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Abstract

This paper examines the effects of competition on bank stability in the United Kingdom between 1994 and 2013. We construct several measures of competition and test the relationship between competition and bank stability. We find that, on average, competition lowers stability, but that its effect varies across banks depending on the underlying financial health of the institution. Competition encourages relatively less sound banks (closer to insolvency) to reduce costs, lower portfolio risk and increase capital ratios, strengthening their stability, while it lowers the incentives of relatively more sound banks (farther from insolvency) to build capital ratios, weakening their stability. These findings imply trade-offs at the bank-level that may need to be weighed when evaluating policies with consequences for competition.

Key words: Bank competition, bank stability, Boone indicator, Lerner index.

JEL classification: G21, G28, L22.

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1 Introduction

Although competition in banking markets can benefit consumers by improving choice, lowering borrowing rates and raising deposit rates, the impacts on bank stability remain less obvious. Theories on the links between competition and stability suggest that competition may have both favourable and unfavourable effects (e.g., see Carletti and Hartman, 2003; Beck, 2008; and Vives, 2011 for good overviews), while the empirical results on this issue provide varying degrees of support for both effects.[1] As a result, understanding whether competition is good or bad for stability continues to be of interest to academics and policymakers (e.g., Tucker, 2015; Bank of England, 2015; Dickinson et al., 2015).

To shed further light on this issue, this paper analyses the effect of competition on bank-level stability in the UK between 1994 and 2013. Discussed in more depth below, we follow much of the literature on this topic and concentrate on competition within a broadly defined banking market (i.e., firms that undertake intermediation services transforming deposits into loans) rather than competition within specific product markets (e.g., within the mortgage market or retail deposit market). Our focus on the UK is motivated by several legislative and regulatory changes aimed at broadening competition in the UK banking markets that occurred in the two decades prior to our estimation period: e.g., the Banking Act of 1979; the 'Big Bang' in 1986; the Building Societies Act of 1986.[2] This trend in deregulation continued into the 1990s with the European Second Banking Coordination Directive of 1993, reducing barriers to entry by allowing European banks to operate in different markets.[3]

The UK banking system consists of a small number of large, dominant institutions together with a large number of small, challenger institutions. Several studies of competition in the UK banking market suggest that the banking sector is best characterised by the model of monopolistic competition (e.g., Heffernan, 2002; Matthews et al., 2007; de-Ramon and Straughan, 2016). To our knowledge, however, there is no research that has examined the effects of competition on stability exclusively for the UK.[4] This issue is of particular importance in light of the UK government's ongoing scrutiny of competition in the UK banking markets (e.g., Cruikshank, 2000; Independent Commission on Banking, 2011; CMA, 2016) and the explicit mandate that the Bank of England's Prudential Regulation Authority, the UK's primary prudential bank regulator, now has to consider competition when discharging its primary safety and soundness objective (e.g., Dickinson et al., 2015).

For these reasons, a key aim of our paper is to shed light on which of the two competing theories on the competition-stability link better characterises the situation in the UK or whether both are valid simultaneously**.** Some studies argue that competition reduces stability (*'competition-fragility'*), since it erodes valuable franchise value and encourages banks to increase risk and operate with low capital buffers (e.g., Keeley, 1990; Hellman et al., 2000). Others contend that competition increases stability (*'competition-stability'*), because as competition in credit markets intensifies and loan rates fall, borrowing firms' probability of default declines, which improves banks' profitability

[1] Providing a sense of just how widely varied these findings have been, Zigraiova and Havranek (2016) use meta-data analysis to examine almost 600 empirical estimates of the competition-stability link across 31 studies published between 2003 and 2014 and find little interplay between competition and stability.

[2] This focus also helps to ensure comparability across the dependent and independent variables in our analysis.

[3] Matthews et al. (2007) and de-Ramon and Straughan (2016) provide more background on these regulatory changes.

[4] Previous studies have used sub-samples of UK banking market to examine the effects of competition on stability in cross-country settings, e.g., Berger et al (2009); Beck et al. (2013); Schaeck and Cihak (2014).

and helps build capital buffers (e.g., Boyd and De Nicoló, 2005; Boyd et al., 2006; Schaeck et al., 2006), thus raising bank stability overall. Some have also argued that both strands of the literature may not necessarily yield opposing predictions and that the link may depend on the degree of competition in a non-linear way (e.g., Martinez-Miera and Repullo, 2010) or on features and incentives of the institutions within the relevant banking markets (e.g., Berger et al., 2009; Tabak, et al., 2012; Liu and Wilson, 2013) and countries (e.g., Beck et al., 2013).

Our paper is most closely related to this last strand of research. We contend that even if market power in asset markets results in riskier assets, the overall stability of a bank need not decrease. This outcome can arise if banks take actions to protect against the loss of franchise value, by, for instance, holding more equity capital. Consequently, when a bank charges higher lending rates and has a riskier loan portfolio, the bank may still choose a lower overall risk. As Berger et al. (2009) points out, this idea suggests that to determine whether one or both of the theories may operate simultaneously, it is important in empirical studies evaluating the effects of market power on bank stability to select dependent variables that reflect both asset risk and overall bank risk. We employ the Z-score, an inverse proxy for overall bank risk, as our main dependent variable of interest. This measure has been widely used in the literature examining the competition-stability link (e.g., Berger et al., 2009; Tabak et al., 2012; Liu and Wilson, 2013; Schaeck and Cihak, 2014; Cummins et al. 2017) and has an added benefit: its component parts reflect proxies for asset risk and leverage risk. In addition to estimating the effects of competition on overall risk (Z-score), we estimate the effects separately for each of these component parts using the same model, which allows us to draw inferences about the two opposing theories.

An additional issue in evaluating the opposing theories is how to measure competition. Zigraiova and Havranek (2016) document that the definition of bank competition used by researchers influences results in a systematic way.[5] To check for robustness of our findings, we include three distinct measures and evaluate the effects of each separately. First, as our main measure of market power, we use the Lerner index, which captures the extent of banks' price-cost mark-ups based on the difference between output price and marginal costs. Second, we employ the Boone (2008) indicator, which is a measure of competition from an efficiency perspective. This second measure captures the impact of competition on the performance of efficient banks, consistent with the industrial organization literature, which demonstrates that competition reallocates profits from inefficient to efficient firms (e.g., Stiroh, 2000). Third, we include the Herfindahl-Hirschman Index (HHI) for assets as another measure of market power.[6]

We carry out our analysis of the effects of competition in three parts. In the first, we estimate measures of the Lerner index and Boone indicator and construct HHI for assets in the UK banking markets over the period 1991 to 2013. In the second, we estimate the link between competition and stability by estimating panel data models where the dependent variable is one of six measures of bank stability: the Z-score or one of its constituent components (i.e., return on assets, equity-to-asset ratio, volatility of return on assets, risk-adjusted return on assets, risk-adjusted leverage ratio). We do this separately for each of our three measures of competition, while controlling for bank-level

[5] In particular, they document that studies using the Panzar-Rosse H-statistic tend to report larger estimates of the competition-stability link, while studies that employ the Boone (2008) indicator generally show smaller estimates.

[6] Importantly for our study, Ziagraiova and Havranek (2016) find no evidence of systematic differences between the findings of studies that use behavioural competition measures (e.g., Lerner index) and that use concentration (HHI) as a proxy for competition.

and macro-economic factors that also influence bank stability. Finally, in the third part, we employ quantile regression to examine whether the effect of competition on stability depends upon the financial health of the bank, as measured by Z-scores, risk-adjusted returns and risk-adjusted capitalization. We explore if relatively weak banks respond differently compared to relatively strong banks, i.e., banks with higher Z-scores, risk-adjusted returns or risk-adjusted capital ratios.[7] In carrying out these steps, the study relies on a proprietary dataset of regulatory information on all UK banks (including foreign subsidiaries) and building societies (see de-Ramon et al, 2017).

By way of preview, our measures of competition confirm the consensus finding that monopolistic competition best characterises competition in the UK banking market. Our findings on the effect of competition on stability *for the UK banking sector* indicate that, consistent with the *competition-stability* view, asset portfolio risk increases with market power (i.e., in a less competitive environment). At the same time, however, our results also lend support to the *competition-fragility* view: we find that *overall* stability increases with market power (i.e., in a less competitive banking market). The overall higher stability comes largely from banks electing to hold significantly more equity capital, consistent with the *franchise value* theory.

We also find that the effects of competition on stability are not homogeneous across financially weak and financially healthy institutions. In particular, our results suggest that, consistent with the *competition-stability* view, the stability of the relatively weakest institutions worsens in the face of greater market power (or in a less competitive environment). However, the stability of the relatively strongest institutions improves with market power (or in a less competitive environment), in line with the *competition-fragility* view. The different effects appear to derive mainly from the relatively strongest banks' desire to hold higher equity capital, consistent with the *franchise value* paradigm. This last set of findings suggests that policymakers may need to consider that the effects of competition on sector stability may be contingent on the stability of banks operating in the relevant banking market.

Our paper contributes to the research on the competition-stability link in a number of ways. First, to our knowledge, this is the first study that examines whether the strength of competition and stability varies according to the underlying risk of a bank solely for the UK. Our findings are useful for reconciling the mixed results on this issue in cross-country settings. Second, we offer some initial insights into the factors contributing to the competition-stability link in the UK. Third, we employ both the Boone indicator and Lerner index to examine the effects of competition on stability. Because these measures derive from different perspectives (i.e., cost efficiency versus market power), each offers a different explanation of the channels through which competition contributes to stability.

The remainder of this paper is structured as follows. Section 2 briefly discusses the relevant literature. Section 3 outlines our empirical approach and describes the measures of stability and competition used in this paper in more detail. Section 4 discusses our data and sample. Section 5 reports results. Section 6 concludes.

[7] Schaeck and Cihak (2014) examine heterogeneous responses to competition using a sample of European banks and find that less stable banks, i.e., those with low Z-scores, benefit less from competition than more stable banks. Liu and Wilson (2013), focusing on Japanese banks, find that the relationship between competition and stability, measured by Z-scores, differs according to the initial risk of the banks. They find that competition enhances the stability of high risk banks, while it weakens the stability of initially lower risk banks. We extend both analyses to consider other aspects of bank stability.

2 Relevant literature

Our paper expands on the theoretical and empirical literature examining the relationship between competition and stability in the banking system. The literature on this topic sets out two competing views of the response of banks to changes in competition intensity. The first view, known as the *competition-fragility* hypothesis, suggests that competition erodes market power, decreases profit margins and, in turn, reduces *franchise value*, which creates incentives for banks to take greater risks (e.g., see Marcus, 1984; Keeley, 1990). A key implication underlying this idea is that as banks gain market power, their franchise value increases. Since this franchise value reflects intangible capital that banks will only realise if they do not go bankrupt, the larger the value, the more reluctant banks become to increase risk. In this case, they elect to take more prudent actions by, for example, holding more equity capital or by increasing underwriting standards or screening activities.[8]

The second main view, known as the *competition-stability* hypothesis, posits that as banks gain market power, it is also possible that their portfolio risk increases. This theory contends that more competitive banking systems result in more, rather than less, stability. The idea behind this view is that banks with market power will earn rents by charging higher rates on loans. However, higher borrowing rates may increase the riskiness of banks' asset portfolios because of adverse selection (Stiglitz and Weiss, 1981) and moral hazard (risk-shifting) problems. Such higher borrowing rates, by discouraging safe borrowers and encouraging riskier projects, means that the overall quality of banks' asset portfolios worsens. Boyd and De Nicolo (2005) formalise this idea and show that higher competition that lowers lending rates also reduces the likelihood of borrower default. As a result, banks will face lower credit risk on their loan portfolios in more competitive markets, which acts to improve bank profitability and capital, bolstering stability overall.

Allen et al. (2011) also show how competition in credit markets can lead to higher stability through a different mechanism. In particular, they demonstrate theoretically that market discipline on the asset side of the balance sheet can provide incentives for banks to fund themselves with higher capital as a way of committing to monitor borrower risk and reduce funding costs overall. They go on to show that these incentives are strengthened where there is more competition in loan markets, offsetting the hypothesized de-stabilising effects of competition under the franchise value paradigm (i.e., more competition leads banks to increase risk to raise returns).

Together, the papers by Boyd and De Nicolo (2005) and Allen et al (2011) offer different, but complementary, explanations for how heightened competition in loan markets can lower loan portfolio risk and raise bank stability overall. Underlying both papers, however, is the assumption that competition affects banks similarly. Our study contributes to this literature by providing some initial empirical insights into whether the potentially stabilising effects of competition are different across banks in the UK.

Extending the Boyd and De Nicolo (2005) model, Martinez-Miera and Repullo (2010) develop an alternative view which shows that the effects of competition on stability may depend on the degree of competition in the relevant banking markets. In particular, they show that while increased

[8] Market failures in banking markets can also be exacerbated by competition. Besanko and Thakor (1993) show that asymmetric information increases as competition erodes the information value of borrower relationships, ultimately increasing bank risk taking, consistent with the *competition-fragility* hypothesis.

competition which lowers lending rates can improve borrowers' ability to repay loans and thereby reduce the credit risk of a bank's loan portfolio, in turn, improving bank profitability and stability, lower lending rates can also reduce interest revenues, dampening bank profitability and stability. Their model suggests that the relationship between competition and stability is not monotonic, but rather U-shaped, involving two countervailing effects: (i) a credit risk-shifting effect (e.g., in the spirit of Boyd and De Nicolo, 2005), which, by implication, improves earnings and (ii) an interest margin-effect that reduces earnings. As a result, the impact of an increase in competition (i.e., reduction in market power) can go either way, depending on which of these effects dominates. They go on to show that the risk-shifting effect dominates in very concentrated markets such that increased entry (i.e., more competition) reduces credit risk, as measured by non-performing loans. In already competitive markets, the margin effect is shown to dominate such that further entry (i.e., more competition) reduces interest revenue, thus worsening profitability.

Jiménez et al. (2013) test this hypothesis using detailed deposit and commercial loan market data from Spain. They focus exclusively on evaluating the relationship between competition and loan portfolio risk, as measured by non-performing loan ratios, rather than overall bank stability using an index like the Z-score. To proxy competition, they employ measures of loan and deposit market concentration by region and product-level Lerner indices (as more direct measures of market power). Using the standard measures of market concentration in both loan and deposit markets, they find support for the non-linear relationship posited by Martinez-Miera and Repullo (2010). In loan markets, the relationship is convex and consistent with the predictions of Martinez-Miera and Repullo (2010), suggesting that as competition increases, non-performing loan ratios first decline and then increase beyond a certain point.[9] Their results based on product-level Lerner indices show that non-performing loans are inversely associated with the degree of market power in the loan market: i.e., credit risk declines as market power in banks' loan markets increases.[10] This evidence is more supportive of the *franchise-value* paradigm and does not provide evidence for the 'risk-shifting' paradigm identified by Boyd and De Nicolo (2005).[11] However, because their study only considers loan portfolio risk, which is just one aspect of a bank's risk profile, it is difficult to draw conclusions on the effects of competition on stability more broadly. As discussed below, our study addresses this possible shortcoming by employing similar measures of competition and evaluating their effects on a measure of overall bank stability (Z-score) as well as its components representing portfolio risk.

Berger et al. (2009) address this issue by regressing measures of loan portfolio risk (non-performing loan ratios), bank risk overall (Z-scores), and bank equity capital (to assets) ratios separately on several measures of market power (i.e., HHI deposits, HHI loans and Lerner index) in a cross-country setting using data for 8,325 banks in 23 developed countries. They argue that even if market power in the loan market results in riskier loan portfolios, the overall risk of a bank need not increase if banks take actions to protect their valuable franchises, by funding balance sheets with

[9] In deposit markets, while traditional measures of concentration support the nonlinear relationship between competition and risk-taking in the loan portfolio, the relationship is unexpectedly concave. The authors point out that this unexpected result warrants further research on the influence of competition when it affects both sides of the balance sheet.

[10] Using a Lerner index computed for deposit products in the Spanish banking system, they find no statistically significant association between non-performing loan ratios and market power in deposit markets.

[11] Zigraiová and Havránek (2016) report meta-analysis that considers how the inclusion of non-linear effects of competition affects the relationship with financial stability measures (including the Z-score). They find that studies including quadratic terms of competition lend considerably more support to the competition-stability hypothesis.

more equity capital or taking other risk-mitigating actions. Their results show that banks with higher market power are more stable overall (i.e., have higher Z-scores), consistent with *competition-fragility* hypothesis. Their results also provide support for one element of the *competition-stability* hypothesis – namely that market power increases loan portfolio risk (as measured by higher non-performing loan ratios). They go on to show that the positive impact of market power on overall financial stability is at least partially explained by banks holding materially higher equity capital ratios. Importantly, their results are consistent with the idea that the two main competing theories need not lead to opposing views, but can hold concurrently depending on how measures of risk and stability are defined in these studies.

Using different measures of competition and risk and data from 10 Latin American countries between 2003 and 2008, Tabak et al. (2012) also find evidence supportive of non-linear effects of competition and that the two competing theories can hold simultaneously. They use the Boone indicator as their main measure of competition and a modified version of the Z-score as their main measure of stability and find evidence that competition affects risk taking behaviour in a non-linear way. In particular, they find that both high and low levels of competition improve stability, consistent with the *competition-stability* and *competition-fragility* hypotheses, respectively. At the same time, they find that banks facing average, or 'middle-of-the-range', levels of competition take on more risk. The amount of shareholder capital plays a crucial role in explaining this non-linear effect. In highly competitive markets shareholder capital supports stability of large banks, while in less competitive environments shareholder capital is key to discipline banks to maintain stability.

Boyd et al (2006) offer some additional insights into the driving factors underlying the competition-stability link. Using bank-level data from the US for 2003 and separately from non-industrialised countries spanning 1993 to 2004, they find that more competition (i.e., lower concentration measured by HHI assets) is associated with greater bank stability (i.e., higher Z-scores), consistent with the *competition-stability* hypothesis. They also document that the effect of competition on Z-scores is primarily driven by a positive association between concentration and volatility of return on assets, suggesting that banks reduce their asset portfolio risk as competition intensity increases.

In a cross-country analysis, Beck et al (2013) document evidence that country-level factors affect the strength of the relationship between competition and stability. Using data from 79 countries (including developed and developing economies), they regress bank-level Z-scores on the Lerner index and country-level controls. They find a positive coefficient on the Lerner index in their pooled, cross-country models (and, importantly, they find the same for regressions using data for the UK only), consistent with the franchise value paradigm and the *competition-fragility* hypothesis. They show, however, that a reduction in market power (i.e., increase in competition) has a larger impact on banks' risk-taking incentives in countries that have more strict activity restrictions, lower systemic fragility, better developed stock exchanges and more general deposit insurance. Of note, as part of their robustness checks, they test whether the relationship between competition and stability also depends on banks' relative riskiness. They argue that distressed banks have a greater incentive to exploit competition towards more aggressive risk-taking. They go on to state that their unreported results of different specifications (controlling for individual distress) show that competition has an even stronger positive relationship with bank fragility for distressed banks.

Discussed below, our study also considers possible cross-bank heterogeneity in the effects of competition on stability by conditioning on the underlying financial strength of the institution.

Using a cross-country sample of European banks spanning 1995 to 2005, Schaeck and Cihak (2014) explicitly examines for such heterogeneous effects and finds that competition, as measured by the Boone indicator, not only enhances stability, but that its effect is more pronounced for healthy banks than for fragile banks. They employ quantile regression to condition on bank stability (Z-score) and find that fragile banks at the lower tail of the distribution benefit less from competition. In other words, relatively more fragile banks, i.e., those with lower earnings, lower capital ratios and lower and more volatile earnings, are likely to find it harder to survive increases in competition (relative to more efficient banks in their study). Importantly, their results suggest that relying on a single measure of central tendency may not be adequate in assessing the impact of competition.[12] Our paper contributes to this research by employing quantile regression to test for heterogeneous effects conditioned on bank-level health, based on Z-scores. We extend this analysis to consider whether the effects also depend on (i) measures of portfolio risk and capital adequacy and (ii) the inclusion of data from the 2007-09 financial crisis.

In a single country setting, Liu and Wilson (2013) also investigate whether the relationship between competition and stability varies according to the initial risk of commercial and cooperative banks in Japan. They study a short time period between 2000 and 2009 in a dynamic set up identifying banks in different risk quantiles and interacting that classification with competition. Their baseline results, which do not account for underlying bank risk, indicate that competition lowers bank stability, supporting the *competition-fragility* hypothesis. When considering bank risk, however, they find that the effects of competition are different and, moreover, that the two competing theories of competition hold simultaneously. Competition improves the stability of banks with high initial levels of risk, consistent with the *competition-stability* hypothesis, while at the same time it weakens the stability of banks with lower initial levels of risk, consistent with the *competition-fragility* hypothesis. This study's results provide yet further impetus for our approach that considers bank risk when investigating the relationship between competition and stability. We also focus on examining the competition-stability link in a single country setting. This helps ensure consistency in measures of our dependent and independent variables and avoids having to control for potentially confounding factors that can influence the link (e.g., as documented in Beck at al., 2013).

3 Empirical approach

We investigate the link between bank stability and competition by initially estimating models of the form:

$$Stability_{i,t} = \alpha + \beta Competition_t + \Phi X_{i,t} + \Theta Y_t + \mu_i + \varepsilon_{i,t} \,, \qquad (1)$$

where $Stability_{i,t}$ is a measure of stability for bank i at time t, $Competition_t$ is the level of industry-wide competition, and $X_{i,t}$ and Y_t are vectors of bank-level and macroeconomic controls,

[12] Cummins et al. (2017) examine the competition-stability link for the European life insurance markets using quantile regression and find that the responses of insurers to competition are not homogeneous, but differ depending on the financial condition of the firm. Their results show that the soundness-enhancing effect of competition is larger for weak insurers compared with financially healthy ones.

respectively.[13] We use several different indicators as dependent variables to proxy for bank stability: the Z-score, return on assets, equity-to-assets, standard deviation of return on assets, risk-adjusted return on assets and risk-adjusted leverage ratio; and three distinct proxies for competition: the Boone indicator, Lerner index and HHI assets, all discussed in more depth below.[14] We examine the relationship between stability and competition using separate regressions for each measure of competition. Except where noted otherwise, we lag our explanatory variables by two periods (i.e., 6 months) to address potential endogeneity issues.[15] We include bank fixed effects μ_i to control for unobservable bank characteristics over time, and $\varepsilon_{i,t}$ is a random error that has a normal distribution.

Our main coefficients of interest are those associated with the degree of bank market competition, $Competition_t$. As described below, increasing values of each of our competition measures are associated with less intensive competition conditions (or, alternatively, more market power). More specifically, a higher (i.e., less negative) Boone indicator is associated with less intensive competition; a higher Lerner index is associated with greater market power; and a higher HHI is associated with greater concentration, which can be interpreted as greater market power under certain conditions. Finding a positive coefficient β in equation (1) would suggest that less competition (more market power) is associated with greater stability, which is supportive of the franchise value paradigm and consistent with the *competition-fragility* hypothesis. In contrast, finding a negative coefficient would imply that a less competitive environment (more market power) reduces bank stability, providing evidence in support of the risk-shifting paradigm (e.g., Boyd and De Nicoló, 2005) and the *competition-stability* hypothesis.

3.1 Dependent variables

To provide a direct measure of *overall* bank stability, we construct the Z-score, which is common in the literature examining the relationship between financial stability and competition (e.g., Boyd et al., 2006; Schaeck and Čihák, 2014; Ijtsma et al., 2017; Cummins et al., 2017). The Z-score is an accounting-based measure of risk calculated at the firm level as:

$$Z_{i,t} = \left(RoA_{i,t} + k_{i,t}\right) / \sigma_{i,t}^{RoA}, \tag{2}$$

where $RoA_{i,t}$ is the return on assets for deposit-taker i at time t, $k_{i,t}$ is the capital (equity to assets) ratio and $\sigma_{i,t}^{RoA}$ is the standard deviation of the return on assets. We use a four-year (16 quarter) rolling window (of annualised) returns to calculate $\sigma_{i,t}^{RoA}$, which allows for sufficient variation in the

[13] Discussed in the results section, we also evaluated the link using a quadratic competition term in equation (1) to examine for non-linear effects. While the results of this specification (discussed in Appendix B) suggest that the effects of competition on stability may be less pronounced when competition is extremely intense or when market power is extremely intense, the results were generally consistent with the competition-fragility view.

[14] We use only aggregate measures of competition and concentration in this study. While we do have a firm-level measure in the Lerner index, the use of a firm-level competition indicator in the framework shown in equation (1) is problematic. This is because both the Z score and Lerner index use individual bank measures of return on assets per period in their construction, raising possible endogeneity issues. Using the aggregate median of the Lerner index partially addresses this issue. We also employ lagged values of the median of the median Lerner index as an instrument in estimating equation (1) to address the potential endogeneity issues further. A key caveat in using an aggregated measure of the Lerner index is that we can only investigate the effect of sector-wide competition conditions, rather the market power of individual firms, on bank stability.

[15] As discussed below, formal tests for possible endogeneity of the measures of competition support this choice.

denominator and avoids the Z-score from being driven primarily by the fluctuations in the level of the return on assets and the capital ratio.

Following the literature (e.g., Laeven and Levine, 2009), we interpret the Z-score as a 'distance to default' metric, measuring the number of standard deviations a bank's return on assets has to decline to deplete its equity. In this sense, the Z-score encompasses risk across a firm's activities. A higher Z-score implies a lower probability of insolvency and hence greater stability. To deal with outliers and the highly skewed nature of the Z-scores in our sample, we use the logarithm of the Z-score in our estimations.

While the Z-score provides a measure of overall bank stability, it has an added benefit in that its constituent parts proxy for different aspects of a bank's stability that can be used to undertake a more nuanced analysis of the effects of competition, which can help in understanding whether one or both of the competing theories may explain the case for the UK. In particular, we focus on five components of the Z-score to establish whether effects on overall stability are attributable to the effects of competition: (i) profitability (i.e., $RoA_{i,t}$); (ii) capitalisation (i.e., $k_{i,t}$); (iii) volatility of profits (i.e., $\sigma_{i,t}^{RoA}$); risk-adjusted profitability (i.e., $RoA_{i,t}/\sigma_{i,t}^{RoA}$); and (v) risk-adjusted capitalisation (i.e., $k_{i,t}/\sigma_{i,t}^{RoA}$).[16] We use each component as an alternative dependent variable in equation (1) to study the effects of competition on different aspects of stability.

The coefficients on the competition indicators in specifications involving the profitability measures ($RoA_{i,t}$ and $RoA_{i,t}/\sigma_{i,t}^{RoA}$) can provide evidence on the risk-shifting effects as posited by Boyd and De Nicoló (2005). Negative values for β in equation (1) would imply that as market power increases (competition decreases), bank profitability, both on an unadjusted and risk-adjusted basis, declines, supporting the risk-shifting paradigm and the *competition-stability* hypothesis. Further, the coefficients on the competition indicators in specifications employing the two capitalisation measures ($k_{i,t}$ and $k_{i,t}/\sigma_{i,t}^{RoA}$) can provide indirect evidence on the franchise-value effect. Positive values for β would imply that as market power increases (competition decreases), bank capitalisation increases, supporting the franchise value effect and the *competition-fragility* hypothesis.

3.2 Explanatory variables

We employ three distinct measures of competition and include each in separate regressions to examine their effects on bank stability: the Boone indicator, the Lerner index and the HHI for assets. This subsection provides background on each competition measure. It also describes the bank-level and macro-economic controls used in each specification.

3.2.1 The Boone indicator

The Boone indicator measures competition from an efficiency perspective. This measure relies on the output-reallocation effect of competition: an increase in competition intensity, either as a result of an endogenous strengthening of competitive effort or from lowering of market barriers to entry, will lead to a relative increase in output of the most efficient firms in the market (Boone, 2008). As straightforward measures of efficiency are not generally available for the financial sector, the Boone

[16] Other studies have evaluated the impact of competition components of Z-scores (e.g., Beck et al., 2013 and Schaeck and Cihak, 2014 for banks; Cummins et al., 2017 for EU life insurers).

indicator is generally modelled empirically as the (time varying) elasticity of profits to average variable costs. Profits should vary more widely for any given change in variable costs when competition intensity is greater, indicated by a higher (negative) elasticity. Lower (more negative) values of the Boone indicator imply more intense competition, whereas higher (less negative) values point to less intense competition.

We modify the Boone indicator to account for the strategic behaviour of firms in building market share. In the presence of switching costs for consumers, deposit-takers can temporarily increase deposit interest rates to increase their customer base and expand their balance sheets. This strategic behaviour increases variable costs but is not related to changes in the efficiency of the firm. Consequently, without adjusting for this behaviour, estimates of the Boone indicator will be too high (less negative) than that implied by the underlying efficiency of the industry. We set out our estimation methodology in more detail in Appendix A.[17]

Figure 1A shows how the standard and adjusted Boone indicators evolved over our sample period. The indicator evolves over the period in several ways: (i) a long-term trend of falling competition over the whole period; (ii) shorter lived increases in competition of between two to four years; and (iii) high frequency increases and decreases in competition. As expected, the adjusted Boone indicator is lower than the standard estimate where firms are engaged in strategic 'market share competition', indicating that the standard measure is underestimating competition intensity where this behaviour is present. However, the distortion is generally limited to the period of the late 1990s, which is consistent with the period of consolidation and strong competition intensity identified in de-Ramon and Straughan (2016). We use the adjusted Boone indicator in our analysis.[18]

3.2.2 The Lerner index

The Lerner index is a commonly used measure of market power, computed as the ratio of the difference in the output price P and marginal cost $MC_{i,t}$ to the output price: $L_{i,t} = \left(P_{i,t} - MC_{i,t}\right)/P_{i,t}$.[19] Appendix A provides more detail on how we calculated this measure, which ranges between 0 and 1. High (low) values denote high (low) market power, which studies typically interpret as a sign of lower (higher) competition intensity. In contrast to the Boone indicator, which is estimated from the conditional mean of the data for all firms in each period, the Lerner index is derived from a total cost function estimated on a firm-by-firm basis in each period. Figure 1B shows that the median and average values of the Lerner index evolve in a similar pattern through the period, from values of around 0.07 at the beginning of the sample, to around 0.11 at the end, suggesting an overall increase in market power, consistent with a general decline in competition intensity over this period. Figure 1B also shows shorter-lived periods where competition intensified and weakened. We use the median measure of the Lerner index in our analysis, although note that (unreported) results using the average Lerner index are not materially different.

[17] We note that banks may also decide to pass on efficiency gains to customers in the form of lower loan rates as a way to build market share, but to do this they need additional funding, hence our focus on the deposit-side in making the adjustment.

[18] We also examined the link between stability and competition using the standard Boone indicator. The results (available upon request) are qualitatively similar.

[19] Output price *P* is the rate of return on assets, calculated as the sum of interest and non-interest revenue divided by total assets.

3.2.3 The Herfindahl-Hirschman Index (HHI)

Many studies examining the links between competition and stability have used the HHI as a direct measure of competition (e.g. Berger et al, 2009). The HHI is a measure of market-share concentration, with higher values reflecting more concentrated, less-competitive market conditions. However, concentration measures can be poor measures of competition (Bikker et al, 2012); the measured HHI may reflect the long-term *outcome* of competition or firms' strategic behaviour rather being indicative of the competitive behaviour itself. We use the HHI for total assets as a measure of concentration across the markets in which deposit takers compete to compare our results against past studies that rely on such measures. The HHI measure excludes non-banks markets shares which may represent an important part of some banking markets. The HHI for assets, set out in Figure 1C, shows that concentration remained broadly unchanged over the first decade of our sample, then started to rise around 2001. We also note that the HHI for total loans and deposits follow a similar path.

3.2.4 Bank-level and macroeconomic controls

We include a number of bank-level controls to account for other factors that influence bank stability.[20,21] We use bank size (log of total assets) in all of the specifications to consider the possibility that, on the one hand, larger banks may be influenced by 'too-big-to fail', moral hazard incentives. On the other hand, larger banks may also be better diversified across geographic regions and asset classes. In addition, we include the ratio of loan loss provisions to assets as a proxy for asset quality, with the idea that higher ratios reflect potentially higher credit risk. To account for business model diversification, we include the ratio of total loans to assets and the ratio of non-interest revenue to total revenue. We also include the ratio of wholesale funding to total liabilities to capture exposure to liquidity risk.

The estimation period encompasses a full economic cycle as well as periods of notable turmoil in the banking sector, including the 2007-09 financial crisis and the small banks' crisis experienced in the UK during the early 1990s.[22] To account for macroeconomic conditions, we incorporate three variables: the rates of UK real GDP growth, unemployment (lagged 4 periods) and inflation.[23] We expect bank-stability to be positively related real to GDP growth and negatively associated with unemployment.

[20] Our choice of bank-level controls is based on the literature on the determinants of bank failure and bank distress (e.g., Cole et al., 1995; Cole and White, 2012; Poghosyan and Čihák, 2011).

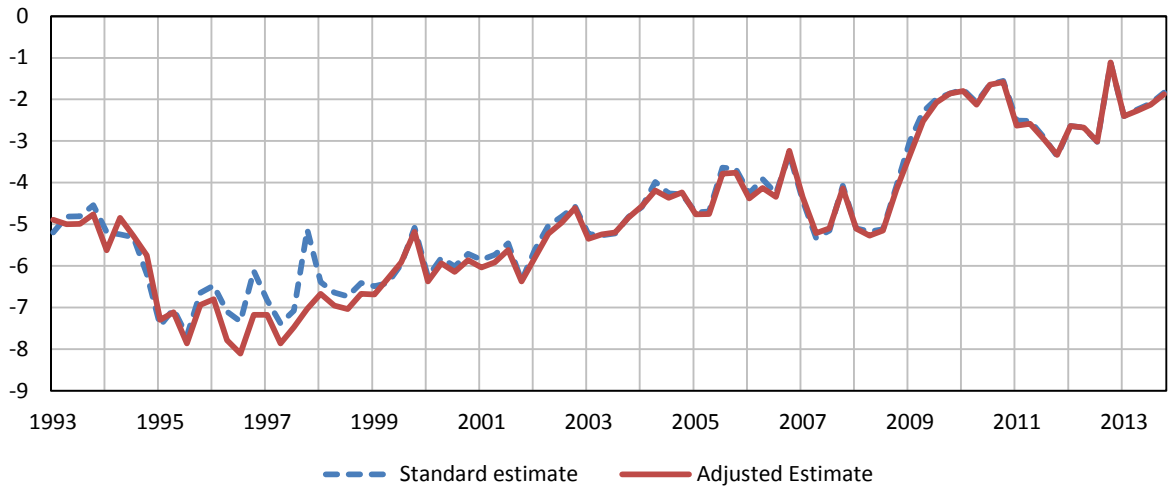
[21] We test for endogeneity of the lagged bank-level and macroeconomic controls with the Z-score due to their possible correlation via a dynamic adjustment of income sources and funding side characteristics. We find that the bank-level controls are exogenous except for non-interest revenue; we use an instrument for it consisting of two additional lags.

[22] See Balluck et al. (2016) for more detail on the UK small banks' crisis.

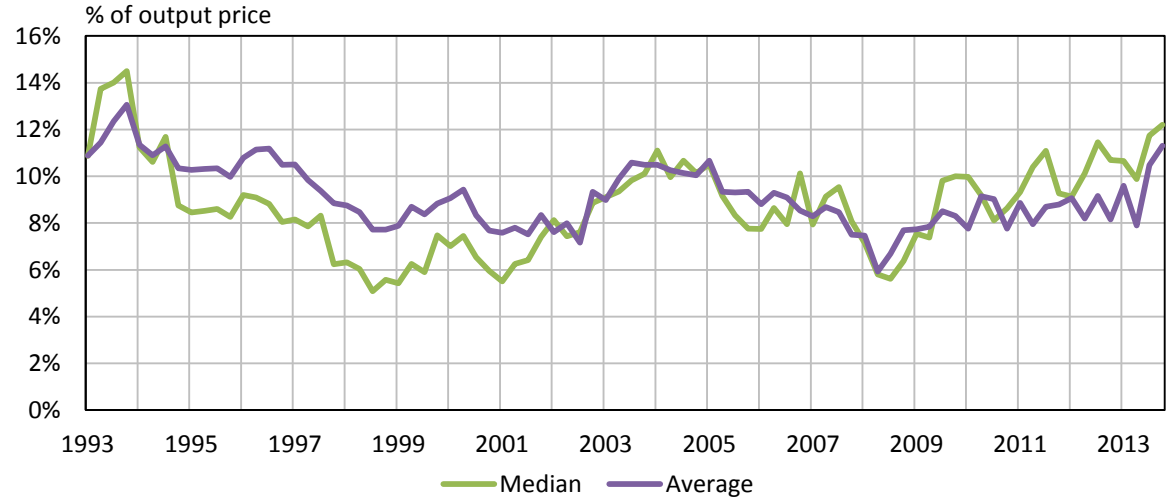
[23] Annualised real GDP growth per quarter from UK Office for National Statistics (ONS); unemployment from Labour Market statistics (ONS); and annualised inflation from consumer expenditure deflator (ONS).

Figure 1: Measures of competition and concentration used, 1993-2013

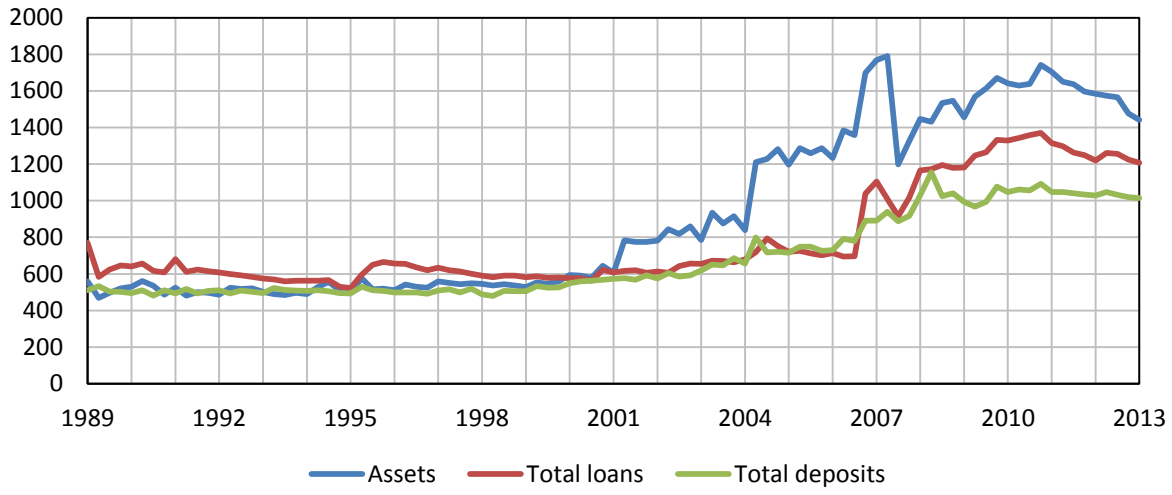
A. Boone indicator, adjusted for changes in market share



B. Median and average Lerner Index



C. Herfindahl-Hirschman Index for total assets, deposits and loans



Source: Authors' calculations

4 Data and sample selection

We construct an unbalanced panel dataset using the Bank of England's Historical Banking Regulatory Database (HBRD), which contains detailed balance sheet and income statement information assembled from regulatory reports submitted by UK regulated firms (e.g., see de-Ramon et al., 2017). Our panel dataset includes quarterly information on more than 250 firms spanning the period 1989 to 2013. The original sample includes data on UK regulated commercial banks, building societies and foreign bank subsidiaries operating in the UK.[24]

In defining the relevant banking market for this study, we focus on firms that undertake a financial intermediation role of transforming deposits into loans in the UK. This focus means that our initial sample includes a broad range of business models that tie together products and services across several financial markets including deposits, loans and payment services offered to different customers (households and businesses). Given the fungible nature of banks' funding and the ability to cross-subsidise activities across the balance sheet, measuring competition in each market would require assigning costs arbitrarily to each activity. Instead, we measure UK banking market competition at an aggregate level and identify prices and costs (or concentration) based on an overall balance sheet-based approach rather than an activity-based approach.

Because of our focus on evaluating the effects of competition on stability in the UK banking market, we employ a number of filters to ensure we capture information that is most relevant for this market. First, to capture relevant 'banking' firms, we exclude firms that do not either fund their activities significantly with deposits or use their funding to provide loans. In particular, we exclude those firms that have a loan-to-assets ratio of less than 10% and a deposit-to-assets ratio less than 20%.[25] Second, to mitigate the influence of non-UK activities, we use data reported at the individual firm level rather than the group level. This approach helps ensure we capture activity booked in the domestic UK market, and not foreign activity booked by large, UK-regulated international groups that have material exposures to non-UK markets. Finally, to reduce the influence of extreme outliers, we winsorise all firm-level variables at the top and bottom 1% tails of the distribution. Table 1 provides summary statistics for the variables used in our empirical analyses.[26] After applying the filtering rules, the total size of the sample available for panel regressions varies between approximately 12,000 and 16,500 observations.[27]

[24] Data for building societies cover a shorter timeframe, 1994 to 2013. Our sample excludes data on foreign branches operating in the UK, as we do not have the necessary financial data to estimate their Z-scores or market power.
[25] Such firms tend to be niche institutions that do not compete directly with mainstream firms in the UK banking market.
[26] For completeness, the table includes variables used in our robustness checks, detailed in Appendix B.
[27] Appendix E table E.1 presents simple pairwise correlation coefficients between the variables used in the regression. This analysis shows competition variables are significantly and positively correlated. It also shows that Z-scores are negatively correlated with the Boone indicator and Lerner index, and positively associated with HHI for assets.

Table 1
Summary statistics

Variable	Number of Obs.	Mean	Standard deviation	Median	Minimum	Maximum
Dependent Variables						
Stability measures						
Z-score	15,528	51.381	45.379	37.510	0.431	282.845
Return on assets (%)	15,466	0.683	1.437	0.483	-9.707	9.035
Equity to assets ratio (%)	16,578	12.304	12.203	7.519	0.015	192.147
Risk-adjusted capital ratio	15,528	46.338	43.028	32.829	0.708	266.316
Risk-adjusted return on assets	15,528	2.956	3.152	2.523	-3.102	17.359
Revenue mix	16,333	0.068	0.213	0.004	0.000	2.433
Explanatory Variables						
Competition/concentration indicators						
Boone Indicator (adjusted)	92	-4.897	1.719	-5.049	-8.113	-1.111
Lerner Index (median)	97	0.087	0.020	0.086	0.051	0.145
HHI assets	97	924.7	461.4	645.1	469.2	1791.6
Bank-level controls						
Bank size (Total assets) (£million)	16,628	15,485	89,409	606	0.800	1,694,721
Provisions to assets ratio (%)	16,507	1.117	2.896	0.266	0.000	34.462
Total loans to assets ratio (%)	16,468	53.293	26.948	61.886	0.000	98.216
Wholesale to total deposits ratio (%)	16,598	70.963	34.698	89.636	0.000	117.048
Non-interest revenue to total revenue (%)	16,216	19.450	21.225	12.044	-10.388	95.199
Mortgages to total loans ratio (%)	14,127	43.110	43.840	21.803	0.000	100.000
Trading book to total assets ratio (%)	12,303	3.728	14.461	0.000	0.000	96.995
Tier one capital to total assets ratio (%)	14,589	11.055	9.965	7.205	1.203	86.298
Tier one capital to total capital ratio (%)	14,481	90.961	22.649	94.840	50.273	297.026
Non-interest expense to interest received	14,567	0.427	0.530	0.278	0.012	9.286
Macroeconomic controls						
GDP growth	93	0.019	0.021	0.023	-0.060	0.047
Inflation	97	2.807	1.883	2.409	-0.314	8.158
Unemployment	87	6.863	1.727	6.365	4.684	10.618

This table reports summary statistics on variables used in the estimations examining the link between competition and stability. See Appendix D for variable definitions. All variables are derived from the Bank of England HBRD database (de-Ramon et al., 2017) except for macroeconomic controls: UK GDP growth, inflation and unemployment rates come from the UK Office for National Statistics. The database covers the period from December 1989 to December 2013 at quarterly frequency. The data used in the estimations (and reported here) are winsorised by eliminating observations that fall beyond the lowest 1% and highest 99% of the distribution.

5 Results

5.1 Baseline results

Estimates of the regressions using the log of the Z-score and the competition indicators are shown in Table 2 below. The table reports the results of estimating panel data models with bank-effects for each competition measure separately. In employing this approach, however, we recognise that there is a chance that the competition measures (in particular, the Boone indicator and Lerner index) are endogenous.[28] With respect to the Boone indicator, such endogeneity might occur if in periods of market-wide instability weaker, less-efficient institutions increase leverage and balance sheet size (potentially raising accounting RoA) in an attempt to avoid insolvency. These actions can be

[28] At least part of this concern stems from the fact that the Z-scores and the two structural competition measures are based on measures of profitability, meaning that there could be a mechanical relationship between stability and competition in our specifications. Our use of an aggregate Lerner index mitigates this issue (which is also confirmed by formal endogeneity tests discussed later).

misinterpreted as a sign of increased competition. To address this concern, we employed the lag of each competition measure in the specifications and undertook formal tests to evaluate whether these lagged measures were in fact exogenous. The endogeneity test statistic reported at the bottom of Table 2 suggests that we cannot reject the null hypothesis of exogeneity of any of our lagged competition measures.

The results show that the coefficients on the Boone indicator, the Lerner index and the HHI for total assets are all positive and significant at the 1% level, indicating a negative relationship between competition and stability.[29] While these findings are all consistent with the *competition-fragility* hypothesis, each competition measure attempts to gauge separate and distinct features of banks. The Lerner index, for example, is a measure of pricing power and, in that sense, is a proxy for current and future profits that derive from such power. As such, it fits well with the theoretical concept of banks' franchise value. The HHI is also commonly used as an alternative proxy for market power in the literature and we use it in that context. The positive coefficients on the Lerner index and HHI suggest that heightened market power improves overall bank stability. This result lends support to the franchise value paradigm and is consistent with the *competition-fragility* hypothesis more broadly. The Boone indicator, on the other hand, is a measure that captures a reallocation effect of profits from the least to the most efficient banks as competition intensifies. In this respect, it better reflects aspects of efficiency in the relevant banking market.[30] The positive coefficient on the Boone indicator is more suggestive of the idea that less competition, which implies a reduced reallocation effect, bolsters bank stability overall. We explore these relationships and the factors that drive each in more detail below.

The sign of the coefficients for the macroeconomic and bank-level controls are consistent across all measures and generally in the direction expected. Firm stability increases as inflation and unemployment rates fall and as economic growth increases. At the firm level, less reliance on relatively more volatile (less liquid) wholesale deposit funding is associated with improvements in stability. Bank-level stability is lower at larger institutions and at institutions with higher measures of credit risk (provisions to assets) and higher sources of non-interest revenue. While the total loans to assets ratio is insignificant, excluding this control does not materially change the regression coefficients or significance and is included for completeness.

[29] Recall that for all competition measures, increases in each measure are associated with less competition.

[30] Schaeck and Cihak (2014) discuss the link between competition and efficiency in more detail. Their results also suggest that efficiency is the conduit through which competition contributes to stability.

Table 2
Regressions of ln(Z-score) on competition, macroeconomic and bank-level characteristics

Dependent variable: ln(Z-score)	Boone Indicator (adjusted)	Lerner Index (median)	HHI (assets)
Competition indicator	0.0171***	2.0902***	0.0740***
	(0.0050)	(0.3690)	(0.0250)
Macroeconomic controls			
GDP growth	2.8482***	2.3986***	2.9251***
	(0.3420)	(0.3400)	(0.3480)
Inflation	-0.0256***	-0.0270***	-0.0330***
	(0.0060)	(0.0060)	(0.0060)
Unemployment rate	-0.0969***	-0.1053***	-0.0923***
	(0.0050)	(0.0050)	(0.0050)
Bank-level controls			
Non-interest revenue to total revenue	-0.0118***	-0.0118***	-0.0118***
	(0.0010)	(0.0010)	(0.0010)
Bank Size	-0.0767***	-0.0664***	-0.0795***
	(0.0180)	(0.0150)	(0.0190)
Provisions to assets ratio	-2.2289***	-2.4260***	-2.1849***
	(0.5150)	(0.5180)	(0.5140)
Total loans to assets ratio	-0.0096	0.0086	-0.0061
	(0.0760)	(0.0760)	(0.0760)
Wholesale to total deposits ratio	-0.1844***	-0.1865***	-0.1851***
	(0.0550)	(0.0550)	(0.0550)
Number of observations	12,124	12,124	12,124
R-square overall	0.0856	0.0873	0.0857
Endogeneity test statistic of competition (p-value)	0.1520	0.6147	0.6279

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z-score for firm *i* at quarter *t*. We estimate Equation (1) separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The endogeneity test statistics reported do not reject the null that the corresponding competition measures are exogenous. ***, **, * means significant at the 1%, 5% and 10% level, respectively. Standard errors are in parenthesis.

To get a sense of the economic significance of competition on stability, we calculated the extent to which competition influences the Z-score using the marginal impact of each competition measure estimated in the regressions in Table 2 and the competition trends of Figures 1A to 1C.[31] In particular, we undertook a simple experiment and assumed that competition increases from the low levels evident after the crisis in early 2010 to the higher levels characterising the early 1990s. Under this scenario, the Boone indicator would fall from -2.3 to -6.3, the Lerner index from 10.1% to 7.5%, and the HHI from 1600 to 522. Such increases in competition would reduce Z-scores by, on average, 6% (based on the Lerner index), 7% (based on the Boone indicator) and 8% (based on the HHI). While for the few firms close to insolvency already (i.e., with Z-scores close to 0) such increase in competition may imply more material effects, the economic significance of an increase on bank stability appears relatively modest in general.

[31] The marginal impact of the competition measure on the Z-score is calculated from the estimated regressions as $(\partial \ln Z)/\partial C = (1/\bar{Z}\,).(\partial Z/\partial C) = \beta \Leftrightarrow \partial Z/\partial C = \beta \bar{Z}$ where Z is the Z-score, $\bar{Z}$ is the average of the Z-score, C is the competition measure and β is the coefficient on the competition measure.

We also decompose the Z-score into its constituent elements, i.e., the return on assets, $RoA_{i,t}$; the capital ratio, $k_{i,t}$; and the standard deviation of the return on assets, $\sigma_{i,t}^{RoA}$, and examine how competition affects each as a step towards understanding the main drivers behind the negative association between competition and stability overall. Table 3 summarises results from this analysis. The results from the return on assets analysis show that the coefficients on all competition measures are negative and statistically significant, indicating that competition positively affects profitability. The results with respect to the Lerner index and HHI suggest that reductions in market power improve profitability, which is more consistent with the risk-shifting view of Boyd and De Nicolo (2005) and with the *competition-stability* hypothesis. The finding with respect to the Boone indicator suggests that more competition fosters efficiency in banking markets (i.e., increases the market disciplining effects and incentives to reduce costs), thereby improving profitability overall, which is also supportive of the *competition-stability* hypothesis.

When looking at the results for capitalisation ratios, we find that the coefficients are all positive and statistically significant, indicating that more competition (less market power) may encourage banks to hold less capital. These findings provide support for the franchise value paradigm and are consistent with the *competition-fragility* hypothesis. The impacts on capital ratios appear to be driving the lower Z-scores in the face of heightened competition.

The outcome for asset return volatility is mixed. The coefficients on the Boone indicator and HHI for assets show that greater competition intensity and reduced concentration reduce volatility, which is more consistent with the *competition-stability* hypothesis. The negative sign on the coefficient of the Lerner index, however, suggests that reductions in market power (more competition) increase volatility. This association aligns better with the franchise value paradigm and the idea that banks increase asset risk as a way of offsetting the loss of valuable franchises under heightened competition, which is consistent with the *competition-fragility* hypothesis.

To evaluate these contrasting results and shed more light on the underlying drivers of bank-level stability, we disaggregate the Z-score into two additive components: $RoA_{i,t}/\sigma_{i,t}^{RoA}$ and $k_{i,t}/\sigma_{i,t}^{RoA}$.[32] The first component measures risk-adjusted asset returns, a proxy typically used by analysts to gauge a bank's overall asset portfolio risk. Similarly, the second component represents the standardised risk-adjusted capitalisation of a bank. Higher (lower) values of either component correspond with lower (higher) risk. The final two rows in Table 3 provide evidence of the effects of competition on these two parts of the Z-score. The negative and statistically significant coefficients on the risk-adjusted asset returns indicate that competition reduces asset portfolio risk. The results for the Lerner and HHI specifications indicate that market power worsens asset portfolio risk, providing further support for the risk-shifting paradigm and the *competition-stability* hypothesis. The finding for the specification that includes the Boone indicator suggests that competition encourages efficiencies that improve risk-adjusted returns, consistent with the *competition-stability* hypothesis. When looking at the risk-adjusted capital ratio, we see that coefficients are all positive and statistically significant. This result suggests that less competition (more market power) encourages banks to hold higher risk-adjusted capitalization ratios, which is overall more consistent with the *competition-fragility* hypothesis.

[32] Cummins et al., (2017) undertake similar analysis in their review of the effects of competition on stability in the European life insurance markets.

Table 3
Regressions of alternative stability measures on competition measures

	Boone indicator (adjusted)	Lerner Index (median)	HHI (assets)
Dependent Variables:			
ln(Z-score)	0.0171***	2.0902***	0.0740***
	(0.0050)	(0.3690)	(0.0250)
Return on assets ($RoA_{i,t}$)	-0.1013***	-2.8177***	-0.3992***
	(0.0090)	(0.5420)	(0.0380)
Capital Ratio ($k_{i,t}$)	0.6639***	15.4240***	3.0963***
	(0.0520)	(2.9360)	(0.2570)
Asset return volatility ($\sigma_{i,t}^{A}$)	0.0326***	-1.2906***	0.1548***
	(0.0090)	(0.4690)	(0.0400)
Risk adjusted asset returns ($RoA_{i,t}/\sigma_{i,t}^{A}$)	-0.2885***	-7.4497***	-1.2955***
	(0.0180)	(1.5000)	(0.0850)
Risk adjusted capital ratio ($k_{i,t}/\sigma_{i,t}^{A}$)	2.1889***	178.7400***	9.4712***
	(0.2460)	(18.0290)	(1.1960)

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z-score (top row) for firm *i* at quarter *t*, the component of the Z-score (i.e., return on assets, $RoA_{i,t}$, capital Ratio, $k_{i,t}$, or asset return volatility, $\sigma_{i,t}^{A}$), and the additive ratios terms of the Z-score (risk-adjusted asset returns, $RoA_{i,t}/\sigma_{i,t}^{A}$, or the risk-adjusted capital ratio, $k_{i,t}/\sigma_{i,t}^{A}$). We estimate Equation (1) separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included and are lagged two periods (with the exception of unemployment which is lagged 4 periods). All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. ***, **, * means significant at the 1%, 5% and 10% level, respectively. Standard errors are in parenthesis.

To sum up, these outcomes outline two opposing influences on firm stability: greater competition supports firm profitability, but induces lower capital ratios. The tension between these two factors is reinforced by the results of the regressions using the two additive components of the Z-score, i.e., the risk-adjusted asset return and the risk-adjusted capital ratio. Greater competition is associated with improvements in risk-adjusted returns (negative coefficient), but also with lower risk-adjusted capital ratios (positive coefficient), or higher leverage. For the average Z-score, the negative influence of competition on firm leverage has a greater impact on overall firm stability than the positive influence on firm portfolio risk.

5.2 Robustness checks

We subject the above findings to a number of robustness tests. Overall, the additional results show that our primary finding that competition increases the risk of individual UK banking institutions is robust to: using alternative definitions of markets (i.e., deposits and loans); employing different measures of bank-level risk (i.e., revenue mix and leverage ratio); controlling for firm ownership and firm size; and excluding periods of economic turbulence from our estimation sample. Annex B discusses these results in more detail.

Our baseline results above assume a homogeneous relationship between competition and bank stability. While we include firm fixed effects to control for differences in stability that can arise from unobserved firm-level features, the strength of the association between stability and competition may also depend on such features or the relative position of firms within the market. If this is the

case, then the full-sample, average relationship reported above could potentially hide a substantial amount of cross-bank heterogeneity.

5.3 Testing for heterogeneous effects

Beck et al. (2013) provide some initial evidence indicating that the effects of competition on banks risk-taking incentives may indeed depend on the relative health of the banks in the market. In discussing robustness checks of their findings of the effect of competition on stability, they posit that distressed banks have greater incentives to exploit competition towards more aggressive risk-taking (e.g., as a way of gambling for resurrection). They test this idea formally using various specifications that control for individual bank distress and find that competition has an even stronger positive relationship with bank fragility for distressed banks. The implication here is that the effects of competition may be more pronounced for less stable banks; and, therefore, it may be important to consider this aspect when examining the relationship between competition and stability.

Using quantile regression techniques, Schaeck and Cihak (2014) investigate this issue directly for a sample of European banks. Cummins et al. (2014) follow a similar approach and test this idea for a sample of European life insurers. Both studies provide evidence showing that the effects of competition are not homogeneous across firms, but importantly depend on the underlying financial health of the institutions, as measured by Z-scores.

For these reasons, we take a more circumspect view about drawing conclusions based merely on the average associations reported earlier and undertake additional analysis that looks more closely at whether the effect of competition on stability depends on the financial condition of UK banks. We are interested in understanding if relatively less stable banks react to competition differently from more stable banks (i.e., those with higher Z-scores). To examine this issue, we also use quantile regression which allows us to shed additional light on the effect of competition conditional on the distribution of the Z-score. This feature facilitates a more complete picture of the underlying relationship between firms with different Z-scores.[33]

Table 4 presents the quantile regression results. The table reports coefficients on each of our three competition measures for several quantiles (i.e., percentiles ranging from the 5^{th} to 95^{th}) of the distributions of Z-scores (columns 1 to 3) and each additive part of the Z-score, i.e., the risk-adjusted RoA (columns 4 to 6) and risk-adjusted capital ratio (column 7 to 9).[34] The equations for each quantile are estimated using bootstrap methods for the variance-covariance matrix of the estimators, which allows us to test formally whether coefficients on competition differ significantly across quantiles. We use F-tests to determine whether coefficients on competition are equal across quantiles.

With respect to the analysis of Z-scores, two things stand out. First, F-tests reject the null hypothesis of equality across all percentiles for each specification, providing evidence of heterogeneous responses to competition. The key implication here is that the effects of competition

[33] We extend the analysis to consider the impacts on the components of the Z-score, i.e., risk-adjusted returns and risk-adjusted capital ratios, to provide initial insight into the underlying drivers of the disparate response to competition. This extension is a contribution of our study.

[34] Table C.1 in Annex C reports more details on each specification using quantile regression and shows that macroeconomic and firm-level controls for all equations generally behave in line with expectations and the conditional mean results discussed earlier.

on stability may differ depending on the health of individual institutions within the banking markets. Second, we observe that the coefficients increase across the percentiles, and, moreover, that they switch from being non-positive to positive at around the 25th percentile in all cases. Indeed, the negative and statistically significant coefficients on the Boone indicator (column 2) and Lerner index (column 3) for the relatively least stable firms (i.e., those in the 25th percentile or below of Z-scores) suggest that less competition (more market power) worsens the stability of these firms, consistent with the *competition-stability* hypothesis. This result contrasts with the effects of competition on the most stable firms, i.e., those in the 40th percentile or higher. For these firms, the coefficients are positive, indicating that less competition (more market power) increases stability, consistent with the *competition-fragility* hypothesis and, therefore, with the conditional mean results reported earlier. These results are consistent with Liu and Wilson (2013) who find that the strength of the relationship between competition and stability of Japanese commercial and cooperative banks varies across initial levels of risk. They find that competition improves stability of the weakest banks in Japan, while at the same time it reduces stability of heathier banks. We build on this work to try to understand these findings by looking at the two additive components of the Z-score.

To explore the factors driving these contrasting outcomes in more detail, we estimated the relationship for the two additive components of the Z-score. Table 4 reports the results for the risk-adjusted return on assets (columns 4 to 6) and the risk-adjusted capital ratio (columns 7 to 9) using quantile regression. F-tests reject the null hypothesis of equality of coefficients across quantiles for each of the additive measures, suggesting that banks' responses to competition are different.

For the analysis of risk-adjusted returns (reported in columns 4 to 6), we observe that the coefficients on competition are consistently negative (and statistically significant) across all quantiles, suggesting that less competition (more market power) reduces risk-adjusted returns for all banks. The negative association is consistent with an outcome implied by mechanisms underlying Boyd and De Nicolo (2005): less competition (more market power) increases the credit risk of bank borrowers, which leads to higher losses and lower earnings overall. This result aligns better with the *competition-stability* hypothesis and with the results based on the unconditional results reported earlier. While F-tests reject the equality of coefficients across quantiles, it is not obvious from a review of these coefficients that the effects of competition depend in a systematic way on the relative profitability of the banks. Still, Figure 2 suggests that the stability-enhancing effects of competition may be most pronounced at banks with the relatively highest risk-adjusted returns in the market, i.e., those in the 90^{th} percentile and above. The F-tests rejecting the equality of coefficients across quantiles confirms this effect.

With respect to the analysis of risk-adjusted capital ratios (reported in columns 7 to 9), we find evidence supporting the idea that banks' responses to competition depend on the relative strength of their risk-adjusted capital ratios. Moreover, the results show a break in sign on the coefficients, indicating that competition can both enhance and weaken stability depending on the underlying capital position of a bank. In particular, the results suggest that less competition (more market power) reduces incentives for banks with relatively low risk-adjusted capital ratios, i.e., those in the 20^{th} percentile or lower where the sign on the coefficient is negative, to hold higher capital ratios. The intuition underlying this result is that when market power increases, banks with higher risk of insolvency (i.e., those with weak capital ratios) may decide to dial up risk, e.g., by increasing leverage or variance of returns, in an attempt to exploit market power and gamble for resurrection. The idea

that banks increase leverage (i.e., use less equity to support lending) in the face of lower competition is consistent with Allen et al. (2011) who show that banks prefer to rely on monitoring directly rather than use equity to signal monitoring of loans. Overall, the negative sign on the coefficients of competition for this cohort of banks is consistent with the *competition-stability* hypothesis.

When looking at the coefficient for banks with relatively stronger risk-adjusted capital ratios, we find that the relationship changes. The coefficients on competition for banks with strong capital position, i.e., those in the 40th percentile and above, are all positive and statistically significant, suggesting that less competition (more market power) increases incentives for these banks to hold higher capital ratios. This result is supportive of the franchise value paradigm and consistent with the *competition-fragility* hypothesis. This can arise if banks hold higher capital to reduce the likelihood of insolvency and the loss of valuable franchises.

Together, the results with respect to risk-adjusted returns and risk-adjusted capital ratios suggest that the driving force behind the heterogeneous responses of the Z-score may derive, in part, from greater incentives of weaker banks' to increase leverage (hold less equity) or increase asset risk (increase standard deviation of return on assets) in an attempt to exploit less competitive conditions (more market power) as a way of gambling for resurrection. For these institutions, competition may actually be more effective in strengthening market discipline and boosting incentives to lower costs, improve operational efficiency and raise capital ratios, all of which contributes to higher overall stability, consistent with *competition-stability*. For relatively stronger banks, competition reduces incentives to build capital ratios, largely explaining why the *competition-fragility* hypothesis holds for such firms.

Figure 2 illustrates these effects. It shows that coefficients on all three measures of competition are uniformly negative (and statistically significant) across all quantiles for the analysis of risk-adjusted return on assets (RoA/σ). More competition is unambiguously associated with higher risk-adjusted returns (charts b.i., b.ii. and b.iii.). In contrast, the coefficients on competition for the specification examining the risk-adjusted capital ratio (k/σ) reflect the pattern shown for the Z-score overall. In particular, for the weakest institutions, more intense competition is associated with higher capital ratios, but the relationship switches for healthier institutions (charts c.i., c.ii. and c.iii). The charts also show that the quantile estimates are statistically different from the conditional mean estimates (depicted by the dashed line) across a broad range of Z-score percentiles.

Together, these findings imply not only that the effects of competition on stability may differ depending on the health of individual institutions, but also that the effects of competition on stability can be countervailing within banking markets. Such offsetting effects mean there may be trade-offs to weigh, especially on overall system-wide stability, when considering policies aimed at affecting competition. To our knowledge, this latter finding has not been documented in previous empirical studies investigating the competition-stability link.[35]

[35] We subject the quantile regression findings to a number of robustness tests; Appendix B discusses them in more detail. Overall, the additional tests confirm the evidence of heterogeneous responses to competition and of an increasing pattern in the coefficients on competition, moving from negative, at the lowest quantiles to positive in the higher quantiles.

Table 4

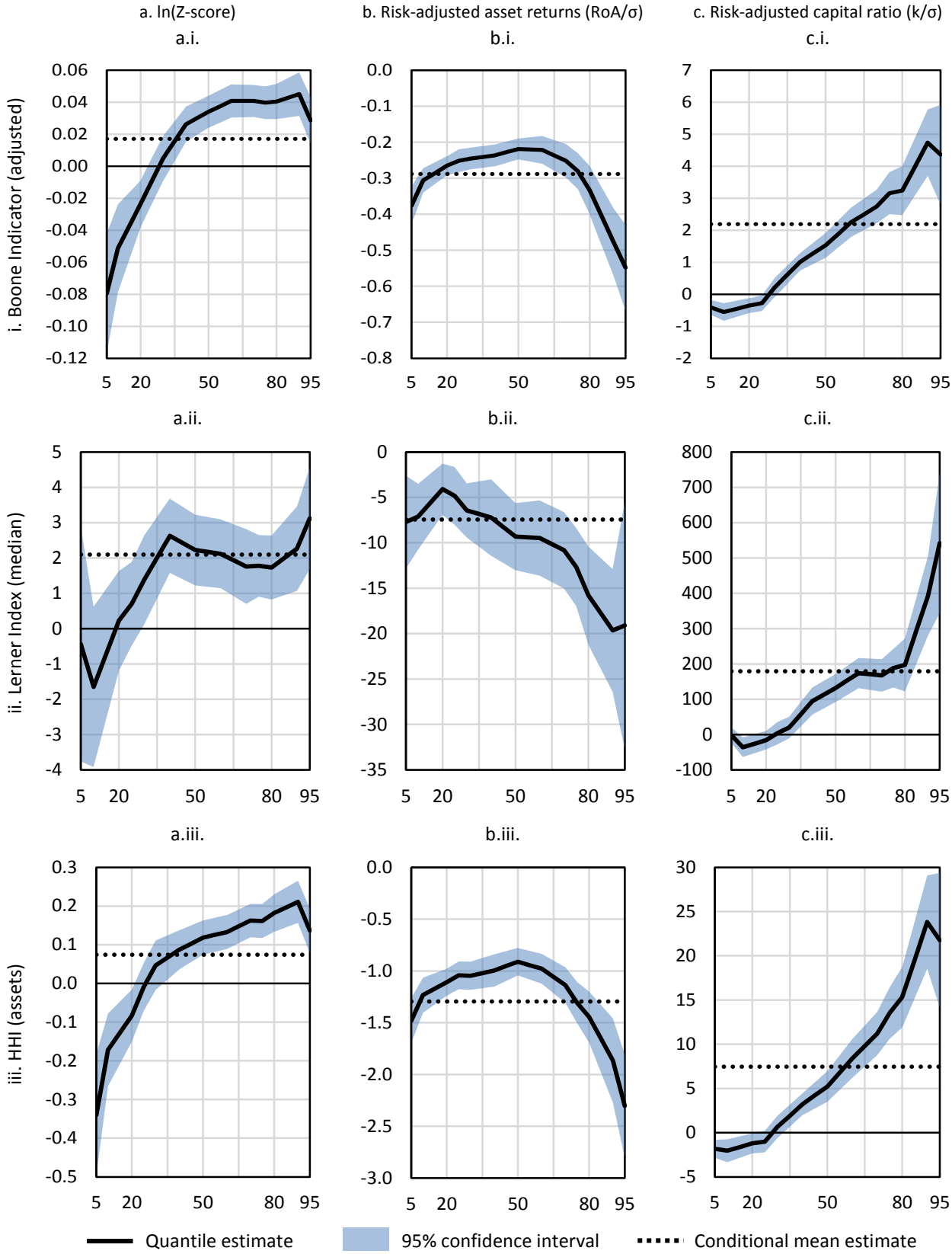
Selected outcomes from quantile regression of ln(Z-score), return on assets (risk-adjusted) and capital ratio (risk-adjusted) on competition measures, macroeconomic and firm-level controls

Dependent variable:	ln(Z-score)			RoA/σ			Capital ratio/σ		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Competition Measure:	Boone indicator (adjusted)	Lerner Index (median)	HHI (assets)	Boone indicator (adjusted)	Lerner Index (median)	HHI (assets)	Boone indicator (adjusted)	Lerner Index (median)	HHI (assets)
Percentile:									
5	-0.080***	-0.440	-0.340***	-0.377***	-7.720***	-1.482***	-0.409***	-1.830	-1.824***
	(0.02)	(1.66)	(0.08)	(0.03)	(2.55)	(0.11)	(0.11)	(11.1)	(0.51)
10	-0.051***	-1.650	-0.171***	-0.306***	-7.121***	-1.234***	-0.555***	-36.14***	-2.046***
	(0.01)	(1.14)	(0.05)	(0.02)	(1.81)	(0.08)	(0.14)	(13.9)	(0.65)
20	-0.024***	0.222	-0.084**	-0.265***	-4.100***	-1.109***	-0.357***	-16.26	-1.208**
	(0.01)	(0.70)	(0.03)	(0.01)	(1.41)	(0.07)	(0.12)	(13.1)	(0.57)
25	-0.009	0.701	-0.009	-0.251***	-4.844***	-1.043***	-0.279**	3.817	-1.013*
	(0.01)	(0.59)	(0.03)	(0.02)	(1.59)	(0.07)	(0.12)	(15.8)	(0.61)
30	0.005	1.386**	0.047	-0.245***	-6.439***	-1.047***	0.211	19.55	0.634
	(0.01)	(0.63)	(0.03)	(0.02)	(1.49)	(0.07)	(0.15)	(15.3)	(0.63)
40	0.026***	2.626***	0.087***	-0.237***	-7.223***	-0.996***	1.013***	94.45***	3.197***
	(0.01)	(0.53)	(0.03)	(0.02)	(2.10)	(0.08)	(0.14)	(19.2)	(0.62)
50	0.034***	2.222***	0.119***	-0.219***	-9.322***	-0.911***	1.528***	131.4***	5.216***
	(0.01)	(0.50)	(0.02)	(0.01)	(1.85)	(0.07)	(0.19)	(19.9)	(0.86)
60	0.041***	2.117***	0.133***	-0.221***	-9.482***	-0.979***	2.249***	173.7***	8.386***
	(0.01)	(0.49)	(0.02)	(0.02)	(2.07)	(0.07)	(0.23)	(21.3)	(1.10)
70	0.041***	1.758***	0.162***	-0.252***	-10.83***	-1.137***	2.742***	167.3***	11.21***
	(0.01)	(0.53)	(0.02)	(0.02)	(2.10)	(0.09)	(0.26)	(23.0)	(1.22)
75	0.040***	1.774***	0.161***	-0.281***	-12.67***	-1.308***	3.156***	187.6***	13.54***
	(0.01)	(0.44)	(0.02)	(0.02)	(2.15)	(0.10)	(0.33)	(27.3)	(1.46)
80	0.040***	1.727***	0.182***	-0.334***	-15.79***	-1.446***	3.235***	196.8***	15.31***
	(0.01)	(0.45)	(0.02)	(0.03)	(2.69)	(0.12)	(0.38)	(37.4)	(1.71)
90	0.045***	2.262***	0.211***	-0.478***	-19.66***	-1.864***	4.732***	392.8***	23.81***
	(0.01)	(0.60)	(0.03)	(0.05)	(3.38)	(0.20)	(0.52)	(56.4)	(2.64)
95	0.029***	3.118***	0.136***	-0.548***	-19.12***	-2.305***	4.361***	541.9***	21.76***
	(0.01)	(0.72)	(0.03)	(0.06)	(6.79)	(0.25)	(0.78)	(99.2)	(3.80)
F-stat (equality of all coefficients)	9.42***	2.63***	7.54***	8.13***	2.65***	5.38***	23.58***	11.02***	14.93***

This table reports the results from applying quantile regression on Equation (1), where the dependent variables are the natural log of the Z-score and its additive parts: risk adjusted return on assets and capital ratio (RoA/σ and k/σ) for firm *i* at quarter *t* separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. Each model estimates results for each quantile based on all banks in the sample and the full estimation sample timeframe 1994 to 2013. All explanatory variables enter with two lags except of unemployment that enters with four lags. Standard errors, reported in parentheses for each coefficient, are estimated using bootstrap procedures and are consistent across all quantiles. Each model presents the point estimate with the standard error underneath in parentheses. All variables are lagged by 2 quarters. The F-stat reported is for the null hypothesis that all estimated coefficients are equal. ***, **, * indicate significance at 1%, 5% and 10% levels, respectively.

Figure 2

Marginal Impact of Competition Measures on Percentiles of Measures of Risk



Each chart shows the estimated coefficients on the competition measure (vertical axis) from the regression with each percentile of the risk measure (horizontal axis) as the dependent variable and macroeconomic and bank level controls. The conditional mean estimates, represented by the dotted line, are independent of the quantiles of the Z-score.

6 Conclusions

This study contributes to the ongoing debate about the effects of competition on bank stability. Theories on this issue suggest competing effects. Under the *competition-fragility* hypothesis, competition erodes market power, reduces interest margins, and, in turn, lowers bank franchise values. This result encourages banks to take on more risk to increase returns, thus lowering stability. Under the alternative *competition-stability* hypothesis, more competition (i.e., lower market power) in credit markets lowers loan rates and improves borrowers' ability to repay loans, and mitigates moral hazard and adverse selection problems associate with higher lending rates. This result leads to better overall stability. Empirical studies provide varying degrees of support for each theory.

We document evidence that these hypothesized effects need not be mutually exclusive, but may hold simultaneously, implying trade-offs for stability. Using a proprietary dataset covering all commercial banks, building societies and foreign bank subsidiaries in the UK, we construct three distinct measures of competition over the period 1989 to 2013 for the UK: the Boone indicator, Lerner index and HHI for assets. We then use each separately to examine the relationship between competition and the stability of individual banking firms, as measure by bank-level Z-scores.

Our investigation of the relationship between competition and stability reveals, on average, a negative link between the two: higher levels of competition are found to decrease bank-level stability, consistent with the *competition-fragility* hypothesis. Although we find a statistically significant negative association between competition and stability, the economic significance of the impact of competition appears relatively modest. Supplemental analyses examining the effects of competition on components of Z-scores offer some evidence in support of both theories. We find that bank profitability increases in the face of mounting competition, which squares better with the 'risk-shifting' paradigm and with the *competition-stability* hypothesis. At the same time, we find that bank capital ratios fall as competition increases, which is more supportive of the franchise value paradigm and the *competition-fragility* hypothesis. Consequently, the overall net negative effect of competition on bank stability appears to be driven by incentives to hold lower capital ratios.

While it appears as though the franchise value paradigm dominates the risk-shifting paradigm, thus supporting the *competition-fragility* hypothesis on average, these effects are not homogeneous across financially weak and financially healthy banks. Our quantile regression results indicate that competition has notably different -- including potentially favourable -- effects on stability depending on the underlying financial strength of a bank. We find evidence showing that financially weak banks (i.e., those with the lowest Z-scores) benefit from greater levels of competition intensity. For these institutions, we observe that bank profitability and capital increase as a result of accelerating competition, consistent with the *competition-stability* hypothesis.

Our results provide some potentially useful insights for policymakers tasked with developing policies aimed at supporting effective competition in banking markets. First, while we find evidence suggesting that competition may lower bank stability, the economic significance of such effects is modest overall. Second, our quantile regression results suggest that facilitating effective competition may actually drive improvements in the stability of those firms that are already closer to default, but lower the stability of relatively safe firms. Together, these results suggest that there may be trade-offs to consider when weighing the effects of competition on system-wide stability.

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Appendix A: Constructing measures of competition

This appendix describes in more detail the three measures of competition used in this study and how we estimated each of them. The measures are constructed from balance sheet, income and expenditure data reported by individual (i.e., non-group) banking entities (commercial banks and building societies) operating in the United Kingdom that are authorised and directly regulated by the UK Prudential Regulation Authority. Non-group data represent more closely activities undertaken within the domestic UK banking markets. We also include UK incorporated subsidiaries of international banks operating in the UK loan and deposit markets.

The Boone Indicator

The Boone indicator measures competition from an efficiency perspective. The measure relies on the output-reallocation effect: any increase (decrease) in competition intensity will lead to a relative increase (decrease) in output by the most efficient firms (e.g., see de-Ramon and Straughan, 2016 for more detail). Typically for the deposit-taking sector, output is proxied by a measure of variable profits, and efficiency is proxied by a measure of average variable costs. The Boone indicator is estimated as the time-varying coefficient on the (log of) average variable cost from an equation with variable profit as the dependent variable and average variable cost as a regressor, after controlling for other factors that influence variable profits. The estimated coefficient on the average cost is effectively a measure of the elasticity of variable profits to average variable cost. The estimated equation is of the form:

$$\pi_{i,t} = \alpha_t + \beta_t \ln\left(c_{i,t}\right) + \Phi X_{i,t} + \eta_{i,t} \,, \tag{A.1}$$

where $\pi_{i,t}$ is variable profits for firm i and time t, $c_{i,t}$ is average variable costs, $X_{i,t}$ are other control variables and $\eta_{i,t}$ is the error term. The Boone indicator is given by β_t, which is estimated for each time period t using interactions between average variable costs and a time-fixed effects dummy variable.

To estimate A.1, we measure variable profits as the ratio of total revenue less variable costs (i.e., interest paid, staff expenditure, other variable costs including occupancy) to total assets. Average variable costs are measured as variable costs scaled by variable revenue derived directly from current activity (i.e., interest received, foreign exchange receipts, investment income, fees and other charges). We use a number of bank-level variables common in the literature in addition to variable profit and average variable cost as a control for heterogeneity in firm's business models. These control variables include average risk on balance sheet, provisions, Tier 1 capital, the loans-to-assets ratio, the proportion of retail funding, other non-interest earning assets and balance sheet size. To eliminate the effects of outliers, we winsorise all variables at the first and 99th percentiles.

One issue to address with the estimation is the co-variance of the deposit-to-assets ratio and other bank controls with the measure of average variable cost. Firms' deposit-to-assets ratios are raised by increasing variable funding costs (through higher deposit interest rates), which also influences average variable cost. Moreover, average variable costs will be influenced by the structure of firms' balance sheets included in the bank-level controls. To address any potential endogeneity between average variable cost, the deposit-to-assets ratio and the other controls, we include one-quarter-lagged average variable cost as an instrument and use a two-stage least squares

process to estimate the two series. As we use average variable cost as a proxy for the efficiency of a firm, the Boone indicator in this case will be negative (higher costs / efficiency reduce profits / output) and bounded by zero, with competition intensity diminishing as the Boone indicator approaches zero.

We also consider an extension to the standard estimate of the Boone indicator to take account of the 'competition for market share' phenomenon which tends to distort the measure of competition. The modification is based on insights from Klemperer (1995) which looks at the implications for firm profits in the presence of customer switching costs. Customers for bank deposits from the UK deposit-taking sector are 'sticky' which is consistent with the presence of switching costs for consumers. If the market for deposit takers has switching costs, firms have two strategies: one is to raise deposit interest rates now (i.e. increase variable costs) to attract additional customers that increase future profits; the other is to maximise profits from existing customers (and risk losing them in future to other banks). The first strategy distorts the measurement of competition as the firm's average variable cost rises although the efficiency of the firm may not have changed – hence the Boone indicator will suggest that competition is weaker (the Boone indicator is less negative) than efficiency would imply.

The strategy any firm takes will depend on which actions maximise the value of both current and future profits: $V_t = \pi_t + \delta V_{t+1}(\sigma_t)$ where V_t is the total value of current (time t) profits (π_t) and discounted future profits (δV_{t+1}), and where future profits depend positively on *current* market share (σ_t). Rearranging, we note that current profit π_t is a negative function of the change in market share: $\pi_t = \delta V_{t+1}(\sigma_t) - V_t(\sigma_{t-1}) \approx f(-\Delta\sigma_t)$ where $\Delta\sigma_t$ is the change in market share. Subsequently, we add the change in the deposits-to-assets ratio for each firm as a proxy for the change in market share when estimating the adjusted Boone indicator, β_t^a:

$$\pi_{i,t} = \alpha_t + \beta_t^a \ln(c_{i,t}) + \Phi X_{i,t} + \sum_{j=0}^{4} \gamma \Delta d_{i,t-j} + \eta_{i,t} \,. \qquad \text{(A.2)}$$

The addition of this control does not violate any of the conditions for the Boone indicator to be a sufficient measure of competition, as set out in Boone (2008). We expect that the coefficient on the change in the deposits-to-assets ratio to be negative in our estimated equation, providing a test as to whether the adjustment is valid.

The Lerner index

The Lerner index measures the price-cost margin for individual firms over time and a central tendency measure (the average or median) across all firms in a market or industry is used as a proxy for market power and competition. The values of the index reflect theoretical outcomes from the competitive process: under perfect competition the index is zero as the output price (marginal revenue) equals marginal cost, and economic profits are zero. The Lerner index is positive as a firm's market power increase and price rises above marginal cost in a Cournot static (quantity-setting) oligopoly model.

We follow a well-established approach to estimating the index (e.g., Berger et al., 2009; Fernández de Guevara, 2007). The Lerner index ($L_{i,t}$) is computed as the ratio of the difference in the output price (P) and marginal cost ($MC_{i,t}$) to the output price: $L_{i,t} = \left(P_{i,t} - MC_{i,t}\right)/P_{i,t}$. The output price is calculated as interest and non-interest revenue per unit of total output (proxied by

total assets). The marginal cost $MC_{i,t}$ is not directly observable, either for the firm or for a particular product supplied by the firm. The marginal cost is derived empirically from the parameters of an estimated total cost function which is generally of the form:

$$\begin{aligned}\ln(c_{i,t}) = \alpha_0 + \alpha_1 \ln Q_{i,t} + \tfrac{1}{2}\alpha_2 (\ln Q_{i,t})^2 + \sum_{j=1}^{3} \beta_j \ln(w_{j,i,t}) \\ + \tfrac{1}{2} \sum_{k=1}^{3} \sum_{j=1}^{3} \alpha_{kj} \ln(w_{k,i,t}) \ln(w_{j,i,t}) + \sum_{j=1}^{3} \delta_j \ln(w_{j,i,t}) \ln Q_{i,t} \\ + \lambda_1 E_{i,t} + \tfrac{1}{2}\lambda_2 E_{i,t}^2 + \theta_1 T + \theta_2 T^2 + \sum_{j=1}^{3} \lambda_j T \ln(w_{j,i,t}) + \Phi' X_{i,t} + \varepsilon_{i,t} ,\end{aligned} \tag{A.3}$$

where $c_{i,t}$ is the total cost for firm i at time t, $Q_{i,t}$ is total output, the $w_{j,i,t}$ are input costs, $E_{i,t}$ is equity capital, T is a time trend, $X_{i,t}$ contains other relevant control variables and $\varepsilon_{i,t}$ is the error term. We identify three input costs common to the literature for the financial sector: staff (labour) costs, physical capital (buildings and other business costs) and funding (interest paid on deposits). The marginal cost is then calculated as the derivative of total cost with respect to output:

$$MC_{i,t} = \frac{\partial c_{i,t}}{\partial Q_{i,t}} = \left(\alpha_1 + \alpha_2 \ln Q_{i,t} + \sum_{j=1}^{3} \delta_j \ln w_{j,i,t} \right) \frac{c_{i,t}}{Q_{i,t}} . \tag{A.4}$$

The Lerner index calculated for each bank i ranges from 0 to 1, with values approaching 1 indicating increasing levels of market power (wider margins) on the part of the firm. We derive the Lerner index from estimates of the total cost function shown in equation A.3. Variables used in the specifications have been winsorised at the first and 99th percentiles to reduce the impact of outliers. We also impose homogeneity of inputs so that the elasticity of all cost inputs sum to one by using funding costs as a numeraire. The estimated model parameters are robust to the inclusion of different controls.

The Herfindahl-Hirschman Index

As an additional measure, we employ the Herfindahl-Hirschman Index (HHI). The HHI is a relative measure of concentration, calculated as the sum of the each banks' share in a market squared: $HHI = \sum_{i=1}^{N} s_i^2$ where s is the market share of the bank in a particular market and N is the total number of firms in the industry. Bank shares are calculated on a scale between zero and 100 such that a monopoly industry will have an HHI of 10,000 while increasingly atomised industry will have an HHI approaching zero. We follow other papers from the literature (e.g. Beck et al., 2006; Berger et al., 2009; Anginer et al., 2014) and compute the HHI for UK assets of UK deposit takers. We recognise that the HHI is not a direct proxy for competition but it is useful in providing comparisons with previous studies and in helping evaluate the results from the other competition measures.

Appendix B: Robustness checks

This appendix provides more details on the robustness checks performed on findings from the conditional mean analysis.

Alternative market measures

The limitations of the data mean that the measures of competition used in this analysis reflect competition across all markets in which deposit takers participate. To gauge whether the effects on firm risk are different for different markets in which firms compete, we constructed the HHI for total deposits and loans to proxy competition in separate market segments and used each in separate regression of the Z-score. The HHI for deposits and loans may be loosely interpreted as indicators of concentration within these two separate markets, in contrast to the HHI for assets which is interpreted as concentration across all activities.[36] Table B.1 shows that the coefficients on the HHI for total loans and total deposit are not significant, suggesting that only concentration across all deposit-taking activities, rather than in separate market segments (i.e. loans and deposits), influences overall firm risk.

Alternative risk measures

We employed two different measures of bank-level risk as dependent variables. The first measure we considered was the mix of revenue between the traditional commercial deposit-taking operations and non-interest generating activities, such as investment banking and trading activities.[37] Expansion of non-interest revenue is associated with more volatile bank returns (Stiroh, 2004, 2006) and fee-based activities are linked to higher revenue and earnings variability (DeYoung and Roland, 2001). Table B.2 (columns 1, 2 and 3) shows that the coefficients on competition are negative in each specification, indicating that the non-interest revenue ratio increases as competition increases. This is consistent with the idea that UK banks venture into more risky, non-traditional activities as a way to offset pressures on net interest margins that stem from more intensive competition in traditional banking markets.[38] These results provide further support for the competition-fragility hypothesis.

Our second measure was the equity (to assets) ratio, which is a well-established indicator of deposit-taker failure (e.g., Cole et al., 1995; Cole and White, 2012). Lower values, indicating greater leverage of the balance sheet, are typically associated with a greater risk of firm failure. While we examined this measure in our analysis of the Z-score components, the underlying specification in that analysis was similar to that for the Z-score, which may be less appropriate for evaluating banks' choice of equity ratios. Following the literature on the determinants of bank capital ratios (e.g., Berrospide and Edge, 2010), we developed a specification of UK banks' choice of equity ratios that included measures of competition. Table B.2 (columns 4, 5 and 6) shows that the coefficients on each of the competition measures are positive (and statistically significant), indicating that equity ratios decline as competition increases, further supporting our main finding of competition-fragility.

[36] Concentration in loans and deposits was similar across the period ahead of the crisis, reflecting the traditional deposit-funding model for loans, although post-crisis deposit markets were less concentrated as interbank deposits were reduced.
[37] We calculate this measure as the ratio of non-interest revenue to total revenue.
[38] Bushman et al. (2016) document similar patterns between non-interest revenues and competition for US banking institutions.

Alternative ownership structure

Our sample contains a mix of firms with different ownership characteristics, which previous research shows can affect firms' risk-taking behaviour (e.g., see Saunders, Strock and Travlos, 1990; Iannotta et al., 2007). To evaluate whether our results may have been driven by these features, we constructed three distinct dummy variables denoting whether a firm is owned by its depositors (building societies), owned by shareholders (UK banks), or owned by a foreign parent (foreign banks), and interacted these with each of our competition measures. The coefficients on these interaction terms represent the effects of competition on the stability of each ownership type. Table B.3 reports the results and shows that the coefficients are positive on all interaction terms, confirming that the competition-fragility hypothesis holds across the three ownership classes.

Alternative estimation period

Our main results employ an estimation period spanning the 2008-09 financial crisis as well as the UK small banks crisis of the early 1990s. To examine whether competition-fragility applies during more benign conditions, we excluded observations from these crisis periods.[39] Table B.4 reports the results of these regressions and shows that, with the exception of the HHI, the coefficient on competition remains positive, indicating that lower stability is associated with heightened competition. The main results, however, are weakened somewhat by the exclusion of observations from these turbulent periods. While the price effect of competition picked up through the Lerner index is statistically significant, the coefficient on the Boone indicator is not.

At the same time, when we look at the association between the components of the Z-score over the benign period (Table B.5) greater competition supports firm profitability, but induces lower capital ratios in the same way as they do with the entire sample. This is also the case for the two additive components of the Z-score, i.e., the risk-adjusted asset return and the risk-adjusted capital ratio. Greater competition is associated with improvements in risk-adjusted returns (negative coefficient), but also with lower risk-adjusted capital ratios (positive coefficient), or higher leverage. For the benign period the negative influence of competition on firm leverage is balanced against the positive influence on firm portfolio risk resulting in no significant reduction in overall firm stability.

Controlling for asset size

We partitioned our sample by firm size to evaluate whether the effect of competition on stability differs based on bank size. We augmented our baseline specification (Equation (1)) with an interaction term on our competition measure, which isolates the impact of competition on firms according to asset size. The coefficient on this interaction term represents the marginal effect of competition on the stability of this set of firms.[40] Table B.6 reports the results of the augmented specifications for the largest decile showing that the sign on the interaction term is negative in each case. This finding suggests that the impact of competition on the stability of the largest UK firms is less pronounced. Indeed, the results based on the adjusted Boone indicator suggest that (the net impact of) competition has a neutral impact on Z-scores for the largest institutions.[41]

[39] To the extent that accounting valuations may have been distorted during the crisis, this additional test may also help address measurements related to our index of stability.

[40] We tested the interaction with the largest decile, quintile and quartile but the marginal effects of the latter two are not significant and are not presented here.

[41] The net impact of competition on the largest firms is -0.0121, but the associated t-static is 1.35, which is not enough to reject the null hypothesis that overall effect of competition on large bank stability is zero.

Testing for nonlinear effects

We included a quadratic term in the main specification (Equation (1)) to evaluate whether the effects of competition on stability are non-linear. There is ample evidence in the literature suggesting that the effects of competition may depend on the level of competition (market power) already in place (e.g., Berger et al., 2009; Tabak et al, 2012; Jiménez et al., 2013). Table B.7 reports the results of this amended specification and shows that for the Lerner index (where the coefficient on the competition indicator is not significantly different from zero), and for the HHI (where the coefficient is marginally significant) the relationship is linear. In addition, the sign on the squared term is also consistent with the findings from our baseline model, i.e., higher competition (lower market power) reduces banks Z-scores, supporting the competition-fragility hypothesis. The finding with respect to the Boone indicator is suggestive of a non-linear association (consistent with Tabak et al., 2012, who also document a similar relationship using the Boone indicator). However, a closer inspection of the results shows that the inflection point approximates -3.9, which, for our sample, rests at roughly the 75^{th} percentile of the distribution of the Boone indicator. This means that only for a small portion of our sampled Boone measures would the relationship turn in the opposite direction supporting the competition-stability view. It is mainly for this reason that we focus on the linear results in the body of the paper.

Alternative quantile regression estimation methods

We conducted a number of robustness checks on the quantile regressions and find consistent results of that the effect of competition on stability with respect to the financial health of banks. First, substituting for the variables identified by the conditional mean regression as endogenous with further lags produced no significant differences in coefficient estimates of the competition indicators (see Figure B.7). Second, excluding further outliers results in no significant differences in coefficient estimates. Third, excluding the period spanning the 2008-09 financial crisis and the UK small banks crisis of the early 1990s weakens the results in a similar way as with the conditional mean estimates. Overall it confirms the *competition-stability* result for low Z-score firms and the negative effect on the Z-score only for the most stable firms (in this case the largest 75th to 90th percentile of the Z score).

Table B.1
Regression of ln(Z-Score) on alternative concentration measures

Dependent variable: ln(Z-score)	(1)	(2)
Concentration measure		
HHI for Total Loans	0.0446	
	(0.0400)	
HHI for Total Deposits		0.0874*
		(0.0450)
Macroeconomic controls		
GDP growth	2.7961***	2.9972***
	(0.3720)	(0.3820)
Inflation	-0.0270***	-0.0293***
	(0.0060)	(0.0060)
Unemployment rate	-0.0977***	-0.0958***
	(0.0050)	(0.0050)
Bank-level controls		
Non-interest revenue to total revenue	-0.0114***	-0.0116***
	(0.0010)	(0.0010)
Bank Size	-0.0634***	-0.0719***
	(0.0190)	(0.0190)
Provisions to assets ratio	-2.1830***	-2.1841***
	(0.5150)	(0.5140)
Total loans to assets ratio	0.0072	-0.0014
	(0.0760)	(0.0760)
Wholesale to total deposits ratio	-0.1864***	-0.1855***
	(0.0550)	(0.0550)
Number of observations	12,124	12,124
R-square overall	0.0854	0.0854
Endogeneity test (p-value)	0.7787	0.2577

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z-score for firm *i* at quarter *t*. We estimate Equation (1) replacing the concentration measure, HHI assets, used in our baseline specification with alternative measures based on loans and deposits constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The endogeneity test statistics reported do not reject the null that the corresponding competition measures are exogenous. ***, **, * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are reported in parenthesis.

Table B.2
Regression of alternative risk measures on competition indicators

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:		Revenue Mix			Capital ratio	
Competition measure						
Boone indicator (adjusted)	-0.0008			0.8377***		
	(0.0020)			(0.0660)		
Lerner index (median)		-0.5243***			24.3830***	
		(0.1260)			(3.9740)	
HHI (assets)			-0.0142**			3.1992***
			(0.0070)			(0.2980)
Macroeconomic controls						
GDP growth	-0.6194***	-0.6328***	-0.6928***	-0.2124	-13.8810***	0.7927
	(0.1151)	(0.1065)	(0.1144)	(2.1352)	(2.3440)	(2.1582)
Inflation	-0.0016	-0.0001	0.0003	-0.1036***	-0.0703*	-0.3953***
	(0.0012)	(0.0013)	(0.0015)	(0.0384)	(0.0398)	(0.0440)
Unemployment rate	0.0066***	0.0067***	0.0056***	-0.0883**	-0.1787***	0.0349
	(0.0012)	(0.0011)	(0.0013)	(0.0385)	(0.0405)	(0.0407)
Bank-level controls						
Bank Size	0.0343***	0.0406***	0.0420***	-4.7453***	-3.4418***	-4.6779***
	(0.0060)	(0.0040)	(0.0060)	(0.2500)	(0.1800)	(0.2660)
Total loans to assets	-0.0110	-0.0076	-0.0074	0.1866	1.0342	0.5235
	(0.0160)	(0.0160)	(0.0160)	(0.9660)	(1.0110)	(0.9660)
Trading book assets to assets	0.0034***	0.0034***	0.0033***	-0.0502***	-0.0741***	-0.0515***
	(0.0010)	(0.0010)	(0.0010)	(0.0120)	(0.0120)	(0.0120)
Funding (Retail to total deposits)	0.0158	0.0149	0.0160			
	(0.0170)	(0.0180)	(0.0170)			
Leverage Ratio	-0.0024***	-0.0022***	-0.0022***			
	(0.0010)	(0.0010)	(0.0010)			
Return on assets	0.0215***	0.0213***	0.0211***			
	(0.0030)	(0.0030)	(0.0030)			
Real estate assets to total assets	-0.0002	-0.0001	-0.0002			
	(0.0000)	(0.0000)	(0.0000)			
Non-interest expenditure ratio	0.1495***	0.1547***	0.1525***			
	(0.0160)	(0.0150)	(0.0160)			
Non-interest revenue ratio				-0.0124	0.0090	-0.0023
				(0.0090)	(0.0090)	(0.0080)
Provisions to total assets ratio				32.2670***	28.4340***	31.3880***
				(5.2620)	(5.2360)	(5.2300)
Tier one to total capital ratio				0.0644***	0.0681***	0.0663***
				(0.0060)	(0.0060)	(0.0060)
Number of observations	10,232	10,232	10,232	10,979	10,979	10,979
R-square overall	0.2038	0.2049	0.2043	0.2610	0.2333	0.2574
Endogeneity test for competition	0.0837	0.0007[(a)]	0.6690	0.0000[(a)]	0.4109	0.0004[(a)]

This table reports the instrumental variables linear panel regression for the effects of competition on bank stability using alternative measures of risk: non-interest revenue mix (columns 1 to 3) and the capital (equity to total assets) ratio (columns 4 to 6). We estimate separate regressions for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The endogeneity test is to reject the null hypothesis that the competition indicator is exogenous; (a) In this cases the hypothesis can be rejected and further lags of competition are used as instruments. ***, **, * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are reported in parenthesis.

Table B.3
Regression of ln(Z-Score) on competition measures accounting for ownership structure

Dependent variable: ln(Z-score)	Boone indicator (adjusted)	Lerner index (median)	HHI (assets)
Competition measure			
Boone indicator (adjusted)*Building Society	0.0224***		
	(0.0060)		
Boone indicator (adjusted)*UK Banks	0.0207**		
	(0.0090)		
Boone indicator (adjusted)*Foreign	0.0114		
	(0.0090)		
Lerner index (median)*Building Society		3.7380***	
		(0.4710)	
Lerner index (median)*UK Banks		1.7886***	
		(0.6100)	
Lerner index (median)*Foreign		1.1937*	
		(0.6130)	
HHI (assets)*Building Society			0.0566**
			(0.0250)
HHI (assets)*UK Banks			0.0652*
			(0.0370)
HHI (assets)*Foreign			0.0851***
			(0.0310)
Macroeconomic controls			
GDP growth	2.9127***	2.4553***	3.0984***
	(0.3440)	(0.3420)	(0.3440)
Inflation	-0.0249***	-0.0272***	-0.0334***
	(0.0060)	(0.0060)	(0.0060)
Unemployment rate	-0.0993***	-0.1076***	-0.0926***
	(0.0050)	(0.0050)	(0.0050)
Bank-level controls			
Non-interest revenue to total revenue	-0.0116***	-0.0115***	-0.0117***
	(0.0010)	(0.0010)	(0.0010)
Bank Size	-0.0791***	-0.0680***	-0.0614***
	(0.0180)	(0.0150)	(0.0180)
Provisions to assets ratio	-2.3377***	-2.4913***	-2.1891***
	(0.5190)	(0.5180)	(0.5190)
Total loans to assets ratio	0.0390	0.0653	0.0157
	(0.0770)	(0.0760)	(0.0760)
Wholesale to total deposits ratio	-0.1150**	-0.0993*	-0.073753
	(0.0570)	(0.0560)	(0.0570)
Number of observations	11,971	11,971	12,078[(a)]
R-square overall	0.0883	0.0912	0.0867
Endogeneity test (p-value)	0.0543	0.2544	0.8226[(b)]

This table reports the effects of competition on bank stability measured by the Z-score. Common macroeconomic and bank-level controls from the literature are included. The regressions include competition measures interacted with dummy variables denoting whether the firm is owned by depositors (Building Society), shareholders (UK Banks), or a foreign parent (Foreign). All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. ***, **, * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are reported in parenthesis. (a),(b) Only the competition interaction with UK commercial banks is exogenous; the regression uses further lags as instruments for the interaction between competition and building societies and foreign banks subsidiaries.

Table B.4
Regression of ln(Z-Score) on competition measures (benign sample period)

Dependent variable: ln(Z-score)	Lerner index (median)	HHI (assets)	Boone indicator (adjusted)
Competition indicator	1.2617***	-0.0100	0.0122
	(0.4800)	(0.0420)	(0.0100)
Macroeconomic controls			
GDP growth	3.4779***	3.4761***	3.2598***
	(0.7330)	(0.7310)	(0.7320)
Inflation	-0.0239***	-0.0165*	-0.0196***
	(0.0080)	(0.0090)	(0.0070)
Unemployment rate	-0.1079***	-0.1089***	-0.1006***
	(0.0080)	(0.0090)	(0.0090)
Bank-level controls			
Non-interest revenue to total revenue	-0.0113***	-0.0107***	-0.0109***
	(0.0020)	(0.0020)	(0.0020)
Bank Size	-0.0275	-0.0185	-0.0237
	(0.0290)	(0.0300)	(0.0300)
Provisions to assets ratio	-3.0855***	-3.0011***	-3.0626***
	(1.0260)	(1.0210)	(1.0310)
Total loans to assets ratio	-0.0648	-0.0548	-0.0599
	(0.1080)	(0.1080)	(0.1080)
Wholesale to total deposits ratio	0.0077	0.0055	0.0051
	(0.0710)	(0.0710)	(0.0710)
Number of observations	8,082	8,082	8,082
R-square overall	0.0800	0.0798	0.0797
Endogeneity test statistic (p-value)	0.8796	0.8899	0.4153

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z score for firm i at quarter t. We estimate Equation (1) separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. The regression uses all banks in the sample and the estimation timeframe spans 1995 to 2007 (i.e., excludes the UK small banks crisis and the period from the start of the 2007-09 financial crisis). All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The endogeneity test statistics reported do not reject the null that the relevant competition measures are exogenous. ***, ** and * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are reported in parenthesis.

Table B.5
Regression of alternative risk measures (benign sample period)

Dependent Variables	Boone indicator (adjusted)	Lerner index (median)	HHI (assets)
ln(Z-score)	0.0122	1.2617***	-0.0100
	(0.2430)	(0.0090)	(0.8140)
Return on assets ($roa_{i,t}^{A}$)	-0.0561***	-3.0105***	-0.2281***
	(0.0000)	(0.0000)	(0.0000)
Capital Ratio ($k_{i,t}$)	0.1537**	12.0670***	0.6162*
	(0.0430)	(0.0010)	(0.0520)
Asset return volatility ($\sigma_{i,t}^{A}$)	0.0116	-0.9463	0.0397
	(0.4710)	(0.1940)	(0.5390)
Risk adjusted asset returns ($roa_{i,t}^{A}/\sigma_{i,t}^{A}$)	-0.1646***	-9.6746***	-0.9329***
	(0.0000)	(0.0000)	(0.0000)
Risk adjusted capital ratio ($k_{i,t}/\sigma_{i,t}^{A}$)	3.3120***	156.6100***	9.4069***
	(0.0000)	(0.0000)	(0.0000)

This table reports the coefficient estimates for competition measures (columns) with risk measures as the dependent variable (rows). Specifications include macroeconomic and bank level controls; estimation timeframe spans 1995 to 2007 (i.e., excludes the UK small banks crisis and the period from the start of the 2007-09 financial crisis). Explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables. ***, ** and * indicate significance at the 1%, 5%, and 10% level, respectively. Standard errors are reported in parenthesis.

Table B.6

Regressions of ln(Z-Score) on competition measures with large firm effects

Dependent variable: ln(Z-score)	Boone Indicator (adjusted)	Lerner Index (median)	HHI (assets)
Competition indicator	0.0190***	1.7952***	0.0750***
	(0.0060)	(0.3690)	(0.0250)
Competition indicator*Top10	-0.0311***	-0.2587	-0.0371***
	(0.0080)	(0.4320)	(0.0180)
Macroeconomic controls			
GDP growth	2.8482***	2.5517***	2.9251***
	(0.3420)	(0.3390)	(0.3480)
Inflation	-0.0256***	-0.0276***	-0.0330***
	(0.0060)	(0.0060)	(0.0060)
Unemployment rate	-0.0969***	-0.1033***	-0.0923***
	(0.0050)	(0.0050)	(0.0050)
Bank-level controls			
Non-interest revenue to total revenue	-0.0118***	-0.0097***	-0.0118***
	(0.0010)	(0.0010)	(0.0010)
Bank Size	-0.0767***	-0.0514***	-0.0795***
	(0.0180)	(0.0160)	(0.0190)
Provisions to assets ratio	-2.2289***	-2.2355***	-2.1849***
	(0.5150)	(0.5110)	(0.5140)
Total loans to assets ratio	-0.0096	0.0217	-0.0061
	(0.0760)	(0.0750)	(0.0760)
Wholesale to total deposits ratio	-0.1844***	-0.1779***	-0.1851***
	(0.0550)	(0.0540)	(0.0550)
Number of observations	12,124	12,152[(a)]	12,124
R-square overall	0.0856	0.0896	0.0857
Endogeneity test statistic (p-value)	0.5464	0.0510[(b)]	0.1510

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z-score for firm *i* at quarter *t*. We estimate Equation (1) separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. We interact each competition measure with a dummy variable, Top10, equal to 1 if a bank is in the top 10th percentile according to asset size and 0 otherwise. All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. The endogeneity test statistics reported do not reject the null that the relevant competition measures are exogenous. ***, **, * means significant at the 1%, 5% and 10% level, respectively. Standard errors are in parenthesis.

Table B.6

Regressions of ln(Z-Score) on competition and competition squared

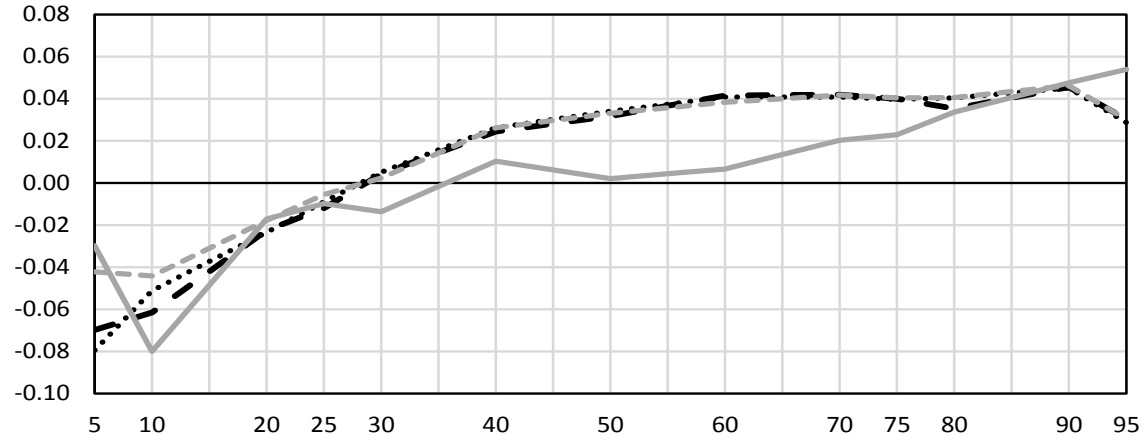
Dependent variable: ln(Z-score)	Boone Indicator (adjusted)	Lerner Index (median)	HHI (assets)
Competition indicator	-0.0675***	-3.8807	-0.5539*
	(0.0260)	(2.3850)	(0.3160)
Competition indicator squared	-0.0085***	34.4460**	-0.1320**
	(0.0030)	(13.7170)	(0.0660)
Macroeconomic controls			
GDP growth	2.6004***	2.4220***	2.9271***
	(0.3490)	(0.3400)	(0.3480)
Inflation	-0.0240***	-0.0258***	-0.0330***
	(0.0060)	(0.0060)	(0.0060)
Unemployment rate	-0.0858***	-0.1065***	-0.0841***
	(0.0060)	(0.0050)	(0.0060)
Bank-level controls			
Non-interest revenue to total revenue	-0.0116***	-0.0116***	-0.0119***
	(0.0010)	(0.0010)	(0.0010)
Bank Size	-0.0713***	-0.0641***	-0.0784***
	(0.0180)	(0.0150)	(0.0190)
Provisions to assets ratio	-2.4044***	-2.4940***	-2.2342***
	(0.5210)	(0.5200)	(0.5150)
Total loans to assets ratio	-0.0003	0.0084	-0.0070
	(0.0760)	(0.0760)	(0.0760)
Wholesale to total deposits ratio	-0.1900***	-0.1859***	-0.1859***
	(0.0550)	(0.0550)	(0.0010)
Number of observations	12,124	12,124[(a)]	12,124
R-square overall	0.0870	0.0882	0.0858

This table reports the results of estimating Equation (1), where the dependent variable is the natural log of the Z-score for firm *i* at quarter *t*. We estimate Equation (1) separately for each of the competition measures, the Boone indicator, Lerner index and HHI (assets), constructed as discussed in Appendix A. Common macroeconomic and bank-level controls from the literature are included. The regression uses all banks in the sample and the full estimation sample timeframe 1994 to 2013. We include the square of the competition indicator to evaluate non-linear effects. All explanatory variables enter with two lags except of unemployment that enters with four lags. The estimation method is panel fixed effects instrumental variables; the regressions are exactly identified. ***, **, * means significant at the 1%, 5% and 10% level, respectively. Standard errors are in parenthesis.

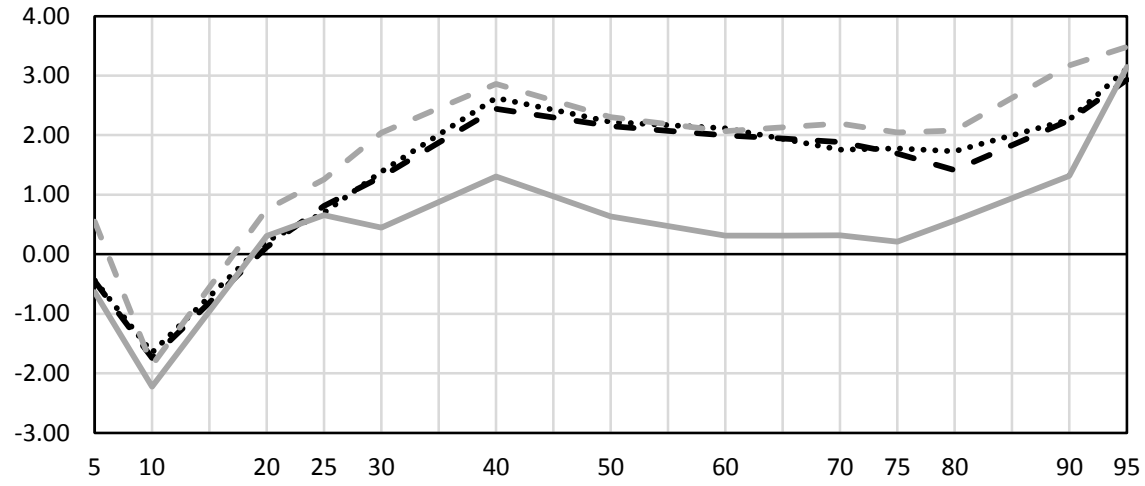
Figure B.7

Quantile coefficient estimates from regression of ln(Z-score) on competition indicators

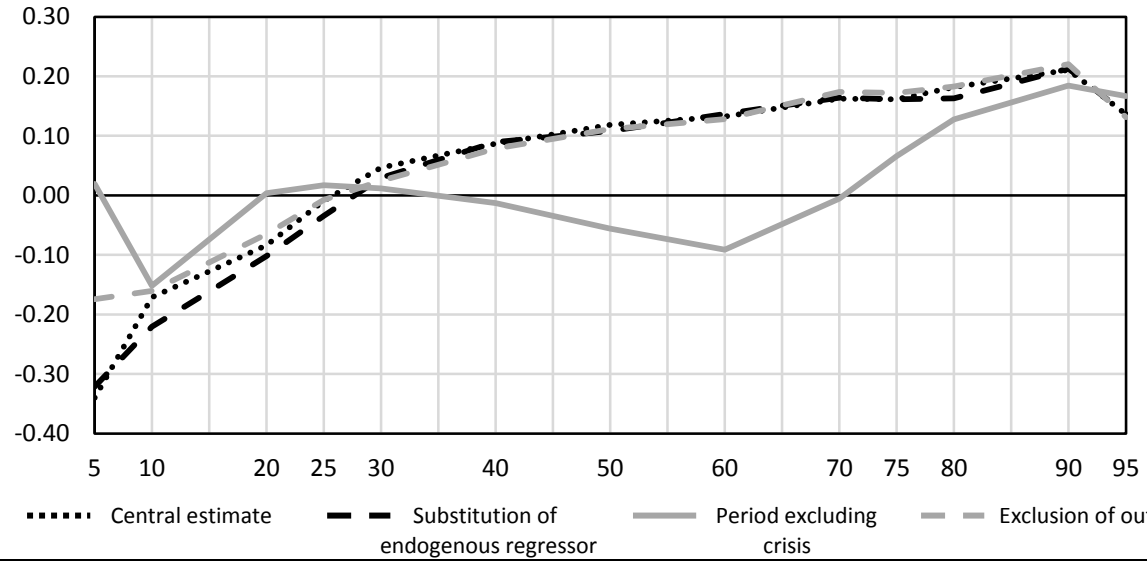
A. Boone indicator (adjusted)



B. Lerner Index (median)



C. HHI (assets)



This chart shows the coefficient estimates for each competition measure (vertical axes) by percentiles of the ln(Z-score) (horizontal axes) for estimation options (line shade). Negative values of the coefficients are consistent with the competition-stability hypotheses, positive values are consistent with the competition-fragility hypothesis.

Appendix C: Additional background on quantile regressions

Table C.1
Quantile regression of ln(Z-score) on competition, macroeconomic and bank-level characteristics

Dependent variable:	Ln(Z-score)					Risk-adjusted return on assets					Risk-adjusted capital ratio				
Quantile of dependent variable	5	25	50	75	95	5	25	50	75	95	5	25	50	75	95
Boone indicator (adjusted)	-0.08***	-0.01	0.03***	0.04***	0.03***										
	(0.00)	(0.22)	(0.00)	(0.00)	(0.00)										
Lerner index (median)						-0.44	0.70	2.22***	1.77***	3.12***					
						(0.79)	(0.24)	(0.00)	(0.00)	(0.00)					
HHI (assets)											-0.34***	-0.01	0.12***	0.16***	0.14***
											(0.00)	(0.76)	(0.00)	(0.00)	(0.00)
Macroeconomic controls															
GDP growth	5.34***	2.28***	2.32***	1.69***	-0.58	8.79***	2.68***	1.03**	0.29	-1.53***	4.34***	2.57***	2.40***	2.02***	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.34)	(0.00)	(0.00)	(0.03)	(0.48)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.99)
Inflation	-0.03	-0.01	-0.03***	-0.03***	-0.03***	-0.05**	-0.01	-0.03***	-0.03***	-0.03***	0.00	-0.01	-0.04***	-0.05***	-0.05***
	(0.16)	(0.13)	(0.00)	(0.00)	(0.01)	(0.05)	(0.13)	(0.00)	(0.00)	(0.01)	(0.98)	(0.16)	(0.00)	(0.00)	(0.00)
Unemployment rate	-0.06***	-0.09***	-0.11***	-0.10***	-0.07***	-0.06**	-0.09***	-0.13***	-0.11***	-0.09***	-0.09***	-0.08***	-0.10***	-0.09***	-0.06***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bank-level controls															
Bank Size	-0.09***	-0.09***	-0.09***	-0.07***	-0.05***	-0.10***	-0.09***	-0.09***	-0.07***	-0.04***	-0.09***	-0.09***	-0.09***	-0.07***	-0.04***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total loans to assets ratio	0.90***	0.30***	-0.06	-0.17***	-0.14**	0.82***	0.32***	-0.04	-0.14***	-0.09	0.85***	0.30***	-0.06	-0.15***	-0.14**
	(0.00)	(0.00)	(0.18)	(0.00)	(0.03)	(0.00)	(0.00)	(0.32)	(0.00)	(0.12)	(0.00)	(0.00)	(0.21)	(0.00)	(0.02)
Provisions to assets ratio	-16.6***	-13.6***	-5.62***	-3.10***	-2.75***	-15.5***	-13.4***	-6.19***	-3.27***	-3.06***	-16.6***	-13.7***	-5.69***	-2.89***	-2.74***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wholesale to total deposits ratio	-0.50***	-0.45***	-0.52***	-0.44***	-0.28***	-0.38***	-0.44***	-0.53***	-0.45***	-0.26***	-0.48***	-0.44***	-0.53***	-0.44***	-0.27***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Non-interest revenue to total revenue	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Pseudo R-squared	0.124	0.124	0.124	0.124	0.124	0.121	0.121	0.121	0.121	0.121	0.124	0.124	0.124	0.124	0.124
Number of observations	13,265					13,265					13,265				
F-stat (equality of all coefficients)	9.42***					2.63***					7.54***				

This table reports the results from applying quantile regression on Equation (1), where the dependent variables are the natural log of the Z-score alongside each of its additive parts risk adjusted return on assets and capital ratio (RoA/σ and k/σ respectively) for firm *i* at quarter *t*. Each model estimates results for each quantile based on all banks in the sample and the full estimation sample timeframe 1994 to 2013. All explanatory variables enter with two lags except of unemployment that enters with four lags. Standard errors, reported in parentheses for each coefficient, are estimated using bootstrap procedures and are consistent across all quantiles. Each model presents the point estimate with the standard error underneath in parentheses. All variables are lagged by 2 quarters except for unemployment lagged 4 periods. The F-stat reported is for the null hypothesis that all estimated coefficients are equal. ***, **, * indicate significance at 1%, 5% and 10% levels, respectively.

Appendix D: Variable definitions

Variable	Definition	Source
Measures of stability:		
Z-score	(Core capital ratio + return on assets)/std dev(return on assets)	Bank HBRD and authors' calculations
Core capital to assets ratio	Total equity/total assets	Bank HBRD and authors' calculations
Return on assets	After-tax net income/total assets	Bank HBRD and authors' calculations
Standard deviation of RoA	Standard deviation of return on assets (based on 12 quarter rolling window)	Bank HBRD and authors' calculations
Risk-adjusted return on assets	Return on assets/standard deviation of RoA	Bank HBRD and authors' calculations
Risk-adjusted capital ratio	Core capital to assets ratio/standard deviation of RoA	Bank HBRD and authors' calculations
Revenue mix	Trading (investment and FX) revenue/total revenue	Bank HBRD and authors' calculations
Measures of competition:		
Boone Indicator	Elasticity of profits to variable costs (estimated)	Bank HBRD and authors' calculations
Lerner Index	Price-cost markup (estimated)	Bank HBRD and authors' calculations
HHI assets	Sum of squared market shares in assets of all banks in the UK	Bank HBRD and authors' calculations
Bank-level controls:		
Bank size	Log of total assets	Bank HBRD and authors' calculations
Provisions to assets ratio (%)	Stock of loan loss reserves/total assets	Bank HBRD and authors' calculations
Total loans to assets ratio (%)	Total loans/total assets	Bank HBRD and authors' calculations
Wholesale to total deposits ratio (%)	Wholesale funding (i.e., non-Retail deposits)/total deposits	Bank HBRD and authors' calculations
Non-interest revenue to total revenue (%)	(Trading, fees and other non-interest revenue)/total revenue	Bank HBRD and authors' calculations
Macroeconomic controls:		
UK GDP growth	Annual rate of real GDP growth	UK Office for National Statistics
UK Inflation	Annual rate of inflation	UK Office for National Statistics
UK Unemployment rate	Unemployment rate	UK Office for National Statistics

This table shows the definitions of the variables used in the regression and other quantitative results and their sources.

Appendix E: Variable correlations

Table E.1
Correlations between risk and competition measures

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	**log Z-score**	1.0000												
(2)	**Boone Indicator (adjusted)**	-0.0102	1.0000											
(3)	**Lerner Index (median)**	-0.0704*	0.5088*	1.0000										
(4)	**log HHI (assets)**	0.0047	0.8590*	0.3759*	1.0000									
(5)	**log HHI (deposits)**	-0.0125	0.8388*	0.3181*	0.9725*	1.0000								
(6)	**log HHI (loans)**	-0.0492*	0.8317*	0.3698*	0.8892*	0.9114*	1.0000							
(7)	**GDP growth**	0.0316*	-0.4323*	-0.0246	-0.4833*	-0.5458*	-0.5784*	1.0000						
(8)	**Inflation**	-0.0792*	0.2125	0.1407	0.4121*	0.4007*	0.4352*	-0.1934	1.0000					
(9)	**Unemployment rate**	-0.1800*	0.1239	0.3658*	-0.0275	0.0694	0.2925*	-0.2132	0.3032*	1.0000				
(10)	**Non-interest revenue to total rev**	-0.3813*	0.1847*	0.1264*	0.1532*	0.1473*	0.1723*	-0.0537*	0.0436*	0.0508*	1.0000			
(11)	**Bank Size (log assets)**	-0.1711*	0.0958*	-0.0008	0.1165*	0.1117*	0.0899*	-0.0504*	0.0082	-0.0830*	-0.0019	1.0000		
(12)	**Provisions to assets ratio**	-0.1867*	-0.1123*	0.0132	-0.1372*	-0.1332*	-0.1208*	0.0719*	-0.0158*	0.0909*	0.0575*	-0.1046*	1.0000	
(13)	**Total loans to assets ratio**	0.2586*	-0.0411*	-0.0257*	-0.0425*	-0.0425*	-0.0496*	0.0059	-0.0192*	-0.0152*	-0.4596*	0.1130*	0.0484*	1.0000
(14)	**Wholesale to total deposits ratio**	-0.2503*	-0.0726*	-0.0122	-0.0726*	-0.0694*	-0.0638*	0.0422*	0.0081	0.0409*	0.1851*	0.1410*	0.0974*	-0.2811*

This table reports the pairwise correlations based on winsorised data (see table 1). Values in brackets are the significance level of each correlation coefficient. * represent a probability<5%, i.e. the coefficient is significant at the 5% level.