fall in GDP is a reasonable assumption and quite probably a conservative one. No doubt the 'true' relation is not linear – though in what way is far from clear. If the non-linearity is that the impact on the value of bank assets gets proportionately bigger for bigger falls in incomes (rather than linearity) then we suspect our calculations are an under-estimate of optimal capital.

[26] However one part of the article uses Basel I/II definitions. So a natural question is whether this makes it more difficult to interpret the results as referring to ideal Basel III rules. When estimating the cost of higher capital requirements, we estimate the extent to which MM holds for banks. Specifically, we regress banks' equity beta on their leverage ratios. Here take *unweighted* bank assets and divide it by Basel I/II measures of Tier 1 capital. This is what we mean by leverage. This was a matter of having a consistent measure of loss absorbing capital over a long period – not that we assumed that Basle II Tier 1 is 'right'. What matters for a correct estimation of the reaction of banks' RoE to their capital ratio (or its inverse, leverage) is not that the levels of the ratios are different but whether they move roughly in the same direction. While it is very likely that the different capital ratios move together it introduces some extra noise into our estimates. We view this as an errors in the variables problem so it is likely to bias downwards the absolute size of the estimated link between the required rate of return on equity and the amount of truly loss absorbing capital required by regulations. That would mean that our estimates of the MM offsets are too low and that we likely over-estimate the rise in the cost of bank funds from using more loss absorbing capital and less debt.

5. Conclusion

The cost to the economy of the financial crisis and the scale of public support to the financial sector has been enormous. One way to reduce such costs is to have banks make greater use of equity funding. It is far from clear that the costs of having banks use more equity to finance lending is large. It is certainly not clear that the decline in banks' capital levels and increase in leverage had improved economic performance prior to the financial crisis.

The MM theorem tells us the cost of higher capital requirements should be close to zero. But there are several reasons to doubt that MM holds in its pure form. Nonetheless our empirical work suggests that there are some MM effects. The costs of stricter capital requirements are fairly small even if we assume a substantial departure from the MM theorem and assume that any extra tax paid by banks is a loss to society. We are also sceptical that the kind of increases in equity funding we find desirable would undermine any potential benefits in constraining bank management from having them heavily reliant on debt that could be withdrawn (or not rolled over). The argument that debt is a powerful disciplining device requires that a significant proportion of funding may be taken away from banks. Our estimate of optimal bank capital is that it should be around 20% of RWAs. If RWAs are between one half and one third of total assets then even with equity at 20% of RWAs debt would be between 90% and 93% of total funding. The notion that this is insufficient debt to capture any benefits from debt discipline seems unlikely.

It is difficult to determine the underlying distribution of potential shocks to banks' asset values and GDP growth. This article has argued that the normal distribution is likely to be a very poor approximation to the likelihood of extreme events. Once one moves away from the normal distribution the benefits of substantially higher capital requirements are likely to be great – both absolutely and relative to the likely costs of having banks hold more capital.

Were banks, over time, to come to use substantially more equity and correspondingly less debt, they would not have to dramatically alter their stock of assets or cut their lending. The change that is needed is on the funding side of banks' balance sheets – on their liabilities – and not their assets. The idea that banks must shrink lending to satisfy higher requirements on equity funding is a non-sequitur. But there is a widely used vocabulary on the impact of capital requirements that encourages people to think this will happen. Capital requirements are often described as if extra equity financing means that money is drained from the economy – that more capital means less money for lending. Consider this from the *Wall St. Journal*, in a report on the Basel negotiations on new rules over bank capital:

> The proposed rules would have driven capital requirements up for all banks, forcing the quality and quantity of these capital cushions to grow . . . . That would be expensive for banks, because the money sits on banks' balance sheets and essentially can't be invested to bring in more profits.[27]

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[27] 'Inching Towards World-Wide Accord on Bank Rules', *Wall St Journal*, 30 August 2010.

This is pretty much the opposite of the truth. At the risk of stating the obvious: equity is a form of financing; other things equal a bank that raises more equity has more money to lend – not less.

Nor is the capital in any sense 'tied up'; it represents funding available to a bank to lend or to acquire other assets. But much commentary on capital rules suggest otherwise. For example, a Reuters report from March 2011 asks which regime for banking regulation across the world will be the one '··· that ties up the least amount of traders' capital'.[28]

In retrospect we believe a huge mistake was made in letting banks come to have much less equity funding – certainly relative to un-weighted assets – than was normal in earlier times. This was because most regulators and governments seem to have accepted the view that 'equity capital is scarce and very expensive' – which in some ways is a proposition remarkable in its incoherence (as shown with clarity and precision by Admati *et al.*, 2010 and with wit and humour by Miller, 1995).

We believe the results reported here show that there is a need to break out of the way of thinking that leads to the 'equity is scarce and expensive' conclusion. That would help us get to a situation where it will be normal to have banks finance a much higher proportion of their lending with equity than had been assumed in recent decades to be acceptable. And that change would be a return to a position that served our economic development rather well, rather than a leap into the un-known.

Appendix A: The Model of Shocks to Incomes

We assume that income (A) follows a random walk with a drift and two distinct random components:

$$\log(A_t) = \log(A_{t-1}) + \gamma + u_{t+1} + v_{t+1}. \tag{A1}$$

The first random component, u, shows the shock in normal times, i.e. is the 'normal' level of economic volatility. This shock follows a white noise process (i.i.d.):

$$u \sim \mathrm{N}(0, \sigma^2). \tag{A2}$$

The other random component (v_t) is zero in normal times, but with given probabilities takes on significant values. There is small chance (probability p) that v takes on a very large negative value. This is an asymmetric shock; there is no chance of an equally large positive shock. There is a second risk, with higher probability (equal to q) that there is a less extreme and symmetric shock that either increases or increases or decreases GDP by a substantial magnitude. Thus:

$$v_{t+1} = 0 \text{ with probability } (1 - p - q)$$
$$v_{t+1} = -b \text{ with probability } p$$
$$v_{t+1} = +c \text{ with probability } q/2$$
$$v_{t+1} = -c \text{ with probability } q/2.$$

We can calculate the moment s of the distribution of GDP from the six parameters – γ, σ, p, q, b and c. The mean (i.e. the first moment) is:

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[28] 'Regulatory Arbitrage Could go Beyond Basel III', Richard Beales, Reuters, 11 March 2011.

$$\mu = \gamma - pb. \tag{A3}$$

The variance (the second moment)

$$s^2 = \sigma_u^2 + (1 - p - q)(pb)^2 + p[(b(p-1)]^2 + (q/2)(pb - c)^2 + (q/2)(c + pb)^2. \tag{A4}$$

From above:

$$\sigma_v^2 = (1 - p - q)(pb)^2 + p[(b(p-1)]^2 + (q/2)(pb - c)^2 + (q/2)(c + pb)^2. \tag{A5}$$

The final moments (third and fourth) are skewness and kurtosis.
Skewness is given by:

$$Skewness = \frac{1}{s^3}\left\{(1 - p - q)(pb)^3 + p[(b(p-1)]^3 + (q/2)[(pb - c)^3 + (c + pb)^3]\right\}. \tag{A6}$$

Kurtosis can be written as:

$$Kurtosis = \frac{1}{\left(\sigma_u^2 + \sigma_v^2\right)^2}\{(1 - p - q)(pb)^4 + p[(b(p-1)]^4 + (q/2)[(pb - c)^4 + (c + pb)^4]\}$$
$$+ 3\left(\frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}\right)^2 + 6\left(\frac{\sigma_u^2\sigma_v^2}{(\sigma_u^2 + \sigma_v^2)^2}\right).$$

We chose the six parameters of the distribution to match the most relevant features of the data on the change in log GDP per capita from a group of 31 countries with observations going back as far as 1,821. For the nineteenth century there are data on only around two-thirds of the countries. There are data on nearly all countries since 1900. The countries are: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, Colombia, Denmark, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Portugal, South Korea, Spain, Sweden, Switzerland, UK, US, Uruguay, and Venezuela. We set the parameters so that the mean and variance of the distribution matched those moments of the data. We also aimed to roughly capture the chances of very extreme falls in incomes and to have skew and kurtosis that were of the same order of magnitude as the data sample moments. Table 7 in the text shows how the chosen parameters match those features of the data sample.

Appendix B: Link between the Value of Banks' Assets and Falls in GDP

Changes in the macroeconomic environment can affect the value of banks' assets through a number of channels. The ability of borrowers to repay bank debt typically varies as their income changes with the macroeconomic cycle. The economic environment also affects the value of asset prices, with a corresponding impact on banks' security holdings and on the value of any collateral that banks may have taken to secure their loans. The degree to which a deterioration in the macroeconomic environment impacts banks' loan portfolio may also depend on the length of the preceding expansion: during prolonged expansions, banks may underestimate the risks of their assets and incur excessive risk.

Stress test models for the banking sector seek to separate out the influence that these and other factors – for example, structural changes of the environment in which banks operate – have on the value of banks' assets, and hence on banks' failure risk; see, for example, Hoggarth and Pain (2002). Some studies also attempt to take into account that the macroeconomic environ-

ment itself may be affected by the amount of bank lending – indeed, this is the exclusive focus of studies of the influence of the supply of bank credit on the economy. In contrast, for the purpose of this article, we are simply interested in whether changes in GDP and changes in RWAs are sufficiently similar in size to corroborate our claim that when GDP has fallen the cumulative decline in the value of a bank's RWAs is about as large as the cumulative decline in GDP. Here we summarise recent evidence on this.

We proceed as follows. We approximate the change in the value of RWAs by the value of losses during a crisis relative to the pre-crisis stock of RWAs. Alternatively, we might have computed the change in the published values of RWAs: however, this would have mixed quantity effects (e.g. new loans being granted, or maturing loans being repaid) with price effects (changes in the value of outstanding loans). To estimate losses, we refer to IMF (2010 Global Financial Stability Review) for the recent crisis. The IMF approximate overall losses by the sum of provisions on loans (as a proxy for losses on the banking book) and changes in the value of security indices for asset-backed securities and corporate debt (as a proxy for losses on the trading book). For previous crises, we ignore any losses on the trading book and focus exclusively on losses on the banking book, measured by provisions. To the extent that trading book assets are more volatile than banking book assets, we therefore tend to underestimate value changes in banks' assets for these crises.

B.1. *Recent Crisis*

IMF 2010 *Global Financial Stability Report* presents estimates of bank write-downs relative to total assets during the 2007–8 banking crisis (Table B1). These estimates include predictions of yet-to-be-realised losses. Peak-to-trough changes in GDP were about as large as the cumulative write-downs relative to total assets, i.e., as the change in the value of un-weighted assets. Assuming that losses fall disproportionately on assets with higher risk weights, it seems likely that that peak-to-trough changes in GDP were probably rather smaller than percentage changes in the value of RWAs for the recent crisis.

Table B1
IMF Estimates of Banks' Losses and Changes in GDP (%)

	US	UK	Euro area	Other Mature Europe	Asia	Total (for these regions)
Write-downs on loans, relative to total loans	7.3	5.9	2.8	4.1	1.4	4.1
Write-downs on securities, relative to total security holdings	6.6	3.5	3.2	3.0	1.8	4.1
Total write-downs relative to total assets	7.0	5.4	2.9	3.9	1.5	4.1
Peak-to-trough changes in GDP	−2.6	−4.9	−4.1	−4.2	−5.2	−3.5

Source: IMF (2010), *Global Financial Stability Report*, April. 'Asia' is Australia, Hong Kong SAR, Japan, New Zealand, and Singapore; 'Other Mature Europe' is Denmark, Norway, Iceland, Sweden, and Switzerland. GDP growth rates are value-weighted changes in real GDP from the peak to the trough during the recession.

We also investigate in more detail the losses that major UK banks provisioned for in their banking book. Table B2 shows that by the end of 2010, their cumulative flow of provisions since the start of the recent crisis had risen to 8.3% of the 2006-value of their gross loans, and 4.1% of their total assets. If we focus only on the value of those in-crisis provisions which are in excess of normal-time pre-crisis provisions, the cumulative excess flow of provisions reached, by the end of 2010, was 6.7% of the 2006-stock of gross loans and 2.9% of the 2006-stock of total assets. During the same time, the peak cumulative decline in UK GDP was 4.9%. Given that these estimates exclude losses on the trading book and any provisions that may still arise in the coming years, they appear to be broadly supportive of our hypothesis.

Table B2
Proxies for the Change in the Value of Banks' Assets (%)

	Pre-crisis annual averages (1997–2006)	2007	2008	2009	2010
1. Year-by-year ratios					
Provisions/total assets	0.3	0.3	0.6	1.0	0.6
(both measured during/at end of the same year)					
Provisions/gross loans	0.4	0.8	1.6	2.3	1.5
2. Cumulative provisions since start of crisis (2007),					
relative to end-2006 assets and gross loans					
Cumulative provisions/end-2006 assets		0.5	1.7	3.1	4.1
Cumulative provisions/end-2006 gross loans		0.9	3.4	6.4	8.3
3. Cumulative excess provisions (above normal-time provisions)					
since 2007, relative to end-2006 assets and gross loans					
Cumulative excess provisions/end-2006 assets		0.2	1.1	2.2	2.9
Cumulative excess provisions/end-2006 gross loans		0.5	2.6	5.2	6.7

Source: Capital IQ. Reported ratios are based on aggregate figures for Barclays, HSBC Holdings, RBS, and Lloyds/HBOS.

The same type of information can also be inferred from banks' losses instead of their provisions (Table B3). Here, it seems plausible to focus on the decline in banks' profits compared to normal-time profits in order to separate the change in the value of banks' assets from the current income that is still derived from these assets. While profits averaged around 1% relative to total assets in normal times, they fell to about 0.2% of total assets during 2007–2010. The *cumulative* shortfall of in-crisis profits compared to normal-time profits reached 3.3% (≈ 4 (1%–0.2%); difference due to rounding) in 2010. One might consider this as a reasonable proxy for the change in the value of total assets (and hence for the percentage change in the value of RWAs). This is less than the estimate that we derived using data on provisions in Table B2 (which is probably more precise).

Table B3
Proxies for the Change in the Value of Banks' Assets (%)

	Pre-crisis annual averages (1997–2006)	2007	2008	2009	2010
Profit before taxes/assets in the same year	1.1	0.7	−0.3	0.2	0.3
Cumulative profit since 2007, relative to end-2006 assets		1.0	0.3	0.6	1.1
Cumulative profit since 2007, deducting an estimate of normal-time profits of 1.1% p.a., relative to end-2006 assets		−0.1	−1.9	−2.7	−3.3

Source: Capital IQ. Reported ratios are based on aggregate figures for Barclays, HSBC Holdings, RBS, and Lloyds Banking Group/Lloyds TSB and HBOS.

B.2. *Earlier Crises*

Corresponding to Table B2, Table B4 contains estimates of total assets and provisions for some major UK banks for the 1990–1 recession. By the end of 1993, the cumulative flow of provisions for bad and doubtful debt since the start of that crisis had risen to 3.7% of the 1990-value of total assets. If we focus only on the value of those in-crisis provisions which are in excess of normal-time provisions (here taken to be 0.3% p.a.), the cumulative excess flow of provisions reached, by the end of 1993, 2.8% of the 1990-stock of total assets. During the same time, the peak cumulative decline in UK GDP was 1.4%.

Table B4
Proxies for the Change in the Value of Banks' Assets (1990–1991 Recession in %)

	1991	1992	1993	1994
Provisions/total assets: year-by-year ratios	1.1	1.2	0.8	0.3
Cumulative provisions since 1991, relative to 1990 assets, %	1.2	2.7	3.7	4.1
Cumulative provisions since 1991, relative to 1990 assets, deducting an estimate of normal-time provisions of 0.3% p.a. of total assets	0.9	2.1	2.8	2.9

Source: Capital IQ and published accounts. Provisions and total assets data for Barclays, HSBC/Midland, Lloyds, Natwest, RBS, and Santander/Abbey.

Both Laeven and Valencia (2009) and the World Bank's Banking Crises database present estimates of the share of non-performing loans relative to total loans during banking crises. Table B5 shows Laeven and Valencia's estimates of peak non-performing loan ratios for more recent banking crises in a range of industrialised countries, and compares it to the peak decline in GDP.

Clearly, the non-performing loan ratio is larger than ultimate losses in the banking book: some non-performing loans are ultimately repaid in full. The evidence suggests that the share of non-performing loans was on average substantially larger than falls in GDP. If about a third of these non-performing loans had to be written off in full, the maximum cumulative decline in the value of a bank's loans would on average have been about the same as the peak cumulative decline in GDP.

Table B5
Peak Shares of Non-performing Loans and Declines in GDP in Previous Banking Crises (%)

	Starting date	Peak share of non-performing loans over all loans	Maximum decline in GDP
Czech Republic	1996	18.0	−1.5
Finland	1991	13.0	−10.0
Hungary	1991	23.0	−18.1
Japan	1997	35.0	−2.2
Korea	1997	35.0	−5.7
Mexico	1994	18.9	−6.2
Norway	1991	16.4	−0.2
Poland	1992	24.0	−13.7
Russia	1998	40.0	−5.3
Sweden	1991	13.0	−4.3
United States	1988	4.1	−0.2
Average		21.9	−6.1

Source: Laeven and Valencia (2009) for crises dates and peak NPL shares; WEO database for cumulative declines in GDP.

Banking sector stress test models can also inform the link between GDP and loan write-offs. For the UK, Hoggarth *et al.* (2005) estimate a VAR which includes bank-specific and macroeconomic variables and find that the maximum impact of a 1% adverse shock to UK output relative to potential leads to a 0.07%–0.19% increase in banks' annual write-offs relative to total loans per year for a period of about two years, depending on the estimation period.[29] This suggests, very roughly, that the cumulative loss that banks made on their loans in excess of normal-time provisions was between 0.15% and 0.4% in response to a 1% decline in GDP. Notice that this estimate of banking book losses excludes any mark-to-market losses on banks' marketable security

[29] This estimate is inferred from the graphical representation of the impulse response function of the write-off ratio following a 1% decline in GDP relative to an estimate of potential GDP. See Figures 14 and 17 in Hoggarth *et al.* (2005).

holdings. It is also not clear what we should, for our purposes, infer from reaction functions that are based on estimates derived from normal and crisis times; we are interested in protecting banks from GDP fluctuations during crises.

We have recalculated optimal capital ratios assuming both less and more sensitivity of the fall in the value of RWAs to a fall in GDP. The base case is a 1:1 percentage fall. Table B6 shows optimal capital ratios when the fall in RWA is only ½ the percentage decline in GDP. Table B7 shows the impact when the decline in the value of RWA is twice the percent decline in GDP. In both cases we calculate optimal capital ignoring the most extreme bad events. Comparing the optimal ratios in Tables B1 and B2 with those in Table 10 in the main text suggests that the impact on optimal bank capital of changing the assumed sensitivity of RWAs to falls in GDP is roughly linear.

Table B6

Optimal Capital Ratios Ignoring the Most Extreme Bad Events – Half Sensitivity of RWA to GDP Fall

	Crises have some permanent effects on GDP growth (%)	Crises have no permanent effects on GDP growth (%)
Base cost of capital	10	9
Lower cost capital	10	10
Higher cost capital	9	9

Table B7

Optimal Capital Ratios Ignoring the Most Extreme Bad Events – Double Sensitivity of RWA to GDP Fall

	Crises have some permanent effects on GDP growth (%)	Crises have no permanent effects on GDP growth (%)
Base cost of capital	35	32
Lower cost capital	37	34

Monetary Policy Committee, Bank of England
Bank for International Settlements
Bank of England

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