Bank Competition and Stability in the United Kingdom: Evidence from Quantile Regressions

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Abstract: This paper examines the effects of competition on bank risk in the United Kingdom between 1994 and 2013. We regress bank-level Z-scores, a commonly-used metric of solvency risk, on the Boone indicator, a measure of competition based on allocative efficiency, and other explanatory variables. We compare results from (i) standard regression techniques and (ii) quantile regression, which provides a broader picture of the effects. Results under (i) indicate that risk increases as competition intensifies, while under (ii) this influence is only evident for the most stable firms. For the most fragile firms, we find that risk is lower when competition is stronger. These stabilizing effects are most evident at large, privately-owned banks. We also find that regulatory pressure (proxied by proximity to required capital minimums) reduces risk-taking incentives prompted by competition. The results have implications for considering the effects of competition on individual and system-wide bank stability.

Key Words: Bank competition, Bank risk taking, Boone indicator, Quantile regression

JEL Classification: G21, G28, L22

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1. Introduction

The relationship between bank competition and bank risk-taking has been of long-standing interest to regulators, policymakers and academics. While this attention has produced a vast body of research on the links between competition and bank risk, there is still no consensus on whether competition increases or decreases risk-taking by banks. Theories on the links suggest that under certain conditions competition may have favourable effects, i.e., the 'competition-stability' view, or unfavourable effects, i.e., the 'competition-fragility' view (e.g., see Carletti and Hartmann, 2003; Beck, 2008; Vives, 2011). Empirical studies on this issue provide varying degrees of support for both views, making it difficult for policymakers to understand the need for (and design of) measures to mitigate costs or support benefits that derive from competition in banking markets.[1]

We contend that at least part of this challenge stems from the fact that much of the extant empirical research relies on regression setups that express the expected value of the dependent value, bank risk, as a function of the independent variables of interest, competition. Researchers have typically drawn conclusions about the relationship between competition and risk based on the coefficient on the competition measure, which, in these setups, provides a summary measure of the average effect for a bank with average risk. If there is significant firm heterogeneity, however, the average effect of competition may provide an incomplete picture of the link between competition and risk. Moreover, this shortcoming may thwart an understanding about the impact of competition on banking system stability more broadly, which depends not on average effects but on individual effects

[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 no definitive systematic evidence on the connection between competition and stability.

aggregated across the entire distribution of banks within the system. This issue may be especially relevant in countries where significant inter-bank variation in solvency risk exists.

Several recent papers offer evidence pointing to the importance, when assessing the effects of competition (on risk-taking behaviour), of considering whether such effects also depend on the underlying risk-profile of a firm. For example, using a large cross-country panel of banks spanning the period 1994 to 2009, Beck et al. (2013) finds that competition has a stronger positive relationship with bank fragility for distressed banks. In a single-country setting, Liu and Wilson (2013) examines this issue using a sample of Japanese banks spanning the period 2000 to 2009 and finds evidence that banks farther from insolvency take on more risk in response to more intense competition, consistent with the competition-fragility view, while those closer to insolvency reduce risk, consistent with the competition-stability view. In a cross-country study of European banks for the period 1995 to 2005, Schaeck and Cihak (2014) finds evidence consistent with the competition-stability view, but that the stabilizing effects of competition are less (more) pronounced for banks closer to (farther from) insolvency. Cummins et al. (2017) documents that the soundness-enhancing effect of competition is stronger for weak insurers compared with financially healthy ones. These papers highlight the idea there could be real differences in the strength and direction of the influence of competition across the conditional risk distribution that may be important for policymakers to consider when assessing the impacts of competition or policy measures that have the potential to alter competition in banking markets.

Using data on all banks and building societies in the United Kingdom for the period 1994 to 2013, we add to this line of research by determining the effects of competition at different points of the conditional risk distribution. The objective of our paper is to learn more about these effects if they are found to vary across the risk distribution. In that direction, we employ quantile regression, a robust estimator that takes into account the heterogeneity of bank risk (e.g., see Koenker and Basset, 1978). Rather than estimating a single measure of central tendency for the competition-risk relationship, quantile regression facilitates the estimation of several coefficients at various points across the conditional distribution of bank risk.[2]

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. 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 (e.g., Matthews et al., 2007; de-Ramon and Straughan, 2019). In addition, 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 UK banking market competition 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, 2019). To our knowledge, however, there is no research that has examined the effects of competition on bank stability exclusively for the UK.[3]

We carry out our analysis of the effects of competition by regressing bank Z-scores, accounting-based measures of distance to insolvency that commonly feature in this line of research (e.g., Berger et al., 2009; Houston et al., 2010; Tabak et al., 2012; Schaeck and Cihak, 2014), on the Boone indicator (e.g., Boone, 2008), a measure of competition based on the reallocation of profits from inefficient to efficient banks, controlling for bank-level and

[2] With the exception of Schaeck and Cihak (2014), the use of quantile regression to highlight this issue is noticeably absent from the previous banking research.

[3] 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).

macro-economic factors that prior research has shown also influence bank risk. Several papers have used the Boone indicator to investigate the role that the efficiency channel plays in linking competition with bank stability (e.g., Tabak et al., 2012; Schaeck and Cihak, 2014; Kick and Prieto, 2015). Our paper adds to that literature by examining whether the transmission via the efficiency channel depends on the underlying risk-profile of a firm. We use standard OLS regression (with fixed effects) and quantile regression to estimate these models and then compare results to illustrate how potential distributional effects of competition within the banking system can have important implications for understanding the impacts of competition not only on risk at the individual firm level, but also on the stability of the wider financial system.

A secondary goal of our paper is to evaluate whether firm type, characterized by both asset size and ownership, and regulatory pressure, proxied by the proximity of a firm's capital ratio to its regulatory capital minimum, change the relationship between competition and stability. Previous research documents evidence of heterogeneous effects of competition based on firm type (e.g., Tabak et al., 2012; Liu and Wilson, 2013; Kick and Prieto, 2015); however, to our knowledge, none has explicitly examined whether the effects vary across the conditional risk distribution using quantile regression. To examine for such differences, we interact our competition measure with an indicator of firm type in both the standard and quantile regression setups. Our interest in examining the effects of regulatory pressure is motivated by a desire to understand whether this measure may dampen risk-taking incentives, which according to the *franchise value theory* (e.g., Marcus, 1984; Keeley, 1990; Hellman et al., 2000), increase as competition mounts. To test this idea, we include an interaction between competition and a measure of regulatory pressure, i.e., a dummy variable equal to one if the institution's capital buffer above its regulatory minimum is in the lowest decile. As discussed below, this multi-dimensional analysis of firm heterogeneity using quantile regression provides an insightful discrimination of the relationships between competition and stability that can help bank regulators and policymakers in designing measures aimed at mitigating costs and supporting benefits that derive from competition. To our knowledge, such analysis is absent in the previous banking research examining the competition-stability link and is a contribution of our paper.

When using standard regression, we find that bank stability is, on average, adversely associated with competition, consistent with the competition-fragility hypothesis. Our findings also suggest that the dominant channel through which this outcome happens is through banks electing to hold significantly lower risk-adjusted capital ratios, supportive of the *franchise value* theory (e.g., Marcus, 1984; Keeley, 1990). Results from quantile regression indicate that the destabilizing effects of competition are evident only in the upper tail (low-risk end) of the conditional risk distribution, suggesting that it may be the relatively safest (most stable) firms in the system that increase risk in response to higher competition. For the most fragile firms in the lower tail (high-risk end) of the risk distribution, we find that competition is favourably related to stability, supportive of the competition-stability hypothesis.[4] These contrasting results under quantile regression are consistent with both the competition-fragility and competition-stability theories holding simultaneously for institutions in the United Kingdom. This finding is in line with the conclusions reached by Berger et al. (2009), which, in a cross-country setting using bank data from 23 developed countries, also find evidence supportive of both theories holding simultaneously. These results suggest that there may be trade-offs to evaluate when considering the effects of competition, especially on overall banking system stability.

[4] This result is also consistent with the idea that the solvency risk of the relatively weakest banks in the UK (as measured by Z-scores) worsened as competition intensity declined during our estimation period. We explore this issue in more depth with quantile regression.

Our analysis of whether firm type influences the effects of competition shows that, under standard regression, the destabilizing effects of competition are most evident for small firms, while for the large (privately-owned) banks, competition has a favourable impact on risk-taking. Results from quantile regression also confirm that the favourable relationship between competition and stability is evident for privately-owned banks as well as for fragile institutions within the lower tail risk-distribution in general. At the same time, these results indicate that competition may have destabilizing effects on the relatively less-risky, most stable mutually-owned building societies and foreign-owned banks in general.

When considering regulatory pressure under standard regression, we find that the destabilizing effects of competition are lower at institutions facing heightened regulatory pressure. Indeed, the results suggest that at these institutions, regulatory pressure is effective in disciplining firms to take steps to reduce inefficiencies and risk-taking in the face of heightened competition. This result also holds under quantile regression, where we find that the destabilizing effects of competition at the healthiest firms are significantly lower if they also face regulatory pressure.

Our results support the idea that the risk-taking effects of competition at the individual bank level can be different within the banking system. This means that the net impacts of competition on banking system stability overall will depend on how these individual effects combine. While our paper is not aimed explicitly at evaluating the effects of competition on banking system stability, its results have some lessons for considering such effects. To highlight a key lesson, we use the results from the standard and quantile regression techniques and simulate the effects of an increase in competition on percentile-based measures of banking system Z-scores used in previous research (e.g., Houston et al., 2011) and by policymakers (e.g., Beck at al., 2010) to assess system soundness. This exercise demonstrates the value of using a technique that facilitates a broader view of the effects across the system, which can be more complicated than can be described using a simple average.

The remainder of this paper is structured as follows. Section 2 describes our empirical approach and the measures of stability and competition used in this paper. Section 3 discusses our data and sample. Section 4 reports results, while Section 5 discusses robustness tests. Section 6 concludes.

2. Empirical approach (Amend as needed to focus on key questions)

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

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

where $Stability_{i,t}$ is a measure of bank-level risk for bank i at time t, $Competition_t$ is the level of industry-wide competition at time t, $X_{i,t}$ and Y_t are vectors reflecting bank-level and macroeconomic controls, respectively, and $\varepsilon_{i,t}$ are error terms. Except where noted otherwise, we lag our explanatory variables by two periods (i.e., two quarters in our setup) to address potential endogeneity issues.[5]

Our main coefficient of interest in this setup is that associated with competition, β. We use the Boone indicator, described in more detail below, as our main measure of competition: decreasing (increasing) values of the Boone indicator imply more (less) competition. As a result, finding a positive value of β would suggest that more competition is associated with lower stability, consistent with the *competition-fragility* hypothesis. In contrast, finding a negative coefficient value would imply that more competition increases bank stability, supporting of the risk-shifting paradigm of Boyd and De Nicoló (2005) and the *competition-stability* hypothesis.

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

Equation (1) is most often estimated using standard least squares regression techniques, producing conditional mean estimates of β and allowing inferences to be made of the *average* effect of changes in competition on bank stability (e.g., Boyd et al., 2006). If there is unobserved heterogeneity, however, then the estimated coefficient is not representative of the entire conditional stability distribution (e.g., Schaeck and Cihak, 2014; Cummins et al., 2017). To account for some heterogeneity in the sample, observed bank-level characteristics (i.e., size, business model, ownership) are sometimes explicitly included in the regression equation (e.g., Tabak et al., 2012; Liu and Wilson, 2016; Kick and Prieto, 2015). However, banks may also have sources of heterogeneity that cannot be easily observed and accounted for. For example, characteristics such as managerial ability and governance structures are not explicitly included in our data, which can cause unobserved heterogeneity. This unobserved heterogeneity may render the dependent variable in (1), and the error term, $\varepsilon_{i,t}$, to be independently, but *not* identically distributed across banks. If this is the case, then least squares estimates become inefficient, an issue that can be particularly acute if the dependent variable is characterized by long tails or extreme observations.

To deal with these issues, we employ quantile regression estimates (e.g., Koenker and Basset, 1978), which are considered robust relative to least squares estimates. Compared with the least squares estimator, the quantile regression estimates place less weight on outliers and are robust to departures from normality. Using our setup in (1), we can illustrate quantile regression as follows:

$$Stability_{i,t} = \alpha + \beta_\theta Competition_t + \Phi_\theta X_{i,t} + \Theta_\theta Y_t + \upsilon_{i,t} \text{ , with}$$

$$Q_\theta\left(Stability_{i,t} \mid Competition_t, X_{i,t}, Y_t\right) = \beta_\theta Competition_t + \Phi_\theta X_{i,t} + \Theta_\theta Y_t \text{ ,} \quad (2)$$

where *Stability* is the vector of bank stability, β is the vector of parameters on competition, Φ is the vector of parameters on bank-controls, Θ is the vector of parameters on macroeconomic controls, and υ is a vector of i.i.d. residuals. The term $Q_\theta\left(Stability_{i,t} | Competition_t, X_{i,t}, Y_t\right)$

denotes the θ^{th} conditional quantile of bank stability given competition, bank-level and macroeconomic controls. The term makes explicit the difference with the standard least squares estimator expressed in Equation (1), which provides information only about the effect of competition at the conditional mean of bank stability. The quantile regression produces coefficient estimates, β_θ, unique to each quantile θ of the conditional stability distribution.[6] Therefore, this technique provides information regarding the variation of the effect of competition on bank risk at different quantiles. This approach allows us to examine whether the effects of competition on bank-level stability differ across banks depending on each bank's underlying risk profile and answer the question of whether competition affects the risk-taking behaviour of relatively more stable banks differently from less stable banks.[7]

2.1. 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; Berger et al., 2009; Schaeck and Čihák, 2014; Ijtsma et al., 2017; Cummins et al., 2017). The Z-score is an accounting based measure of bank-level risk calculated as:

$$Z_{i,t} = \left(RoA_{i,t} + k_{i,t}\right) / \sigma_{i,t}^{RoA}, \tag{3}$$

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. Following the literature (e.g., Laeven and Levine, 2009), we interpret the Z-score as a 'distance to default'

[6] These coefficients can be interpreted as the partial derivative of the conditional quantile of Stability with respect to competition, which represents the marginal change in bank-level stability at the θ^{th} conditional quantile due to a marginal change in competition.

[7] Testing for equality of the coefficient estimates at various quantiles requires estimation of the variance-covariance matrix, which we derive using bootstrapping techniques (e.g., see Koenker and Hallock, 2001; Buchinsky, 1998). The test statistic is computed by using the variance-covariance matrix of the coefficients of the system of quantile regressions. The null hypothesis is that the coefficient on competition at the θ_s^{th}quantile is statistically the same as the one in the θ_t^{th} quantile (H_0: $\beta_{\theta_s} = \beta_{\theta_t}$). The alternative hypotheis is where the coefficients are not equal (H_0: $\beta_{\theta_s} \neq \beta_{\theta_t}$), This test allows us to investigate if the impact of competition on bank risk-taking varies across the conditional risk distribution.

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. 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 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. Figure 1 shows how the distribution of bank-level Z-scores has evolved over time in the UK. In addition, it clearly shows that raw Z-scores are asymmetrically distributed with a number of firms with scores significantly above the median. 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.

2.2. Explanatory variables

Our main competition indicator is the Boone indicator that measures competition from an efficiency perspective. The 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, leads to a relative increase in output of the most efficient firms in the market (e.g., Boone, 2008).[8] 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

[8] We follow Schaeck and Cihak (2014) using average variable costs as a proxy for efficiency in empirical estimation of the Boone indicator. We use annualised quarterly profits and variable cost data in the estimation to ensure quarterly volatility does not distort the results.

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. Appendix A describes this methodology in more detail.[9]

Figure 2 shows how the standard and adjusted Boone indicators evolved over our sample period, 1994 to 2013. 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 five years (e.g., during 1994 to 1999, 2004 to 2009 and 2010 to 2013); and (iii) high frequency increases and decreases in competition lasting one or two quarters throughout the period. 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 (2019). We use the adjusted Boone indicator in our analysis.[10]

We include a number of bank-level controls to account for other factors that influence bank stability. 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).[11] 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

[9] 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.
[10] We also examined the link between stability and competition using the standard Boone indicator. The results (available upon request) are qualitatively similar.
[11] 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.

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 (e.g., Balluck et al., 2016). To account for macroeconomic conditions, we incorporate three variables: the annualised real GDP growth per quarter from UK Office for National Statistics (ONS); unemployment (lagged 4 periods) from Labour Market statistics (ONS); and annualised inflation from consumer expenditure deflator (ONS). We expect bank-stability to be positively related real to GDP growth and negatively associated with unemployment and inflation.

3. 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.[12]

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

[12] 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.

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 bank-level 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%.[13] 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.[14] After applying the filtering rules, the total size of the sample available for panel regressions varies between approximately 15,000 and 16,500 observations.[15]

[13] Such firms tend to be niche institutions that do not compete directly with mainstream firms in the UK banking market.

[14] For completeness, the table includes variables used in our robustness checks discussed below.

[15] Appendix C 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

4. Results

This section compares and contrasts the results of estimating our main model of the relationship between competition and bank risk-taking using standard regression and quantile regression techniques. It also discusses results of models augmented to consider how this relationship changes due to the influence of firm type (as characterized by size and ownership) and regulatory pressure (as proxied by proximity to regulatory capital minimums). Finally, it outlines considerations for policymakers when thinking through the impacts of competition on financial stability more broadly.

4.1. Bank stability and competition: Main model comparisons

Table 2 presents the results of estimating equation (1) using standard OLS regression with fixed effects (columns 2) and equation (2) using quantile regression (in columns 3 to 7). Each model employs the adjusted Boone indicator as our primary measure of competition. We recognize that there is a chance that this measure could be endogenous, 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 misinterpreted as a sign of increased competition. To address this concern, we employed the lag of the Boone indicator and undertook formal tests to evaluate whether the lagged measure was in fact exogenous. In particular, we formally evaluate the null hypothesis that the specified endogenous regressors can be treated as exogenous. The endogeneity test is the difference of two Sargan-Hansen statistics: one for the equation with the smaller set of instruments, where the suspect regressors are treated as endogenous, and one for the equation with the larger set of instruments, where the suspect regressors are treated as exogenous. Under conditional homoskedasticity, this endogeneity test statistic is numerically equal to a Hausman test statistic (e.g., see Hayashi, 2000, pp. 233-34). The test

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are negatively correlated with the Boone indicator and the Lerner index, which we use in robustness checks discussed in Section 5.

statistic is distributed as chi-squared with degrees of freedom equal to the number of regressors tested. The endogeneity test statistic reported at the bottom of Table 2 suggests that we cannot reject the null hypothesis of exogeneity of our lagged competition measure.

Results under standard regression techniques (column 2) show that the coefficient on the Boone indicator is positive and statistically significant at the 1% level. Lower (i.e., more negative) values of the Boone indicator indicate that profits are allocated from less to more efficient banks in the market, thereby indicating that the market is characterized by a high degree of competition intensity. The positive coefficient on the Boone indicator suggests that, on average, the stability of banks operating in high-competition banking markets declines, which is consistent with the competition-fragility view.

When looking at the results generated under quantile regression (in columns 3 to 7), we find strikingly different relationships between bank stability and competition across the conditional risk distribution. In particular, the coefficient on the Boone indicator is negative for firms in the lower tail (high-risk end) of the distribution, indicating that already fragile institutions benefit from heightened competition.[16] This relationship switches from being non-positive to positive for firms in the upper tail (low-risk end) of the distribution, indicating that for the relatively more stable firms within the banking system, risk-taking behaviour is higher as competition mounts, consistent with the competition-fragility hypothesis and with the results under standard regression.

F-tests reject the null hypothesis of equality of the coefficient estimates on the Boone indicators across all quantiles, providing evidence of heterogeneous responses to competition.[17] This means that the effects of competition can be both stabilizing and

[16] Schaeck and Cihak (2014) and Kick and Prieto (2015) also find that lower Boone indicators (i.e., more competition) are associated with lower bank risk, supportive of the competition-stability view.
[17] 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.

destabilizing at the same time depending on the underlying risk-profile of the firms in the banking system. Figure 3 illustrates these effects more intuitively and shows that for the weakest institutions, more intense competition is associated with higher Z-scores (i.e., negative association), but that the relationship switches for healthier institutions. The figure also shows that the quantile estimates are statistically different from the conditional mean estimates (depicted by the dashed line) across a broad range of Z-scores.

Together, these findings imply not only that the effects of competition on stability may differ depending on the underlying stability 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. While the output from this table can help in gauging the trade-offs, previous research has found evidence that the relationship between competition and stability is sensitive to other features related to size, ownership and capitalisation (e.g., Tabak et al., 2012; Liu and Wilson, 2013; Schaeck and Cihak, 2014; Kick and Prieto, 2015) that could potentially influence the effects across the conditional risk distribution. We explore these other features in more depth below and what they mean for evaluating trade-offs and system-wide financial stability.

Under each approach the coefficients on the macroeconomic and bank-level controls are consistent with expectations. We find that firm-level stability increases as inflation and unemployment rates fall and as GDP growth increases. At the firm level, more reliance on relatively more volatile, less liquid non-retail (wholesale) deposit funding is associated with lower stability. 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 loan to asset ratio is insignificant in the standard regression estimation, it is significant in the quantile regressions, and suggests that balance sheet composition explains heterogeneities in stability across the conditional stability distribution. In particular, the results suggest that higher loan to asset ratios are positively (negatively) associated with stability at the low (high) end of the conditional risk distribution.

4.2. Bank stability and competition: Analysis by firm type (asset size and ownership)

To examine whether our results are driven by particular types of banking firms, we modify our main model to allow for heterogeneity in the parameters of the competition measure as follows:

$$Stability_{i,t} = \alpha + \delta FirmType_{f,t} + \beta Competition_t FirmType_{f,t} + \Phi X_{i,t} + \Theta Y_t + \varepsilon_{i,t}\ , \quad (5)$$

where $FirmType_{f,t}$ is a dummy variable classifying firms according to asset size and ownership characteristics. We consider size as a differentiating factor using total assets, given that the largest firms are those most capable of achieving higher leverage (lower equity ratios) due, for example, to too-big-to fail perceptions. We also consider ownership structure as a second differentiating characteristic due to previous theoretical arguments and empirical evidence on the effects of ownership on risk-taking incentives (e.g., see Iannotta et al., 2007). The ownership distinction allows us to understand better the effects that competition has on risk-taking at privately-owned / shareholder-owned (i.e., commercial banks), mutually-owned (i.e., building societies) and foreign-owned (i.e., international banks operating as UK subsidiaries) firms.[18] Examining the UK banking sector directly, Valnek (2009) finds significant differences in the performance and risk-taking between privately-owned banks and mutual building societies, providing yet further impetus for our added focus on ownership.

[18] This distinction between shareholder-owned versus mutually-owned institutions may also capture differences in the business models and legal constraints between banks and building societies which may affect the way that these firms respond to competition. For example, de-Ramon and Straughan (2019) show that building societies had systematically less market power than banks over the period 1994 to 2013 and attribute this to building societies' mutual ownership structure and regulatory constraints, which limits the types of loans they extend (retail and small business) and their funding sources (predominantly retail deposits).

With size-ownership criteria in mind, we construct firm type dummies for large banks (i.e., the top ten largest privately-owned commercial banks each period), large building societies (i.e., the top twelve mutually-owned building societies each period), small commercial banks, small building societies, and foreign-owned banks operating as UK subsidiaries of non-UK domiciled banking groups.[19] When estimating Equation (5), we exclude the large-bank dummy variable and treat these institutions as the reference firm type. The interaction term in this setup allows us to study the effect of competition on stability for each firm type, *f*, separately. Other studies have followed this approach based on interaction terms to investigate for different effects of competition (e.g., Liu and Wilson, 2013; Kick and Prieto, 2015) in traditional regression setups; however, we are unaware of any studies that have included such interactions in quantile regression.

Table 3 reports the results from this exercise. Similar to above, column 2 reports estimates from standard regression, while columns 3 to 7 include those from quantile regression. To save space, we only report parameter estimates for the interaction terms, which reflects the effect of competition for each firm type separately.[20] Results under standard regression provide some first clues as to where additional heterogeneity in firms' responses to competition may rest. In particular, it shows that the coefficient on the interaction term is negative for large banks, suggesting that the stability of these firms improves as competition intensity increases. For all other institutions, the coefficient is positive, indicating that competition has a destabilizing impact at these firms, although the effect appears only significant for small building societies.

Quantile regression results, however, suggests that the effects of competition at different points across the conditional risk distribution also depend, in more subtle ways, on

[19] Foreign-owned banks generally have a much smaller presence than domestic banks in UK retail deposit and lending markets. No foreign banks meet the definition for being a large bank using this process.

[20] The coefficients on the macro and bank-level control variables are similar to those reported in Table 2. The full set of results is available upon request.

the type of firm (as characterized by size and ownership). Table 3 shows that, with the exception of foreign-owned banks, the stability enhancing effects of competition are most evident in the most fragile domestic banks (see columns 3 to 5) and building societies (see column 3). The table also shows that interaction term for large banks is negative, implying that they generally benefit from higher competition. This relationship is also evident in for relatively less stable small banks (columns 4 and 5). The destabilizing effects of competition are most pronounced at the relatively more stable, small building societies (columns 4 to 7), large building societies (columns 5 and 6) and all foreign bank subsidiaries. F-tests (reported at the bottom of Table 3) reject the hypothesis of the equality of coefficients across quantiles for each firm type. This result further supports the idea that the effects of competition are different across the conditional-risk distribution, even after considering the possible additional influence that firm type (characterized by size and ownership) has on risk-taking.

Together, the results show that there is significant variation in the competition-firm stability relationship, both between and within firm types, which could have implications for assessing financial stability more broadly. This issue seems especially acute when comparing the large versus small firm effects, where the results indicate that competition has a generally stabilizing impact on all large banks and small, less-stable banks, but a destabilizing influence on small building societies and banks, especially those that are already more stable, and foreign subsidiaries. These results imply that bank regulators and policymakers may need to consider trade-offs when evaluating measures aimed at altering competition. Such trade-offs may also have important implications for gauging and assessing the effects of competition on sector-wide stability, which we highlight in more detail below.

4.3. Competition and bank stability: Analysis of regulatory pressure

Assessing these trade-offs, however, necessarily requires at least a fundamental understanding of how regulatory pressure might influence risk-taking incentives as competition in banking markets changes.[21] This sub-section examines whether and how regulatory pressure influences the effects of competition on risk-taking behaviour. To characterize regulatory pressure, we construct a dummy variable, regulatory pressure, set equal to one if a firm's regulatory capital buffer (i.e., actual capital ratio above its required minimum capital ratio) is within the bottom 10th percentile and zero otherwise. We modify Equations (1) and (2) to include this dummy variable and an interaction term with the Boone indicator. The coefficient on the interaction term in this setup provides a measure of the marginal effect on risk of competition at banks that are close to their regulatory minimum and, thus, under regulatory pressure. Finding a negative coefficient on the interaction term would be consistent with the idea that regulatory pressure reduces risk-taking incentives at these firms.

Table 4 reports the results of this estimation under both standard regression (column 2) and quantile regression (columns 3 to 7). To save space, we report only the coefficients on the Boone indicator, the interaction term and the regulatory pressure dummy variable. Results under standard regression (column 2) indicate that competition is associated with higher risk (lower Z-scores), but that regulatory pressure mitigates the destabilizing effects of competition on average. Similar results are evident in the quantile regression results for the relatively less risky / more stable institutions (in the 50th, 75tth and 95th quantiles) that also face such pressure. These results are consistent with the idea that regulatory discipline may make the *capital-at-risk effect* greater than the *franchise-value effect* (in the spirit of Hellman et al., 2000), thereby reducing incentives to take risks.

[21] This idea is in line with Fischer and Grout (2014) who suggest that a proactive approach to competition is most likely to improve stability. Although there may be an optimal point of competition in Banking due to fixed entry costs, the authors explain that the optimal competition level may be an academic question rather than practical one. A prudential regulator can always push banks to the right level of risk (undoing moral hazard) regardless of the amount of competition in the system.

4.4. Implications for system-wide bank stability

The results presented so far suggest that there may be real differences in the effects of competition within the system. Results (from the conditional mean regression) in Table 2 indicate that, on average, competition is destabilizing at the individual bank level, which, by extension, might also imply a similar impact for the banking system overall. At the same time, however, results from the quantile regression indicate this destabilizing relationship is evident only for institutions that are relatively more stable (i.e., have higher Z-scores) to begin with, while for the already less stable firms, quantile regression results suggest that competition has a stabilizing influence. These varied effects at the firm level mean that the effects on system-wide bank stability are not obvious and will depend on how the individual effects aggregate across the system.

In this subsection, we undertake a simple exercise to illustrate the implications for evaluating broader financial stability. More specifically, we trace the distribution of Z-scores in the UK banking sector over our sample period 1994 to 2013 and then show how this distribution changes in response to an increase in competition, i.e., moving the Boone indicator to bring it into line with the relatively higher levels of intensity characterizing the mid-1990s in the UK (see Figure 2). Previous papers have used measures of the central tendency of the distribution of bank-level Z-scores to proxy systemic risk of the entire banking sector. For example, Beck et al. (2010) uses the median Z-score to proxy banking sector risk within countries (or groups of countries).[22] Houston et al. (2011) employs the asset-weighted average of bank-level Z-scores to measure overall insolvency risk. Strobel (2011), however, shows that weighted average of Z-scores provides a downwardly biased measure of the weighted average probability of insolvency, raising questions about its use as

[22] This method underlies the Z-scores reported by the World Bank in its database of financial measures (e.g., see Beck et al., 2010).

a measure of systemic soundness. Nevertheless, he goes on to demonstrate that the weighted *n*th percentile of Z-scores gives an unbiased measure of the weighted *n*th percentile of probabilities of insolvency.

Taking the lead from these papers, we simulate the change in the distribution of Z-scores separately using the parameter from standard regression (which reflects the average effect) and the parameters from the quantile regression (which vary across firms depending on their underlying risk) and then examine how several measures of the Z-score distribution compare. Table 5 reports the results of this exercise focusing on institutions in the bottom quintile according to Z-scores (riskiest at the 20^{th} percentile and below) and compares the impact on comparable measures for the relatively most stable institutions in the top quintile (safest at the 80^{th} percentile and above) in our sample. We simulate two alternative Z-scores for each bank-time data point by increasing competition by 2 standard deviations, which is approximately a 3½ point reduction of the Boone indicator, or roughly equivalent to a return of competition to the more dynamic mid-1990s levels from the immediate pre-crisis levels in 2006-2007 (see Figure 2). The first simulation draws on the single parameter estimate from the conditional mean regression, and the second simulation relies on the quantile-specific parameter estimates from the quantile regression. We order the two simulated sets from riskiest to safest according to the original Z-scores. Table 5, columns 2 and 3, show the impact of increased competition on the riskiest quintile of firms. The simulation using the standard regression parameter (column 2) suggests that the competition-fragility effect will reduce the Z-score by 6%. In contrast the simulation using parameters from the quantile regression (column 3) suggests that a competition-stability effect dominates, and that the measures of Z-scores for this group of firms will improve by 13% to 18%. The table also shows that the firms in the riskiest quintile are also some of the largest firms, comprising over 22% of total system assets.

In contrast, Table 5, columns 4 and 5, show the results for the safest quintile. The unfavourable impact of increased competition on the insolvency risk of these firms using the quantile regression estimates is considerably higher than the effect using the conditional mean estimates. At the same time, however, the table shows that these firms tend to be some of the smallest, holding roughly 6% of system assets, making them potentially less important for systemic soundness overall. Together, the disparate results mean that policymakers, when evaluating the consequences of competition on banking system stability more widely, may need to consider trade-offs within the system.

Columns (6) and (7) show the effect of competition on the measures of the Z-Score for the full sample (12,265 observations). The simulation using the conditional mean parameters shows that competition reduces the Z-score by 6% while the simulation using the quantile regression suggest that the overall competition-fragility effect is more muted with asset-weight measures roughly the same or smaller. A regulator using the conditional regression results alone might conclude that competition will harm stability for all firms. Supplementing this with quantile regression can help uncover heterogeneous effects within the system that might lead a regulator to conclude that some firms, including potentially those that may are proportionately more important for sector stability overall, benefit from more intense competition. Combining the conditional mean and quantile regression results may help a regulator identify important trade-offs and where potentially unfavourable effects are more likely to result.

5. Robustness checks

We subjected the above findings to a number of robustness checks. Our additional checks show that the standard and quantile regression results are robust to (i) using different measures of bank risk, (ii) using different measures of competition and (iii) excluding crisis periods from our estimation sample. We discuss results from each of these tests in turn below.

5.1. Alternative measures of bank risk

We employed alternative measures of bank: (i) risk-adjusted profitability, i.e., $RoA_{i,t}/\sigma_{i,t}^{RoA}$, and (ii) risk-adjusted leverage, i.e., $k_{i,t}/\sigma_{i,t}^{RoA}$. Each measure represents a component of the of the Z-score; therefore, examining the relationship between competition with each separately in light of the impacts on the Z-score can shed light on the dominant factors underlying the competition-risk nexus.[23] In particular, the coefficients on the competition indicators in specifications involving the profitability measure can provide evidence on the risk-shifting effects as posited by Boyd and De Nicoló (2005). Finding negative value on β in Equations (1) and (2) would imply that as competition increases, risk-adjusted profitability increases, consistent with the risk-shifting paradigm and the *competition-stability* hypothesis. Further, the coefficients on the competition indicators in specifications employing the leverage measure, i.e., $k_{i,t}/\sigma_{i,t}^{RoA}$, can provide indirect evidence on the *franchise-value effect*. Positive values for β would imply that as competition increases, risk-adjusted capital ratios decrease, supporting the franchise value effect and the *competition-fragility* hypothesis.

To save space, Table 6 reports the coefficient estimates on the Boone indicator using risk-adjusted leverage (Panel A) and risk-adjusted profitability (Panel B). Panel A (column 2) shows that the coefficient on competition is positive under the standard regression approach, implying that capital ratios decline as competition mounts, consistent with competition-fragility. This finding supports the results of our main model using this regression technique. The coefficient estimates on competition under the quantile regressions are similar in sign

[23] Other studies have evaluated the impact of competition on 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).

and significance across the five quantiles to those reported in our main model. These results provide further evidence that the effects of competition on bank-risk are different across the conditional risk distribution. In this case, the negative coefficients found at the 5th and 25th quantiles (columns 3 and 4) indicate that risk-adjusted leverage improves as competition increases, while the positive coefficients reported across the remaining quantiles (columns 5 to 7) indicate that risk-adjusted capitalisation worsens as competition intensifies. The F-test rejects the null hypothesis of coefficient equality on the competition measure, consistent with the findings from the main model.

Panel B shows that the coefficients on competition are consistently negative (and statistically significant for the standard regression (column 2) and across all quantiles, suggesting that heightened competition improves risk-adjusted returns for all banks. The negative association is consistent with an outcome implied by mechanisms underlying Boyd and De Nicolo (2005): more competition decreases the credit risk of bank borrowers, which lowers credit losses and increases earnings overall. These results align better with the competition-stability hypothesis, which, together with the results on risk-adjusted capitalisation discussed above, imply that the two main competing theories on the effects of competition can hold concurrently depending on how measures of risk are defined. The combined results also indicate that the primary way in which relatively stable firms increase their risk profile in response to higher competition is by lowering capitalisation.

5.2. Alternative measures of competition

We employed different measures of competition, replacing the Boone indicator with measures of the Lerner index of market power and the Herfhindal Hirschman index (HHI) of concentration. Table 7 reports the results and shows that, in general, findings remain similar to those of the benchmark specifications (Table 2). The signs on coefficient estimates on the Lerner index (Panel A) and HHI (Panel B) are similar to those on the Boone indicator for the conditional mean and quantile regressions and should be interpreted in the same way. In addition, the table shows that equality of coefficient estimates across the quantiles can be rejected, providing further support that the findings using the Boone are robust.

5.3. Exclusion of crisis period

We excluded crisis periods from our estimation sample. Our main results employ an estimation period spanning the 2007-09 financial crisis as well as the UK small banks crisis of the early 1990s. Table 8 reports the results of this exercise and shows that the signs of the coefficients on competition under the conditional mean and quantile regressions are similar to those of our main model reported in Table 2. The coefficient on competition under conditional mean regression (column 2) is positive, consistent with competition-fragility. Under quantile regression, the signs move from being negative at the lower quantiles, suggestive of competition-stability for relatively weak firms, and positive at the higher quantiles, implying competition-fragility for the relatively most stable firms. The table also indicates we can reject the equality of these coefficients across quantiles, further confirming the results when using Z-scores.

6. Conclusions

This paper contributes to the ongoing debate regarding the effects of competition on bank risk. We estimate the relationship between bank-level risk and competition using quantile regression that permits a broader view of the effects across the conditional risk distribution. Very few studies have examined the effects of risk-taking effects of competition at different points of the conditional risk distribution (e.g., Schaeck and Cihak, 2014; Cummins at al., 2017). We compare results with those produced using standard regression techniques, which feature in much of the research on the effects of competition. The comparisons provide insights into the relationship that can help in reconciling some of the mixed findings in the previous literature and in highlighting implications for assessing the impacts of competition on banking system stability more broadly.

Using data on all banks and building societies in the United Kingdom from 1989 to 2013, we find that competition is, on average, destabilizing based on standard regression techniques. We find more nuanced results under quantile regression, where the destabilizing effects are most evident within institutions that are already relatively more stable (i.e., less risky). For the least stable firms, we find that competition robustly improves individual firm stability, as competition sharpens incentives for these firms to improve efficiency and increase capital ratios. Results are robust to different measures of risk and competition, as well as the exclusion of the crisis periods in the UK, which are potentially marked by significant government intervention that could have given rise to competitive distortions. These results support the idea that, when data sets have significant unobserved heterogeneity, substantial information gains can be realized by employing techniques that allow a thorough analysis at different points of the conditional risk distribution. This paper not only establishes the relationship between solvency risk and competition, but also provides insights into its relative variation along the conditional risk distribution.

Our results have implications for policymakers and regulators. Findings from quantile regression shed light on other dimensions of firm heterogeneity that may be important to consider when designing rules and policies that alter competition – or its effects -- in banking markets. In contrast to the results under standard regression which imply that competition-enhancing regulations may worsen the stability of individual banks, on average, the quantile regression results suggest that this outcome may not necessarily emerge across all banks. Instead, our results show such measures may decrease the risk-taking incentives of already risky banks and increase them at already healthy banks in the system, with implications for financial stability overall. Designing policies that substantially expand the scope of activities or increase the level of competition could potentially have unintended effects on already stable banks' incentives to operate efficiently and take on additional risks.

Whether these effects are good or bad for financial stability overall remains an open question that our paper has not directly addressed. Nevertheless, our study highlights some lessons for ongoing research on this issue. First, the impacts can potentially differ within a banking system. Our evidence using quantile regression is consistent with findings of previous researchers who also document disparate risk-taking effects at different points of the conditional solvency distribution (e.g., Schaeck and Cihak, 2014; Cummins et al., 2017). Such evidence may also help in reconciling some of the mixed results reported in previous studies examining the relationship between competition and stability. Second, we find evidence that promoting competition has benefits if it encourages already less efficient, less stable institutions to operate more efficiently and to reduce risk-taking, lowering the likelihood of failure. Put another way, a lack of competition can foster inefficiencies and risk-taking, increasing the likelihood of failure. Third, we find that a higher degree of regulatory pressure, reduces unintended effects of higher competition on bank risk-taking behaviour (e.g., as posited under the franchise value paradigm). This result is consistent with the idea that – regardless of the degree of competition in the banking market -- adjustments to regulatory measures, including to things like prudential requirements, may be effective in mitigating risks to individual banks and to the system overall that derive from competition.

References

Anginer, D., Demirguck-Kunt, A. and Zhu, M. 2014. 'How does competition affect bank systemic risk?', Journal of Financial Intermediation 23, 1-26.

Balluck, K., Galiay, A., Ferrara, G., and Hoggarth, G. 2016. 'The small bank failures of the early 1990s: another story of boom and bust', Bank of England Quarterly Bulletin, Vol. 56, No. 1, 41-51.

Beck, T. 2008. 'Bank competition and financial stability: friends or foes?', World Bank Policy Research Working Paper No.4656.

Beck, T., Demirguc-Kunt, A., and Levine, R. 2010. 'Financial institutions and markets across countries and over time: The updated financial development and structure database', The World Bank Economic Review 24, 77-92.

Beck, T., De Jonghe, O., and Schepens, G. 2013. 'Bank competition and stability: Cross-country heterogeneity', Journal of Financial Intermediation, Vol. 22, 218-244.

Berger, A., Klapper, L.F. and Turk-Ariss, R. 2009. 'Bank competition and financial stability', Journal of Financial Services Research, Vol. 35, 99-118.

Boone, J. 2008. 'A new way to measure competition', The Economic Journal, 1245-1261.

Boyd, J. and De Nicoló, G. 2005. 'The theory of bank risk taking and competition revisited', Journal of Finance, Vol. 60 No 3, 1329-1343.

Boyd, J., De Nicoló, G. and Jalal, A. 2006. 'Bank risk-taking and competition revisited: New theory and new evidence', IMF Working Paper, WP/06/297.

Buchinsky, M. 1998. 'Recent advances in quantile regression models: A practical guide for empirical research', Journal of Human Resources 33, 88-126.

Carletti, E., and Hartmann, P. 2003. 'Competition and financial stability: What's special about banking?' in Monetary History, Exchange Rates and Financial Markets: Essays in Honour of Charles Goodhart Vol. 2, ed. by P. Mizen, Cheltenham: Edward Elgar.

Cole, R. A. and White, L. 2012. 'Déjà vu all over again: The causes of the US commercial bank failures this time around', Journal of Financial Services Research, Vol. 42, 5-29.

Cole, R., Cornyn, A. B. and Gunther, J. 1995. 'FIMS: A new monitoring system for banking institutions', Federal Reserve Bulletin Vol. 81, 1-15.

Competition and Markets Authority 2016. Retail banking market investigation (available at: https://www.gov.uk/government/publications/retail-banking-market-investigation-overview).

Cruikshank, D. 2000. 'Competition in UK banking: A report to the Chancellor of the Exchequer', (available at: https://www.vocalink.com/media/1603/cruickshank_report_2000.pdf).

Cummins, J., Rubio-Misas, M. and Vencappa, D. 2017. 'Competition, efficiency and soundness in European life insurance markets', Journal of Financial Stability, Vol. 28, 66-78.

de-Ramon, S. and Straughan, M 2019. 'Measuring competition in the UK deposit-taking sector, 1989-2013', European Journal of Finance, 1-20.

de-Ramon, S., Francis, W. and Milonas, K. 2017. 'An overview of the UK banking sector since the Basel Accord: insights from a new regulatory database', Bank of England Staff Working Paper No 652.

Dickinson, S., Humphry, D., Siciliani, P., Straughan, M. and Grout, P. 2015. 'The Prudential Regulation Authority's secondary competition objective', Bank of England Quarterly Bulletin, Vol. 55, No 4.

Fernandez de Guevara, J., Maudos, J. and Perez, F. 2007. 'Integration and competition in the European financial markets', Journal of International Money and Finance 26, 26-45.

Fischer, P. and Grout, P. 2014. 'Competition and prudential regulation', Bank of England Staff Working Paper No 675.

Hayashi, F. 2000. Econometrics. Princeton: Princeton University Press.

Heffernan, S. 2002. 'How do UK financial institutions really price their banking products?' Journal of Banking & Finance, Vol. 26, 1997-2016.

Heckman, L. J. 1979. "Sample Selection Bias as a Specification Error." Econometrica. January, 41(1), 153-61.

Hellman, T., Murdoch, K. and Stiglitz, J.E. 2000. 'Liberalisation, moral hazard in banking and prudential regulation: are capital requirements enough?' American Economic Review Vol. 90, 147-165.

Houston, J., Lin, C., Lin, P., May, Y., 2010. 'Creditor rights, information sharing, and bank risk taking', Journal of Financial Economics 96, 485-512.

Iannotta, G., Nocera, G. and Sironi, A. 2007. 'Ownership structure, risk and performance in the European banking industry', Journal of Banking and Finance, Vol. 31, 2127-2149.

Independent Commission on Banking, 2011. (available at: webarchive.nationalarchives.gov.uk_bankingcommission.independent.gov.uk)

IJtsma, P., Spierdijk, L. and Shaffer, S. 2017. 'The Concentration-stability controversy: new evidence from the EU-25', Journal of Financial Stability 33, 273-284.

Keeley, M. 1990. 'Deposit insurance, risk and market power in banking', American Economic Review, Vol. 80, 1183–2200.

Kick, T., and Prieto, E. 2015. 'Bank risk and competition: Evidence from regional banking markets', Review of Finance 19, 1185-1222.

Klemperer, P. 1995. 'Competition when consumers have switching costs: An overview with applications to industrial organization, macroeconomics, and international trade', The Review of Economic Studies, Vol. 62 No 4, 515-539.

Koenker, R. and Basset, G. 1978. 'Regression quantiles', Econometrica 46, 33-50.

Koenker, R. and Hallock, K. F. 2001. 'Quantile regression', Journal of Economic Perspectives 15, 143-156.

Laeven, L. and Levine, R. 2009. 'Bank governance, regulation, and risk-taking', Journal of Financial Economics Vol. 93 (2), 259-275.

Liu, H. and Wilson, J.O.S. 2013. 'Competition and risk in Japanese banking', The European Journal of Finance, Vol. 19 (1), 1-18.

Marcus, A.J. 1984, ‘Deregulation and bank financial policy’, Journal of Banking and Finance, Vol. 8, 557-565.

Matthews, K., Murinde, V. and Zhao, T. 2007. ‘Competitive conditions among the major British banks’, Journal of Banking and Finance, Vol. 31, 2025-2042.

Poghosyan, T. and Čihák, M. 2011. “Determinants of bank distress in Europe: evidence from a new data set”, Journal of Financial Services Research, Vol. 40, 163-184.

Schaeck, K. and Čihák, M. 2014. ‘Competition, efficiency, and stability in banking’, Financial Management, Spring, 215-241.

Strobel, F. 2011. ‘Bank Insolvency Risk and Different Approaches to Aggregate Z-Score Measures: A Note’, Applied Economics Letters, Vol. 18, pp. 1541–1543.

Tabak, B, Fazio, D, and Cajueiro, D. 2012. ‘The relationship between banking market competition and risk-taking: do size and capitalization matter?’, Journal of Banking & Finance, Vol. 36, 3366–3381.

Valnek, T. 1999. ‘The comparative performance of mutual building societies and stock retail banks’, Journal of Banking and Finance, Vol 23, 925-938.

Vives, X. 2011. ‘Competition policy in banking,’ Oxford Review of Economic Policy, Volume 27, Issue 3, October, 479–497.

Zigraiova, D. and Havranek, T. 2016. ‘Bank competition and financial stability: much ado about nothing?’, Journal of Economic Surveys, Vol. 30, No 5, 944–981.

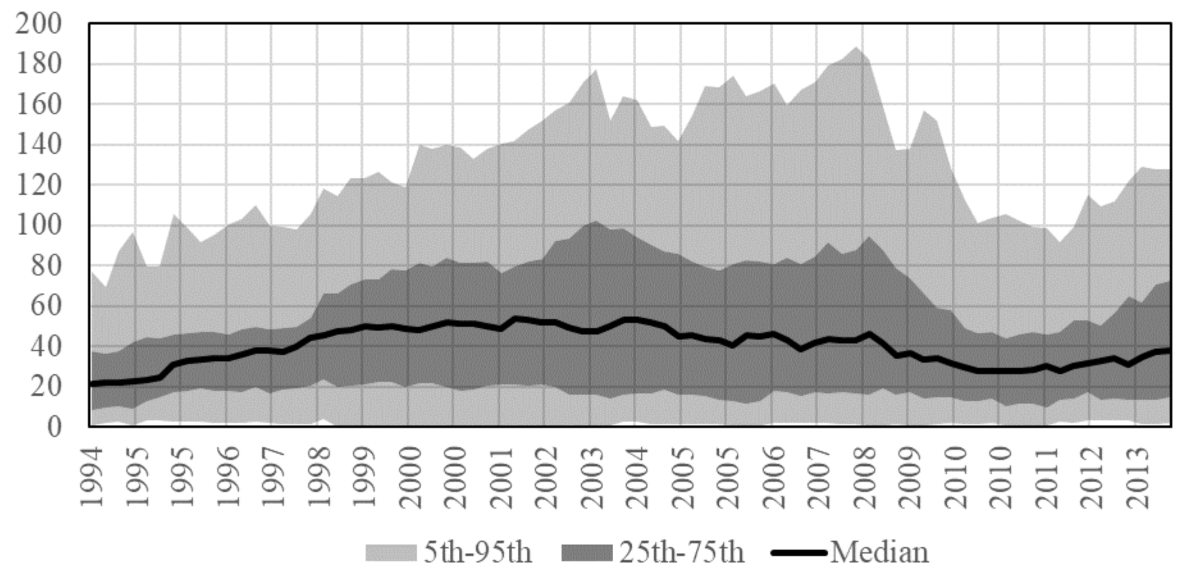

Fig 1. Evolution of bank-level Z-scores (1993 to 2013).

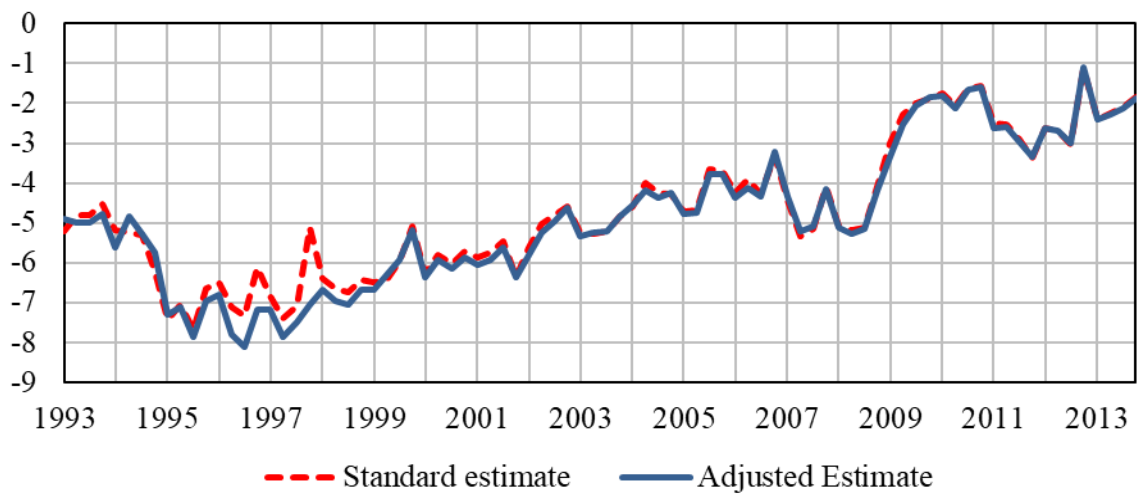

Fig 2. Evolution of the Boone indicator (1993 to 2013).

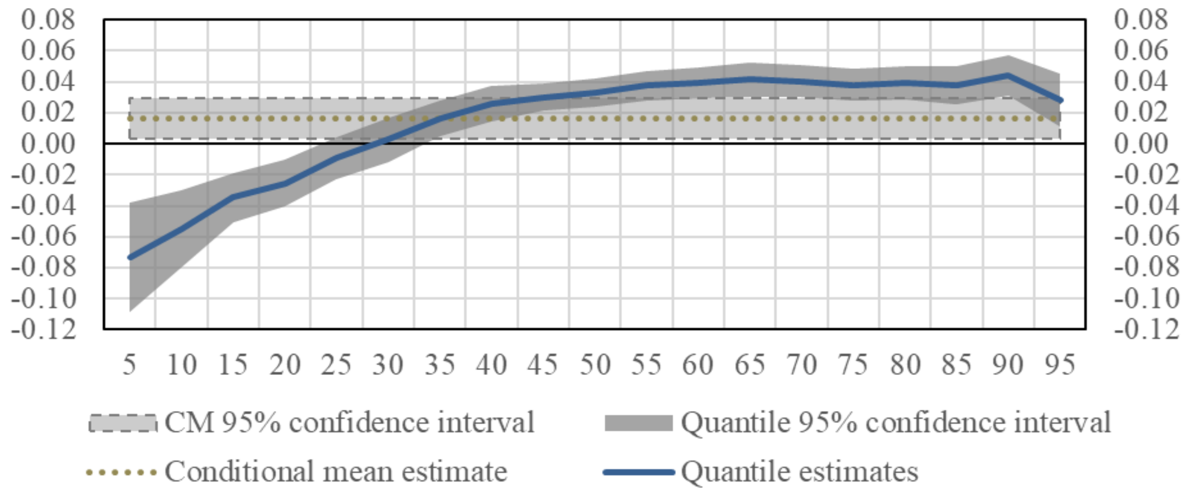

Fig 3. Marginal impact of competition at different points of the conditional risk distribution.

Table 1
Summary statistics

Variable	Number Observations	Mean	Standard Deviation	Median	Minimum	Maximum
Dependent Variables						
Stability measures						
Z-score	15,528	51.381	45.379	37.510	0.431	282.845
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
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
Total loans to assets ratio (%)	16,468	53.293	26.948	61.886	0.000	98.216
Provisions to assets ratio (%)	16,507	1.117	2.896	0.266	0.000	34.462
Non-retail deposit funding (%)	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
Capital buffer over requirements (%)	15,624	19.224	39.214	5.902	0.000	353.286
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

Notes: This table reports summary statistics on variables used in the estimations examining the link between competition and stability. All financial variables are derived from the Bank of England HBRD database (de-Ramon et al., 2017). The database covers the period from December 1989 to December 2013 at quarterly frequency. Macroeconomic control variables come from the UK Office for National Statistics. The data used in the estimations (and reported here) are winsorised by eliminating observations at the 1st and 99th percentiles.

Table 2
The effect of competition on bank-level stability

	Standard Regression	Quantile Regression				
		5th	25th	50th	75th	95th
Dependent Variable: ln(Z-score)	(2)	(3)	(4)	(5)	(6)	(7)
Competition Indicator						
Boone indicator	0.018***	-0.073***	-0.009	0.033***	0.038***	0.028***
Bank-level controls						
Total assets	-0.065***	-0.075***	-0.084***	-0.080***	-0.068***	-0.043***
	(0.018)	(0.012)	(0.004)	(0.004)	(0.004)	(0.007)
Loans-to-assets ratio	-0.038	0.814***	0.248***	-0.095**	-0.185***	-0.133**
	(0.075)	(0.112)	(0.054)	(0.037)	(0.042)	(0.064)
Provisions-to-assets ratio	-2.207***	-15.251***	-11.991***	-5.070***	-3.333***	-3.073***
	(0.515)	(1.628)	(1.280)	(0.526)	(0.309)	(0.464)
Non-retail deposit funding	-0.157***	-0.513***	-0.488***	-0.545***	-0.443***	-0.268***
	(0.054)	(0.088)	(0.030)	(0.030)	(0.031)	(0.048)
Non-interest revenue	-0.012***	-0.022***	-0.018***	-0.018***	-0.017***	-0.016***
Macroeconomic controls						
GDP growth	3.035***	6.302***	3.132***	3.681***	3.009***	0.642
	(0.337)	(1.434)	(0.647)	(0.451)	(0.411)	(0.650)
Inflation	-0.028***	-0.034	-0.015*	-0.037***	-0.038***	-0.030***
	(0.006)	(0.024)	(0.009)	(0.007)	(0.007)	(0.010)
Unemployment rate	-0.095***	-0.055***	-0.075***	-0.100***	-0.090***	-0.060***
	(0.005)	(0.018)	(0.007)	(0.006)	(0.006)	(0.008)
Constant		2.703***	4.515***	5.588***	5.938***	6.079***
		(0.201)	(0.065)	(0.045)	(0.061)	(0.074)
R-squared	0.085	0.117	0.165	0.177	0.178	0.126
Number of observations	12262	13441				
Exogeneity test for competition p > Chi-square(1)	0.207					
F-test for equality of coefficient on competition variable across quantiles p > F(4, 13427)		10.558***				
F-tests for equality of coefficient on competition variable between quantiles						

5th Quantile	29.477***	40.339***	28.458***	28.162***
25th Quantile		7.504***	2.577	3.674*
50th Quantile			0.113	0.329
75th Quantile				0.722

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogeneity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in all specifications is the natural log of the Z-score, and the competition measure is the twice-lagged, deposit-adjusted Boone indicator (see Appendix A for details). Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all banks in the sample and quarterly data between 1994 and 2013. All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

Table 3
Regression of ln (Z-Score) on competition – analysis of the influence of firm type on the effect of competition

	Standard Regression	Quantile Regression				
		5th	25th	50th	75th	95th
Dependent variable: ln (Z-Score)	(2)	(3)	(4)	(5)	(6)	(7)
Interaction terms with Boone indicator:						
Large UK banks	-0.0507*	-0.3224***	-0.0281	-0.0236	-0.0227	-0.0603**
	(0.0266)	(0.0322)	(0.0316)	(0.0231)	(0.0372)	(0.0304)
Large building societies	0.0119	-0.0731***	-0.0138	0.0697***	0.0675***	-0.0477
	(0.0121)	(0.0197)	(0.0138)	(0.0224)	(0.0179)	(0.0434)
Small building societies	0.0252***	-0.0472***	0.0535***	0.0725***	0.0892***	0.0661***
	(0.0073)	(0.0113)	(0.0068)	(0.0069)	(0.0099)	(0.0118)
Small UK banks	0.0154	-0.0426	-0.0509***	-0.0475***	-0.0150	0.0224
	(0.0119)	(0.0262)	(0.0155)	(0.0136)	(0.0120)	(0.0208)
Foreign banks	0.0113	0.0613*	0.0354***	0.0126	0.0023	0.0299*
	(0.0108)	(0.0323)	(0.0110)	(0.0092)	(0.0106)	(0.0163)
Bank-level controls	Yes	Yes				
Macroeconomic controls	Yes	Yes				
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.0859	0.1883	0.1999	0.2065	0.2047	0.2050
Number of observations	12,262	13,441				
Exogeneity test for competition and interaction terms p > Chi-square(5)	3.177					
F-test for equality of coefficient on interac terms across quantiles p > F(4,13423):						
Large UK banks		19.840***				
Large building societies		10.933***				
Small building societies		30.424***				
Small UK banks		4.143***				
Foreign banks		2.509**				

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogeneity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in all specifications is the natural log of the Z-score, and the competition measure is the twice-lagged, deposit-adjusted Boone indicator (see Annexe A for details). The interaction terms measure the effects of competition for (i) large, shareholder-owned institutions (large UK banks); (ii) small, shareholder-owned institutions (small UK banks); (iii) large, depositor-owned institutions (large building societies); (iv) small, depositor-owned institutions (small building societies); and (v) foreign-owned banks. Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all institutions in the sample and quarterly data between 1994 and 2013. All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

Table 4
Regression of ln(Z-Score) on competition – analysis of the influence of regulatory pressure on the effect of competition

	Standard Regression	Quantile Regression				
		5th	25th	50th	75th	95th
Dependent variable: ln (Z-Score)	(2)	(3)	(4)	(5)	(6)	(7)
Boone indicator	0.031***	-0.0776***	-0.0035	0.0358***	0.0435***	0.0337***
	(0.0074)	(0.0182)	(0.0068)	(0.0055)	(0.0054)	(0.0082)
Boone indicator*Regulatory pressure	-0.192***	0.0250	-0.0331**	-0.0532***	-0.0548***	-0.0672**
	(0.0473)	(0.0786)	(0.0168)	(0.0188)	(0.0142)	(0.0295)
Regulatory pressure	-0.947***	0.1151	-0.3351***	-0.4424***	-0.4495***	-0.5612***
	(0.2761)	(0.4579)	(0.0960)	(0.1134)	(0.0736)	(0.1340)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.0770	0.1174	0.1618	0.1714	0.1787	0.1847
Number of observations	12,262	13,441				
Exogeneity test for competition and interaction p > Chi-square(2)	1.614					
F-test for equality of quantile coefficients p>F(4,12521)						
Boone indicator		7.362***				
Boone indicator*Regulator pressure		2.745***				

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogeneity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in all specifications is the natural log of the Z-score, and the competition measure is the twice-lagged, deposit-adjusted Boone indicator (see Annexe A for details). The regulatory pressure dummy variable is one if a firm has a capital buffer in the smallest decile and zero otherwise. Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all banks in the sample and quarterly data between 1994 and 2013. All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

Table 5
Impact of increasing competition on aggregate solvency risk measured using Z-scores

	Impact on Z-score (Riskiest Firms)[1]		Impact on Z-Score (Safest Firms)[2]		Impact on Z-Score (All Firms)	
	(2)	(3)	(4)	(5)	(6)	(7)
Regression methodology	Standard	Quantile	Standard	Quantile	Standard	Quantile
Impacts of competition on:						
Unweighted average	-6%	17%	-6%	-10%	-6%	-9%
Asset-weighted average	-6%	15%	-6%	-11%	-6%	-7%
Unweighted median	-6%	18%	-6%	-12%	-6%	-10%
Asset-weighted median	-6%	13%	-6%	-13%	-6%	-4%
Suggested impact on systemic soundness	Fragility	Stability	Fragility	Fragility	Fragility	Fragility
Share of total assets	22.2%		5.9%		100.0%	

Notes: This table reports the percentage change in the simple average, asset-weighted average, simple median and asset-weighted median of bank-level Z-scores for all firms and for firms in the first and fifth risk quintiles. (1) data between 0th and 20th percentiles; (2) data between 80th and 100th percentiles.

Table 6
Robustness tests for the effect of competition on bank stability – alternative measures of bank stability

	Standard Regression	Quantile Regression				
		5th	25th	50th	75th	95th
	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Dependent variable: Risk-adjusted leverage ratio						
Competition (Boone Indicator)	2.204***	-0.504***	-0.293**	1.536***	3.289***	4.307***
	(0.245)	(0.106)	(0.133)	(0.180)	(0.265)	(0.723)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.103	0.037	0.107	0.153	0.193	0.175
Number of observations	12248	13423				
Exogeneity test for competition p > Chi-square(1)	2.394					
F-test for competition parameter equality p > F(4,13423)		34.306***				
Panel B: Dependent variable: Risk-adjusted returns						
Competition (Boone Indicator)	-0.285***	-0.311***	-0.244***	-0.221***	-0.283***	-0.539***
	(0.018)	(0.020)	(0.014)	(0.014)	(0.022)	(0.055)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.107	0.095	0.102	0.096	0.093	0.129
Number of observations	12223	13414				
Exogeneity test for competition p > Chi-Square(1)	2.662					
F-test for competition parameter equality p > F(4,13414)		12.779***				

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogeneity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in Panel A is the risk-adjusted leverage ratio, while in Panel B, the dependent variable is the risk-adjusted return on assets. In all specifications the competition measure is the twice-lagged, deposit-adjusted Boone indicator (see Annexe A for details). Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all banks in the sample and quarterly data between 1994 and 2013. All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

Table 7
Robustness tests for the effect of competition on bank stability - Alternative measures of competition

	Standard Regression	Quantile Regression				
		5^{th}	25^{th}	50^{th}	75^{th}	95th
Dependent variable: ln (Z-Score)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Competition (Lerner Index)	2.160***	-1.365	0.683	2.329***	1.960***	3.670***
	(0.366)	(1.766)	(0.641)	(0.482)	(0.386)	(0.712)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.086	0.114	0.165	0.176	0.176	0.127
Number of observations	12262	13441				
Exogeneity test for competition p>Chi-Square (1)	2.367					
F-test for competition parameter equality p>F(4, 13441)		3.298**				
Panel B: Competition (HHI - assets)	0.076***	-0.325***	-0.022	0.116***	0.165***	0.145***
	(0.025)	(0.084)	(0.029)	(0.021)	(0.022)	(0.033)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.085	0.117	0.165	0.176	0.177	0.127
Number of observations	12262	13441				
Exogeneity test for competition p>Chi-square (1)	0.259					
F-test for competition parameter equality p>F(4, 13441)		9.706***				

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogeneity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in all specifications is the natural log of the Z-score, and the competition measure is the twice-lagged, Lerner index (Panel A) and the HHI for assets (Panel B). Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all banks in the sample and quarterly data between 1994 and 2013. All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

Table 8
Robustness tests for the effect of competition on bank stability – Sample excluding crisis periods (prior to 1994 and after 2007)

	Standard Regression	Quantiles Regression				
		5th	25th	50th	75th	95th
Dependent variable: ln (Z-Score)	(2)	(3)	(4)	(5)	(6)	(7)
Competition (Boone Indicator)	0.012	-0.038	-0.022	0.003	0.024*	0.054**
	(0.010)	(0.034)	(0.017)	(0.013)	(0.013)	(0.022)
Bank-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes					
Constant		Yes	Yes	Yes	Yes	Yes
R-squared	0.080	0.187	0.207	0.200	0.187	0.123
Number of observations	8105	8699				
Exogeneity test for competition p>Chi-Square (1)	0.405					
F-test for competition parameter equality p>F(4,8699)		2.820**				

Notes: Column (2) reports the estimation of Equation (1) by panel fixed-effects exactly-identified instrumental variables. The exogenity test statistic (based on the Hausman endogeneity test) reported does not reject the null that the competition measure is exogenous. Columns (3) to (7) report the estimation of Equation (2) by quantile regression; Pseudo-R2 are generated for the quantile regressions. The F-stat reported rejects the null hypothesis that all estimated coefficients on the competition parameter are equal across quantiles. The dependent variable in all specifications is the natural log of the Z-score, and the competition measure is the twice-lagged, deposit-adjusted Boone indicator (see Annexe A for details). Common macroeconomic and bank-level controls from the literature are included. The conditional mean and quantile regression estimations use all banks in the sample and quarterly data between 1994:Q1 to 2007:Q2 (excluding data from before 1994, during the UK small banks crisis, and after the start of the 2007-09 financial crisis). All explanatory variables enter with two lags except unemployment which enters with four lags. ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parenthesis. For the quantile regression, standard errors are estimated using bootstrap procedures and are consistent across all quantiles.

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, 2019 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:

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

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:

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

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:

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

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:

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

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: 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
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
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 (Total assets)	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
Non-retail deposit funding (%)	Wholesale funding (i.e., non-Retail deposits)/total deposits	Bank HBRD and authors' calculations
Non-interest revenue to total rev (%)	(Trading, fees and other non-interest revenue)/total revenue	Bank HBRD and authors' calculations
Capital buffer over requirements (%	Total capital minus capital requirement/risk weighted assets	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. Bank HBRD is the Bank of England's Historical Regulatory Database (e.g., see de-Ramon et al., 2017).

Appendix C: Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(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)	**GDP growth**	0.0316*	-0.4323*	-0.0246	-0.4833*	1.0000						
(6)	**Inflation**	-0.0792*	0.2125	0.1407	0.4121*	-0.1934	1.0000					
(7)	**Unemployment rate**	-0.1800*	0.1239	0.3658*	-0.0275	-0.2132	0.3032*	1.0000				
(8)	**Non-interest revenue to total rev**	-0.3813*	0.1847*	0.1264*	0.1532*	-0.0537*	0.0436*	0.0508*	1.0000			
(9)	**Bank Size (log assets)**	-0.1711*	0.0958*	-0.0008	0.1165*	-0.0504*	0.0082	-0.0830*	-0.0019	1.0000		
(10)	**Provisions to assets ratio**	-0.1867*	-0.1123*	0.0132	-0.1372*	0.0719*	-0.0158*	0.0909*	0.0575*	-0.1046*	1.0000	
(11)	**Total loans to assets ratio**	0.2586*	-0.0411*	-0.0257*	-0.0425*	0.0059	-0.0192*	-0.0152*	-0.4596*	0.1130*	0.0484*	1.0000
(12)	**Wholesale to total deposits ratio**	-0.2503*	-0.0726*	-0.0122	-0.0726*	0.0422*	0.0081	0.0409*	0.1851*	0.1410*	0.0974*	-0.2811*