DETECTING ZOMBIE BANKS

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Abstract

Capital adequacy has become the main regulatory tool to achieve financial stability in the last twenty years. While most papers analysed the effect of capital adequacy on risk taking, there is a lack of evidence on the relationship between deleveraging and the return on equity capital. In this paper, we examine the evolution of the banking system in Japan over the period 2000-2016, where the re-capitalization issue has already played a major role in policy making. Specifically, we estimate the shadow return on equity capital for both listed and unlisted banks by measuring the loans-funding-equity technology through the dual cost function, controlling for risk exposure and bad loans, and accounting for both the standard asset-based model of bank outputs, and income-based model. Such an approach is likely to be important if the central bank permits banks with unsustainable balance sheets to continue in existence, and we refer to this as zombie banking. Overall, our results show that deleveraging did reduce the shadow return on equity for the City banks. We also find that that the presence of 'zombie' banks was concentrated and large among the smaller less diversified Regional Banks.

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1. Introduction

During the 2007-2008 financial crisis, worldwide banks received an outstanding amount of financial help from various Governments. Wide ranges of interventions were employed to enforce the stability of banking systems: some actions have been evident (from underwriting bank bonds or equity to banks' nationalization) and other types of help have been less evident (such as the lender of last resort or forcing mergers between banks through a moral suasion). In the US banking[1], the Treasury Department invested between October 2008 and April 2009 about 204.6 USD billions in hundreds of banks through its Capital Purchase Program (of which 92.6 were repaid) in an effort to prop up capital and support new lending (Calabrese et al., 2017). In Europe, governments used a total of €1.6 trillion of state aid to support the banking sector, in the form of guarantees and liquidity support (1.2 trillion Euro), recapitalization (288 million Euro) and asset relief measures (121 million Euro) between 2008 and 2011[2]. Without such a massive set of interventions, a large number of insolvent banks would have collapsed and, this would have also caused solvent banks to collapse due to the contagion effect. In the case of Japan there has been a very long process of restructuring and dealing with problem loans. For example, in the past two decades there were five waves of capital injections from 1998-2009 including Financial Revitalisation Plan, and the wave of bank consolidation among large banks to strengthen their resistance to financial severity (to name a few). The problem however persisted, fuelled by continuous lending to unprofitable firms and weak macroeconomic performance (i.e., high public-sector indebtedness and slow growth) of the banking system. Thus, a weaker growth has undermined a successful bank recapitalisation process in Japan.

Our paper aims to develop a new approach to identify the banks that would have collapsed without Government help (labeled as "zombie banks"). Specifically, we address the following research question: how can we identify banks (either quoted or non-quoted) that are solvent due to the Government help? Various papers attempted to answer these questions by looking at various bank's operating features such as efficiency and profitability (Park and Weber, 2006; Fukuyama and Matousek, 2017), firms receiving subsidized credit (Calabrese et al., 2017) and bank's distance to default (Harada et al., 2010). All these approaches have somehow limitations: methods based on bank's operating features suffer from endogeneity problems (as noted by Caballero et al., 2008, page 1947: "*almost by definition, industries dominated by zombie firms would have lower profitability, and likely also have low growth*"). Methods focusing on distance to default can accurately be measured only for listed banks; and methods based on subsidized credit can be run for non-financial companies. As such, there is not yet an established approach to identify zombie banks (both listed and unlisted) using a one-off rule.

[1] Source of data: CNN Money (http://money.cnn.com/news/specials/storysupplement/bankbailout/)

[2] Source of data: Liikanen report (2012, page 21)

Our approach is based on the business studies cornerstone. Banks (as any other companies) have to provide a positive return to shareholders: a rational investor would not invest in project whose rate of return is negative. As such, banks whose rate of return is negative can be considered intrinsically “defaulted”: only Government may prevent their failure by accepting to have a negative expected rate of return. As such, we identify zombie banks focusing on the short term (banks with at least one negative value for the shadow return on equity), medium term (i.e., banks with a negative shadow return on equity in a year for three or four consecutive years) or long term (i.e., banks with a negative shadow return on equity in a year for five or more consecutive years). Since a large number of banks is unlisted, we develop a new approach that can be applied both to listed and unlisted banks. Specifically, we estimate the shadow return on equity capital for both listed and unlisted banks by measuring the loans-funding-equity technology through the dual cost function, controlling for risk exposure and bad loans, and accounting for both the standard asset-based model of bank outputs, and income-based model.

Overall, we find that that deleveraging did reduce the shadow return on equity for the City banks. We also find that that presence of ‘zombie’ banks was concentrated and large among the smaller less diversified Regional Banks. Our results have important policy implication since provide Central Banks new insights on how identifying zombie banks (banks with unsustainable balance sheets). We focus on Japanese banks since this is a pivotal case of study. Japan have experienced a deep financial crisis from the late 1990s and the problem of zombie banks, zombie lending (loans provided by these zombie banks to help borrowers), and zombie lending (loans provided to borrowers that have survived only because of bank loans).

The remainder of the paper is organized as follows. First, we review bank capital and related literature (section 2). Then, we provide readers with a theoretical framework suggesting how the idea of the dual cost function can be used to measure the bank decision-making that underpins optimizing behaviour subject to the familiar balance sheet constraint that loans and investments should be balanced by deposits, borrowed funds and equity capital. Following this, a formal model of cost minimizing behaviour is used to investigate duality and to derive, via the envelope theorem, a model for estimating the shadow return on equity arising from the equity-capital constraint[3] (section 3). Then, we present our data (section 4) and empirical model (section 5). Using the results of the fitted cost model, we discuss our estimates in the section 6. Finally, we offer analytical and policy conclusions from this analysis (section 6).

2. Related literature

The theory of bank capital and capital standards is well developed. Earlier studies focused mainly on describing the role of bank capital (Taggart and Greenbaum, 1978) or on the impact of credit crunch and found that poorly capitalised banks contracted more than better capitalised peers (Peek and Rosengren, 1995). Also,

[3] Estimating cost of equity is difficult when some banks are not listed on the stock market, even though the necessity to raise equity capital remains important (see for example Berger et al., 1995). Our approach helps circumvent this problem.

better capitalised banks have generally been viewed as safer (Keeley and Furlong, 1990). A different strand of literature later emerged focusing entirely on capital requirements and imperfect information problem (Thakor, 1996). As the importance of financial intermediaries continued to grow in all economies, so has the role they play received more scrutiny, but especially in respect to the regulation of bank capital (i.e., the role capital plays in banks' soundness and risk-taking incentives; or from its role in the corporate governance of banks; or more recently capital's influence on the competitiveness of banks). Consequently, Diamond and Rajan (2000) first formulated the model that explains optimal bank capital structure trade-off effects on liquidity creation, costs of bank distress, and the ability to force borrower repayment. More importantly the proposed theoretical framework is also able to consider the consequences of different recapitalization policies in a banking crisis. However, it is important to highlight that unintended consequences of regulatory capital requirements are also possible. Berger et al., (1995) provides evidence on how regulatory capital requirements may have had unintended effects on bank portfolio risk and/or created allocative inefficiencies (via explosive growth of securitization in the 1980s, or via reduction in commercial lending).

More recently, a number of researchers have given attention to costs management and benefits across the entire balance sheet when subjected to capital regulation (with particular focus on incentives and capital requirements). For example, Milne (2002) focuses on the incentive effects generated by capital regulation, where banks' efforts are aimed at avoiding ex post penalties. Estrella (2004) develops a theoretical framework that allows a bank to adjust its liability structure. Some studies also focus on regulatory constraints and as a consequence ability of banks' to benefit from loans (hence reducing their performance). Again, here the results are mixed, and where for example, Oino (2018), Pelster et al., (2018) and Coccorese and Girardone (2020) find that despite the increase in capital the expansion or growth has surpassed the unit change in capital (although the estimated impact is relatively weak for the later study). Contrary to the positive impact findings, Martynova et al., (2020) poise that more profitable banks have higher risk-taking incentives, consistent with a weakening of bank capital regulation.

We aim to make a number of contributions to the existing literature. Firstly, we relate to the literature on impact of deleveraging and re-capitalization. The Japanese banking system makes for an important and topical case study because of the financial crises that it experienced in the end of the 1990s and the beginning of the decade from 2000. The Japanese banking system has been extensively studied (e.g., Hoshi and Kashyap, 2000 and 2004; Caballero et al., 2008) for the continuous misdirected banking lending from the late 1990s. Japanese banks have lent to otherwise insolvent firms for a long-time period accumulating a huge amount of non-performing loans. The first peak of the banking crisis emerged in 1997 due to the stock market crisis and the high level of non-performing loans (NPL) problem for some large banks. The political and regulatory response in Japan was initially to minimize the existence of the problems and the only real intervention was to recapitalize the offending banks by temporarily nationalizing them. This calmed the financial markets, but banks were surprisingly unconstrained by regulators (apart the appearing compliance to the Basel I capital standards). Of course, the problem of non-performing loans persisted and the capital shortage soon re-emerged

(Hoshi and Kashyap, 2010) and all financial analysts recognized that the Japanese banking system was insolvent as of August 2002 (Kashyap, 2002). On request of the Japanese Financial Services Agency (FSA), Japanese banks started to rebuild their capital from March of 2003 to March of 2007. From 2007 onwards, the worldwide credit turmoil also affected Japan and the crisis was made even more severe in Japan due to the great east earthquake in March 2011. More recent, Nakashima (2016) and Kasahara et al., (2019) also investigated the effects of bank recapitalization policy. In the case of Nakashima (2016), the author concludes that the capital injections significantly reduced the financial risks but at the same time did not substantially improve the profitability of the capital-injected banks and their lending behaviour. For Kasahara et al., (2019), capital injections had a substantial reallocation effect, shifting investments from low- to high-productivity firms.

Secondly, the insolvency impact was not limited to Japan exclusively. Several studies investigated the broader influence and Japanese banking spillover effects on other countries. Namely, Peek and Rosengren (2000) showed that decline in risk-based capital ratios associated with the decline in Japanese stock prices caused Japanese commercial and industrial lending in the United States to decline. Therefore, depending on the way Japanese bank regulators decide to resolve these problems in the future, those decisions might have significant implications for credit availability in the United States as well as in other countries with a significant Japanese bank presence. Allen et al., (2011) provide evidence of de-internalization for Japanese banks' as response to crisis related increases in capital costs, where more specifically, 62 Japanese banks closed their overseas branches, switch their charters from international to domestic.

Thirdly, our paper also relates to the extensive literature on bank capital and risk-taking, where we have two very divided and inconclusive strands of the literature. On one hand, some researchers argue that that capital requirements are effective in reducing bank risk (Keeley and Furlong, 1990; Repullo, 2004; Acosta-Smith et al., 2020). On the other hand, some studies either do not find evidence or find that capital requirements make banks 'riskier' institutions (Kim and Santomero, 1988; Blum, 1999; Hovakimian and Kane, 2000). In a case of Japan, the past studies are also inconclusive. For example, Tongurai and Vithessonthi (2020), show that the relaxation of the capital adequacy requirement has the differential effects on bank risk-taking depending on the bank type (i.e., domestically vs internationally active banks), while Wilcox and Yasuda (2019) focusing on bank capital and other factors affecting supplies of bank credit find that banks with more capital were doing more non-guaranteed lending.

Lastly, our biggest contribution is in the area of bank solvency and government aid to troubled companies. Most of studies dealing with Japan analysed the Japanese case to identify zombie borrowers, i.e., firms that would have been insolvent without bank loans. Following the intuition of Caballero et al., (2008) that provides a wide set of measures to identify zombie firms, we develop a method to identify "zombie banks", i.e., Japanese banks that would have been insolvent without Government aid. We are one of a very few studies that is able to provide a formal econometric model to identify zombie banks, for both listed and non-listed banks. The detailed literature coverage on this phenomenon and said model can be found in the next section.

Overall, by combining the study of banks' capital positions with the analysis of risk taking, we provide evidence on deleveraging and re-capitalization process in Japan. By formulating our measure of bank distress – zombie bank – we are able to identify true zombie banks based on shadow rate of return on equity and bank capitalisation levels.

3. Theoretical framework and hypotheses development

In this section, we discuss the theoretical framework for zombie banks, and we develop our research hypotheses. Firstly, we review the existing measures for identifying zombie banks. Secondly, we develop a theoretical model for the shadow price of equity by modelling banks cost function. Lastly, we develop our research hypotheses.

3.1. Identifying zombie banks: a review of the existing measures

We start by defining zombie banks as insolvent firms, supported by government aid, or by new equity issuing (in most cases, supported by insolvent borrowers). In general, the presence of zombies distorts competition and impact the productivity of the non-zombie banks. Now, looking at Japanese banking industry, only in a few cases insolvent banks were allowed to default, but in general, this problem was denied by the Japanese government.[4]

One of the first papers to investigate this phenomenon was Kane (2000), who investigated how distortions affecting capital allocation, asset prices, and bank solvency, might have played a role in financial crises experienced in Asia during 1990s. Similarly, Hoshi and Kashyap (2000) were first to emphasise the potential insolvency and lending problems for Japanese banking. Furthermore, Hoshi and Kashyap (2004) argue that the macroeconomic factors alone are not likely to explain the full extent of the problems in the Japanese financial system. Rather, the authors believe that the depressed restructuring and dysfunctional banking system with subsidized inefficient firms are crowding out potentially profitable ones.

There is a growing literature on classifying firms as zombies and measuring their impact on the economy (see Ahearne and Shinada, 2005; Hoshi, 2006; Caballero et al., 2008, Mariassunta and Simonov, 2013; Calderon and Schaeck, 2016). Much of the evidence is direct. For example, Hoshi (2006) found out that zombies tend to be less profitable, more indebted, with larger labour force, mostly located outside large metropolitan areas and more likely to be found in non-manufacturing industries. The author also argues that when the proportion of zombie firms in an industry increases, job creation declines and job destruction increases, and the effects are stronger for non-zombies. Similarly, Caballero et al., (2008) support aforementioned conclusion by confirming that zombie-dominated industries exhibit more depressed job creation and destruction, and lower productivity.

[4] For more information see Caballero et al., (2008).

The literature on measuring bank insolvency and/or failure is not that straightforward. While some authors apply accounting-based measures or ratios, like Z-Score (see Altman, 1968), other use market-based measures like distance-to-default (Harada and Ito 2008; Harada et al., 2010). Harada et al., (2010) offer the most up-to-date study on predicting bank failures in Japan. They found that distance-to-default (DD) was generally a reliable measure in predicting bank failures. However, authors outline that it is important to examine if the DD and some other indicators of bank health (such as credit ratings, outstanding of NPLs and the capital adequacy ratio) are related.

In this paper, we contribute to past literature by estimating the shadow price cost of equity as a new measure of bank distress and, specifically, we show several ways of measuring the level of distress: a short-term measure, medium-term and long-term measure. In addition, we also examine in depth the sequence of values of the shadow return by subperiod and by type of bank. We identify true zombie banks as those that operated with a negative value for the shadow rate of return on equity for the entire sample period and well-capitalized banks, i.e., those that operated with a positive value for the shadow rate of return on equity for the entire sample period.

3.2. The shadow price of equity in deposit taking financial institutions

We begin the analysis on the shadow price of equity with discussion of the theoretical ideas, as illustrated in Figure 1 which captures the balance sheet representation of banking industry technology[5].

We describe a deposit taking financial institution by a model of its balance sheet condition expressed as $L = B + E$ where the asset side consists of loans L and the liability side consists of deposits and other borrowed funds symbolised together as B plus the pure loss absorbing capacity, equity capital written as E. To ensure balance sheet solvency in different states of the world, different levels of the loss absorbing capacity embodied in equity capital need to be held by the deposit taking institution. Therefore, we model an expected banking technology represented by the probability weighted input requirement set that permits the analysis of a banking transformation function as its efficient lower bound:

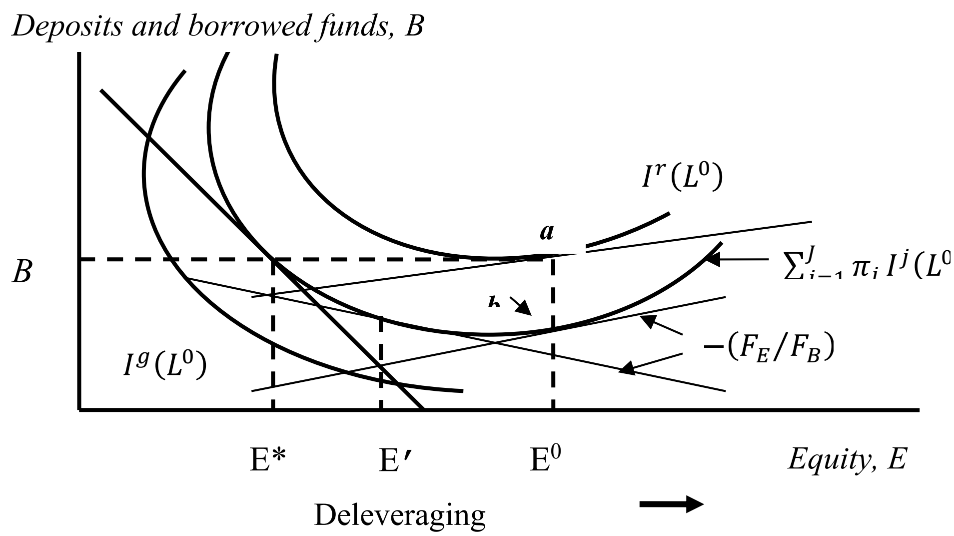
$$\sum_{j=1}^{J} \pi_j \, I^j(L^0) \Rightarrow F(B, E; L) = 0 \qquad [1]$$

This represents the expected solvency relationship between borrowed funds and deposits (B) and equity (E) needed to support a given level of loans, L^0 in different states of the world $j = 1 \ldots J$ with probabilities π_j. In the diagram shown in Figure 1, we illustrate three isoquant representations of the trade-off between borrowed funds and equity capital, i.e., the boundary of the corresponding input requirement set: $I(L)$; each is constructed for a fixed level of loans: L^0. The isoquant labelled $I^g(L^0)$ is the intermediation technology that the bank

[5] A simplified account of one of the models in this section was first published in Weyman-Jones (2016).

expects to face when the economy is growing. However, the isoquant labelled $I^r(L^0)$ is the intermediation technology that the bank expects to face when the economy is in recession. Given the level of risk in this situation it expects to need combinations of higher funds and higher equity to support a given level of loans because the risk of loan default has increased and the with it the risk to the asset side of the balance sheet so that greater loss absorbing capital is needed. The isoquant labelled $\sum_{j=1}^{J} \pi_j I^j(L^0)$ therefore represents the expected technology in different states of the world. The three different equity levels illustrated in the diagram, with the changes: $E * \rightarrow E' \rightarrow E''$ represent the deleveraging required as there are increases in the perceived risk levels associated with a given balance sheet condition: $L^0 = B + E$. In this way, the intermediation technology is implicit in the slope of the isoquant $-F_E(B, E; L^0)/F_B(B, E; L^0)$. In general, this slope is negative with positive shadow prices for the inputs, equity capital and borrowed funds. When a bank is at high risk of defaulting, i.e., when the drop in the value of assets due to the non-performance of some loans becomes close to exceeding the equity capital available to absorb these potential losses, the only options are to raise more equity capital or to call in its loans.

Figure 1: Intermediation technology and equilibrium in different states of the world



In figure 1, movement to the right along the horizontal axis represents the raising of further equity capital for given levels of loans and borrowed funds, i.e., deleveraging of the balance sheet. Horizontal movements across the isoquant map towards higher equity levels trace out reductions in the slope of successive isoquants, and this represents reductions in the ratio of the shadow price of equity capital relative to the shadow price of borrowed funds. There will be an uneconomic region of the banking production technology if there is weak disposability, shown in Figure 1 as the region of positively sloped isoquants. In this region, the positive slope of the isoquant shows that the shadow price of equity capital has become negative[6] and this is associated with the movement towards a much less leveraged balance sheet, in which the bank has had to increase significantly the ratio of equity capital to borrowed funds. We can sum up this argument as follows. The equilibrium conditions lead to the construction of a bank cost function of the form:

Assets-based cost approach:

$$Cost = c^A(assets, equity, input\ prices) \quad [2]$$

To fix these ideas we argue as follows. The long run expected cost minimization problem is:

$$\min_{B,E} C = r_B B + r_E E \quad s.t.: F(B,E;L^0) = 0$$

[3]

The Lagrangean for this problem is:

$$\min_{B,E,\lambda} \Lambda = r_B B + r_E E + \lambda F(B,E;L^0)$$

[4]

With first order conditions:

$$\partial\Lambda/\partial B = r_B + \lambda F_B = 0$$

$$\partial\Lambda/\partial E = r_E + \lambda F_E = 0$$

$$\partial\Lambda/\partial \lambda = F(B,E;L^0) = 0$$

[5]

Rearrange the first order conditions for long run expected cost minimization to obtain:

$$-F_E(B,E;L^0)/F_B(B,E;L^0) = -r_E/r_B \Rightarrow F_E = r_E(F_B/r_B)$$

[6]

If the equity level is constrained to be at least E^0, i.e.: $E \geq E^0$ the problem becomes a short run cost minimisation

$$\min_{B,E} C^s = r_B B + r_E E \quad s.t.: F(B,E;L^0) = 0 \ and \ E \geq E^0$$

[7]

The Lagrangean function is:

$$\min_{B,E,\lambda,\mu} \Lambda^s = r_B B + r_E E + \lambda F(B,E;L^0) + \mu(E^0 - E)$$

[8]

With first order Kuhn-Tucker conditions:

$$\partial\Lambda^s/\partial B = r_B + \lambda F_B = 0$$

$$\partial\Lambda^s/\partial E = r_E + \lambda F_E - \mu \geq 0$$

$$E(\partial\Lambda^s/\partial E) = 0$$

[6] This does not imply that the market cost of equity will ever become negative since the shadow price of equity is a lower bound for the market price as shown below.

$$\partial\Lambda^s/\partial\lambda = F(B,E;L^0) = 0$$
$$\partial\Lambda^s/\partial\mu = E^0 - E \le 0$$
$$\mu(\partial\Lambda^s/\partial\mu) = 0$$

[9]

Here $\mu = \partial C^s/\partial E^0 \ge 0$ by the envelope theorem

The optimality condition at an interior optimum where: $E = E^0$ is:

$$-F_E(B,E;L^0)/F_B(B,E;L^0) = -(r_E - \mu)/r_B \Rightarrow F_E = (F_B/r_B)(r_E - \mu)$$

[10]

If there is allocative efficiency in the borrowed funds market then $F_B = r_B$ and $r_E \ge F_e$ with equality holding when the constraint is not binding. Hence the shadow return on equity is a lower bound for the market cost of equity. The long run and short run cost functions are derived by solving these first order conditions for the equilibrium levels of B and E , and then replacing these terms in the definition of cost. Long run cost is:

$$C = f^l(L^0, r_B, r_E)$$

[11]

At an interior optimum the equilibrium coincides with the equilibrium to the following short run problem with the fixed level of equity:

$$\min_B C^s = r_B B + r_E E^0 \ \ s.t.: F(B,E^0;L^0) = 0$$

[12]

This has first order conditions:

$$r_B + \lambda F_B = 0$$
$$F(B,E^0;L^0) = 0$$

[13]

These can be solved for $E = E^0$ and $B = B(L^0, r_B, E^0)$; this pair of equations involves only one input price, that of the variable input, borrowed funds, so that knowledge of the market price of the quasi-fixed input, equity capital, is not necessary to find the solution to the short run cost minimizing problem. This fact is useful for the econometric specification of the cost estimation. Inserting the solutions in the definition of cost we obtain:

$$C^s = r_B B(L^0, r_B, E^0) + r_E E^0$$

[14]

Consequently, short run cost is:

$$C^s = f^s(L^0, r_B, r_E, E^0) \equiv c^v(L^0, r_B, E^0) + r_E E^0$$

[15]

The short run cost function is separable into variable and fixed cost, and the market price of the quasi-fixed input impacts only on the fixed cost component while the variable cost component is independent of the price of the quasi-fixed input, but not of course the level of the fixed input. Equation [15] is the basis of our description of the asset-based cost model described in equation [2] above. The envelope theorem states that the long run cost function is the envelope of the short run cost functions:

$$C = f^{l}(L^{0}, r_B, r_E) = \min_{E}\{c^{v}(L^{0}, r_B, E^{0}) + r_E E^{0}\}$$

[16]

From this we derive the condition:

$$\partial f^{l}(L^{0}, r_B, r_E)/\partial E = 0 = [\partial c^{v}(L^{0}, r_B, E^{0})/\partial E] + r_E$$

[17]

Consequently:

$$-\partial c^{v}(L^{0}, r_B, E^{0})/\partial E = r_E$$

[18]

Therefore, the negative of the derivative of the short run cost function with respect to the quasi-fixed input is the shadow input price. Converting to log derivatives restates this condition in terms of the shadow input rate of return. This result is well-established in the literature on microeconomics, Braeutigam and Daughety (1983), and has been used to investigate economies of scale in banking by Hughes et al., (2001) and Hughes and Mester (2013) and in the measurement of banking system productivity by Boucinha et al., (2013) Duygun et al., (2015).

Equation [18] is the basis for our argument, stated earlier, that deleveraging leads to reductions in the shadow price of equity capital so that it may eventually become negative. Referring to Figure 1, we can see that when the equity level is required to be at least E^{0}, i.e., when the bank is recapitalizing in a financial crisis with a balance sheet induced recession, the bank will be operating with a positive marginal rate of substitution between borrowed funds and equity, i.e., the shadow rate of return on equity will have turned negative in the uneconomic region of the technology. The objective is to be able to measure the slope of the state contingent isoquant at point *a*, but given the way that risk varies over the different states of the world in the economic cycle, we approximate this by the slope of the expected isoquant at *b*. However, we do incorporate into the estimation, appropriate variables to account for different levels of risk.

We argue in this paper that this effect can be estimated by modelling the cost minimizing behaviour of the banking system, and we are able to do this by using the dual cost function to represent the technology. We capture the risk environment of the system by using risk based and market-based characteristics of the banks.

However, prior to developing a more formal model of cost minimizing behaviour, we now discuss an alternative way of conceptualizing the measurement of bank cost determination by considering whether there are periods and situations in which banking activity may be modelled as income driven only.

The argument for using an income-based model is founded on several reasons. Firstly, if it is true that there is a problem of zombie banks that are permitted to survive despite weak balance sheets then the strategy of the banks may evolve into maximising current income, i.e., focus on the income account, instead of optimising balance sheet outcomes. Secondly, the empirical role of equity seems to be even more important in income-based models than the asset-based models. Thirdly, it has been argued that income-based services are the key outputs of commercial banks. This argument is due to, among others, Wang (2003) who has argued that the loanable funds that banks borrow and lend are "*merely an intermediate input in the production of banking services, just as purchased merchandise is for retailers*". Wang emphasises three functions: (1) mitigating asymmetric information problems, (2) financing loans with borrowed funds, and (3) providing transaction services. Both (1) and (3) consume real resources while, function (2) merely transfers income between ultimate users and suppliers of funds. She argues that to measure the value of bank services, revenues should be computed from interest and non-interest income to arrive at nominal bank value added. This is what we do in the two-output model.

How does this affect our cost function analysis? In comparison with the asset-based cost approach represented in equation [2], the model becomes Income-based approach:

$$Cost = c^Y(income, equity, input\ prices) \quad [19]$$

We argued above that in the assets-based approach the asset-cost elasticity of equity capital would reflect the shadow return on equity when equity capital affects the bank in two different ways: (i) it provides a benefit in the form of loss absorbing capacity and (ii) it incurs a cost as an additional input which may have a higher market price than other sources of funds for the balance sheet. However, in the income-based approach the benefit of the loss absorbing capacity is not counted, since banks are only able to focus entirely on income objectives if their balance sheet equilibrium is no longer important. This is likely especially to be the case when the central bank or monetary authorities are willing to sustain the continued existence of banks whose balance sheet position may be weak or even negative. This is what we described as a period of 'zombie banking'. In this case the income-cost elasticity of equity capital represents only an additional cost without an offsetting benefit. Putting these arguments together with the earlier analysis of asset-based costs, we hypothesise the following likely results:

$$\varepsilon_{C^A,equity} = \partial \ln c^A(assets, equity, input\ prices)/\partial \ln equity = \begin{cases} < 0, in\ normal\ times \\ > 0, in\ deleveraging \end{cases} \quad [20]$$

$$\varepsilon_{C^Y,equity} = \partial \ln c^Y(income, equity, input\ prices)/\partial \ln equity > 0 \quad [21]$$

In other words, the impact of equity capital differs significantly between the asset-based cost of banking approach and the income-based cost of banking approach. A further point made by Reis (2018) is that loss making banks find it difficult to raise further equity capital because potential equity investors are caught in a co-ordination failure with none wanting to recapitalise unless others do so as well. In this case, such banks are stuck in a low-profit equilibrium unable to increase their intermediation activity and of necessity required to rebuild capital slowly from earnings. This will make the income-based model all the more applicable when the central bank permits the continued existence of the banks with weak balance sheets. We will fit both the asset-based cost function and the income-based cost function and in general we may expect to find that the cost elasticity of equity capital differs in sign in the two approaches, being negative in normal times in the asset-based cost function except for banks and periods when extreme deleveraging is required and being positive in general in the income-based cost function. Recall that the negative of the asset-based cost elasticity of equity capital is the shadow rate of return on equity.

3.3. Modelling the cost function and the shadow price of capital

Most studies that examine bank efficiency in Japan apply non-parametric methods represented by DEA (see for example, Fukuyama 1993; Fukuyama et al., 1999; Drake and Hall 2003; Mamatzakis et al., 2016). Altunbas et al., (2000) paper is one of a few studies that applied a parametric method for measuring Japanese bank efficiency. More recently, a study by Fukuyama and Weber (2008) investigated banking inefficiency and the shadow price of problem loans by treating problem loans as a jointly produced undesirable by-product of the loan production process. They questioned previous studies that ignored NPLs and further argued that problem loans should not be treated as a fixed input since they are a by-product of the loan production process. Similarly, Barros et al., (2012) found that non-performing loans remain a significant burden for Japanese banks' performance.

The novelty of this study is the applied model that accounts for risk (and NPLs) and asset quality factors by a financial capital and liquidity ratio. Here the objective is to construct a model of a banking system that is seeking to minimize the total cost of its activity while taking account of its equity capital requirements[7]. This model extends the analysis of section 3.1 and equations (14) to (18) to incorporate multiple outputs and multiple inputs. In section 3.1 we derived two broad approaches: an asset-based cost function and an income-based cost function, equations (2) and (19) respectively. We show that the derivation of the mathematical framework of the cost function is very similar in each of the two approaches, but that the measurement of the variables representing the outputs is the key difference. Therefore, the two cost functions have different elasticity functions and display different behaviour patterns with respect to the outputs and input prices and in particular with respect to the level of equity capital which is treated as a quasi-fixed input.

We assume that each bank uses K variable inputs: $\mathbf{x}' = (x_1, \dots, x_K)$ with input prices: $\mathbf{w}' = (w_1, \dots, w_K)$ in order to produce R outputs: $\mathbf{y}' = (y_1, \dots, y_R)$, However there is an additional quasi-fixed input, i.e. an input which may be a fixed input in the short run but is variable in the long run; for clarity, we symbolise this particular quasi-fixed input as z_0,with input price: w_0. This represents the behaviour of the regulated equity capital of the bank as a quasi-fixed input; hence input z_0 represents the level of the equity capital for a bank.

In Figure 1 we used the idea of the uneconomic region of the production function and this corresponds to the assumptions that the technology displays convexity and weak disposability. Representing the technology at time t by a transformation function $F(\mathbf{x}', \mathbf{y}', z_0, t) = 0$, weak disposability is associated with first order partial

[7] This explanation of the specification is based on Weyman-Jones (2016).

derivatives that are unrestricted in sign, so that the dual cost function can permit both positive and negative shadow prices of equity capital. The dual long run cost function is:

$$c(\mathbf{y}', \mathbf{w}', w_0, t) = \min_{\mathbf{x}, z_0}\{\mathbf{w}'\mathbf{x} + w_0 z_0 : F(\mathbf{y}', \mathbf{x}', z_0, t) = 0\}$$

[22]

In the short run, the quasi-fixed input z_0 is held constant at $\bar{z}_0$, and variable cost, c^v, and fixed cost, $w_0\bar{z}_0$, are summed to produce the dual short run cost function:

$$c^s(\mathbf{y}', \mathbf{w}', \bar{z}_0, t) = c^v(\mathbf{y}', \mathbf{w}', \bar{z}_0, t) + w_0\bar{z}_0 = \min_{\mathbf{x}}\{\mathbf{w}'\mathbf{x} + w_0\bar{z}_0 : F(\mathbf{y}', \mathbf{x}', z_0, t) = 0, z_0 = \bar{z}_0\}$$

[23]

We now derive for this multi-output and multi-input case the equivalent forms to equations (15) to (18) above. The long run cost function envelops the short run cost function as shown by the envelope theorem, i.e.

$$c(\mathbf{y}', \mathbf{w}', w_0, t) = \min_{z_0}\{c^v(\mathbf{y}', \mathbf{w}', \bar{z}_0, t) + w_0\bar{z}_0\}$$

[24]

Differentiating with respect to the input z_0, we find a result analogous in this multi-output and multi-input case to equation (17) above:

$$\partial c(\mathbf{y}', \mathbf{w}', w_0, t)/\partial z_0 = 0 = \partial c^v(\mathbf{y}', \mathbf{w}', \bar{z}_0, t)/\partial z_0 + w_0$$

[25]

When we rearrange equation (25), we achieve the equivalent of equation (18)[8]

$$-\partial c^v(\mathbf{y}', \mathbf{w}', \bar{z}_0, t)/\partial z_0 = w_0$$

[26]

This confirms that the quasi-fixed input's shadow price is given by the negative of the partial derivative of the short run cost function with respect to that input. In our analysis this quasi-fixed input plays the role of equity capital in the banking system. Expressing equation (26) in elasticity form gives:

$$-\partial \ln c^v(\mathbf{y}', \mathbf{w}', \bar{z}_0, t)/\partial \ln z_0 = -e_{z_0}(\mathbf{y}', \mathbf{w}', \bar{z}_0, t) = w_0 z_0/c$$

[27]

This elasticity function is what we measure as the shadow rate of return on equity capital. It can be interpreted as the share of input expenditures going to equity holders valued at the shadow price of equity capital. Since this elasticity function can be measured directly from the short run cost function, we can derive an estimate for both listed and non-listed banks. This is a particularly useful property since it is impossible to observe the market price of equity capital for unlisted banks; instead, we have an expression for the shadow price.

A bank with a relatively high positive shadow return on equity capital (i.e., a negative cost-elasticity with respect to equity capital with a relatively high absolute value) will be among those that may be over-leveraged

[8] See the earlier references to Braeutigam and Daughety (1983), Hughes, et al., (2001), Hughes and Mester (2013) and Duygun et al., (2015).

and heavily reliant on borrowed funds. Negative cost-elasticity that is lower in absolute value, with the shadow rate of return positive but intermediate in value, will be associated with banks that are well-capitalized. However, banks that are significantly distant from the long run equilibrium because they are making strenuous efforts to re-balance their equity-asset ratios towards deleveraging, for example by trying to raise capital or call-in loans, will show a very low and even negative shadow return on equity when they have been forced into the uneconomic region of the loan production technology by the need to deleverage the balance sheet. This is associated with a positive cost elasticity with respect to equity capital and is an effect that can be measured econometrically.

A second implication of the analysis concerns the measurement of returns to scale. As Braeutigam and Daughety (1983) demonstrate, (see also Caves, et al., 1980) the inverse of the elasticity of cost with respect to outputs considering the quasi-fixed input is:

$$E_{c\mathbf{y}}^{-1} = (1 - \partial \ln C / \partial \ln z_0) \Big/ \sum_r (\partial \ln C / \partial \ln y_r) \tag{28}$$

Then $E_{c\mathbf{y}}^{-1} < 1$ implies diseconomies of scale (decreasing returns), $E_{c\mathbf{y}}^{-1} = 1$ implies constant returns to scale and $E_{c\mathbf{y}}^{-1} > 1$ implies economies of scale (increasing returns).

Econometrically, we specify the logarithm of the short run cost function as follows for a panel data sample of $i = 1 \dots I$ banks over $t = 1 \dots T$ years; $u_{it}$is the panel data error term:

$$\ln C_{it} = \ln c^s\,(\mathbf{y}', \mathbf{w}', \bar{z}_0, t)_{it} + u_{it} \tag{29}$$

The econometric model of cost that we use, is the translog function[9] with an additive idiosyncratic error term, u_{it} to capture sampling, measurement and specification error. The cost function is homogeneous of degree +1 in the prices of the inputs. This restriction is achieved by dividing cost and each of the input prices by one of those input prices treated as numeraire, which we label w_K. For convenience we use the following notation: logged outputs are represented by the vector: $\mathbf{ly}' = (\ln y_1, \dots, \ln y_R)$; logged input prices relative to the numeraire are represented by the vector: $\mathbf{l\widetilde{w}}' = (\ln(w_1/w_K), \dots, \ln(w_{K-1}/w_K))$; the logged level of equity capital is $\ln(z_0)$ and additional non-equity exogenous variables are represented by the vector $\mathbf{z}' = (z_1 \dots, z_L)$. Consequently, the translog cost function can be expressed in matrix form as:

$$\begin{aligned} \ln(C/w_K) &= \boldsymbol{\alpha}'\,\mathbf{ly} + 0.5\,\mathbf{ly}'\mathbf{A}\,\mathbf{ly} + \boldsymbol{\beta}'\mathbf{l\widetilde{w}} + 0.5\,\mathbf{l\widetilde{w}}'\mathbf{B}\,\mathbf{l\widetilde{w}} + \mathbf{ly}'\boldsymbol{\Gamma}\,\mathbf{l\widetilde{w}} + \delta_1 t + 0.5\delta_2 t^2 + \boldsymbol{\mu}'\mathbf{ly}\,t + \boldsymbol{\eta}'\mathbf{l\widetilde{w}}\,t \\ &\quad + \rho_1 \ln(z_0) + \tfrac{1}{2}\rho_2 (\ln(z_0))^2 + \boldsymbol{\phi}'\mathbf{ly}\ln(z_0) + \boldsymbol{\xi}'\mathbf{l\widetilde{w}}\ln(z_0) + \mathbf{z}'\boldsymbol{\pi} + u \end{aligned} \tag{30}$$

Of primary interest to us are the elasticity functions which are calculated from the parameter estimates as:

[9] The translog specification used in this paper was specifically developed in order to allow operation in the uneconomic region of the technology, see Kumbhakar and Lovell (2003: 45).

$$\begin{pmatrix} \mathbf{e}_{\mathbf{y}}(\mathbf{y}, \widetilde{\mathbf{w}}, t, z_0) \\ \mathbf{e}_{\mathbf{w}}(\mathbf{y}, \widetilde{\mathbf{w}}, t, z_0) \\ e_t(\mathbf{y}, \widetilde{\mathbf{w}}, t, z_0) \\ e_{z_0}(\mathbf{y}, \widetilde{\mathbf{w}}, t, z_0) \end{pmatrix} = \begin{pmatrix} \boldsymbol{\alpha} & \mathbf{A} & \boldsymbol{\Gamma} & \boldsymbol{\mu} & \boldsymbol{\phi} \\ \boldsymbol{\beta} & \boldsymbol{\Gamma}' & \mathbf{B} & \boldsymbol{\eta} & \boldsymbol{\xi} \\ \delta_1 & \boldsymbol{\mu}' & \boldsymbol{\eta}' & \delta_2 & 0 \\ \rho_1 & \boldsymbol{\phi}' & \boldsymbol{\xi}' & 0 & \rho_2 \end{pmatrix} \begin{pmatrix} 1 \\ \mathbf{ly} \\ \mathbf{l}\widetilde{\mathbf{w}} \\ t \\ \ln(z_0) \end{pmatrix}$$

[31]

This is the formal analysis of the cost function specification, and we fit this equation to two different cases: (i) where outputs are mostly assets emphasising the balance sheet approach to modelling bank activity, i.e., the asset-based costs, and (ii) where outputs are the interest and non-interest components of bank value added, i.e. the income-based costs. There is of course no presumption that the cost technology for an asset-based analysis mirrors that for an income-based analysis. Nevertheless, the specification of the relevant input prices and risk and type variables is the same for both approaches. Only the definition of the relevant outputs differs between the two cost models while the differences in technology are captured by the differences in the elasticity functions and their parameters.

It is important in estimating the model with our pooled sample to distinguish between latent heterogeneity in the sample caused by differences amongst the individual banks and types of banks and the variance in the error term. We address this issue in three different ways, although it turns out that the results are broadly similar over the different approaches. First, we distinguish by types of banks, and in this respect, we added fixed effects for different bank types to the model. The bank types identified in the sample are: five location categories of city and regional banks and two stock market types of listed and non-listed banks. The base banking firm in the sample is the listed city bank category with dummy variables for four regional types and for non-listed banks. We can allow for errors to be correlated across the cost function in [30] and the input share equations which are included in [31] by applying the iterative seemingly unrelated regression model (SUR) based on the feasible generalised least squares (FGLS) estimator of the cost equation and $K-1$ of the share equations. While the OLS estimator is consistent the FGLS estimator is consistent and efficient and, if the errors are multivariate normal, iteration produces maximum likelihood estimates. A second approach to the latent heterogeneity issue is to distinguish individual banks in the sample by applying the one-way fixed effects panel model to the translog cost function, and a third alternative to treating latent heterogeneity is to apply the random effects model. We can choose between the fixed effects model which is consistent in general and the random effects model which is consistent but also efficient under the null hypothesis that the random effects are independent of the regressors by using the Hausman test.

Summarizing the estimation approach:

i) we estimate the translog cost function [30] by three different estimation procedures: SUR with bank type fixed effects, panel fixed effects for individual banks and panel random effects for individual banks.

ii) we generate the first order matrix derivative effects in [31] from the estimates of [30] in order to compute the marginal costs and the shadow return on equity

iii) we use the shadow return on equity estimates to analyse the deleveraging process when there is a potential case of 'zombie banking', i.e., when the monetary authorities maintain the viability and lending processes of banks that are in financial distress.

3.4. Hypothesis development

Two key hypotheses come out of this analysis and we address both of these in the empirical work. The first of these hypotheses concerns the ability to identify different types of banks or different groupings of banks by the shadow return on equity capital. It is the variability in this critical indicator of bank performance that allows the possibility of distinguishing zombie banks over time from those that are performing more adequately. Therefore, we formulate:

Hypothesis 1. Identify distinct time periods: $T^k, k = 1 \dots K$. These could, for example, represent periods when banks are increasing or decreasing their equity-loan ratio to ensure deleveraging or otherwise; identify different groups of banks: $I^s, s = 1 \dots S$. These could, for example, represent different types of loan market such as regional or city banks. If ρ_{sk} is the true shadow rate of return on bank type $s \in I^s$ in subperiod $k \in T^k$, then the null hypothesis is:

H_0: ρ_{sk} is constant across all bank types $s \in I^s$ in subperiod $k \in T^k$;

i.e. $\rho_{sk} = \rho + \varepsilon_{sk}$ where $E(\varepsilon_{sk}) = 0$

Rejection of Hypothesis 1 indicates that the possibility of identifying the behaviour of banks by their shadow return on equity capital exists. We show later in the paper that this hypothesis can be tested by parametric ANOVA and non-parametric Kruskal-Wallis tests.

Hypothesis 2. The second key hypothesis concerns the existence of negative shadow returns on equity capital during deleveraging periods. We show in this paper that there may be two different approaches to modelling the long-term and short-term behaviour of banks by distinguishing between the asset-based cost function model and the income-based cost function model. We show that in the asset-based model, there does arise the possibility of a negative shadow return on equity capital in extreme deleveraging periods since additional equity capital offers both a benefit (in terms of the improved equity-loan ratio) and a cost, but that for the income-based model the shadow marginal cost of equity capital will always be positive since there is no income to be gained by raising further equity. This gives us a pair of null hypotheses to test:

a) Asset based model: shadow return on equity is positive in balance sheet equilibrium periods but negative in deleveraging periods.

b) Income based model: marginal cost of equity is positive in all periods.

We use parametric significance and goodness of fit tests to evaluate these hypotheses.

4. Data and variables

Our sample of data consists of observations on commercial banks (City Banks; Regional Bank Association - R1 & R2; and Second Association of Regional Banks - RII_1 & RII_2)[10] in Japan over the period 2000 to 2016 This is an unbalanced panel with between 110 and 131 banks observed over the period, giving 1869 observations in total after filtering for outliers (described in more detail below). Data have been converted to constant price Japanese Yen using the GDP deflator for Japan.

Table 1. Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
all banks					
Loans	1,869	34096	89927	1102	857485
Securities	1,869	12545	40623	177	503465
off balance sheet and other income	1,869	1826	8778	12	81975
non-desirable outputs	1,869	2826	6236	139	103962
interest income	1,869	811	2135	15	23490
non-interest income	1,869	299	1143	2	11899
price of labour (ratio)	1,869	0.1589	0.0409	0.0132	0.5094
price of capital (ratio)	1,869	0.1792	0.1750	0.0192	2.4341
price of funds (ratio)	1,869	0.0022	0.0024	0.0002	0.0484
total cost	1,869	777	2200	16	24689
equity	1,869	2484	7509	51	85235
listed banks only					
equity	1,381	2534	6234	53	64796
asset size	1,381	61218	167997	2633	1638948
capital asset ratio	1,381	0.0463	0.0111	0.0106	0.0915
equity loan ratio	1,381	0.0708	0.0182	0.0151	0.1352
non-listed banks only					
equity	488	2342	10302	51	85235
asset size	488	57121	241929	1567	2015702
capital asset ratio	488	0.0421	0.0119	0.0046	0.0805
equity loan ratio	488	0.0600	0.0168	0.0061	0.1059

Note: Values are in million Yen at 2010 prices except ratios.

There are two different possible output models:

[10] We follow Radić (2015) and split these banks into three groups with subgroups for each regional association of banks (depending on their size). More specifically, City banks are typical large universal banks with international exposure, and they provide a wide range of banking services to the large companies in Japan. The Regional Bank Association and the Second Association of Regional Banks are smaller in terms of the asset size and market share and tend to focus on retail banking to small and medium sized companies at the regional level.

(a) Four asset-based outputs: loans, securities, off-balance sheet activity and non-desirable outputs (value of non-performing loans);

(b) Two income-based outputs: interest income and non-interest income.

These reflect both the traditional approach to bank production, e.g., Berger and Humphrey (1997), Brissimis et al., (2010) and the newer income-based activity model (e.g., Wang 2003 and Casu et al., 2016). We use three inputs: borrowed funds, labour and capital, and we treat the level of equity capital as the critical quasi-fixed input analysed in the theoretical model described earlier. The price of labour is used to normalise the total cost and the other input prices in order to impose homogeneity of degree +1 on the cost function. Finally, we identify a number of operating environment variables and banking system characteristics to represent the additional vector of variables: $z'\pi$ that condition the risk environment of the banks during the period. The individual variables used are described in more detail in Appendix A. Table 1 reports the sample statistics pooled over the unbalanced panel of data for the key variables: outputs, input prices and equity.

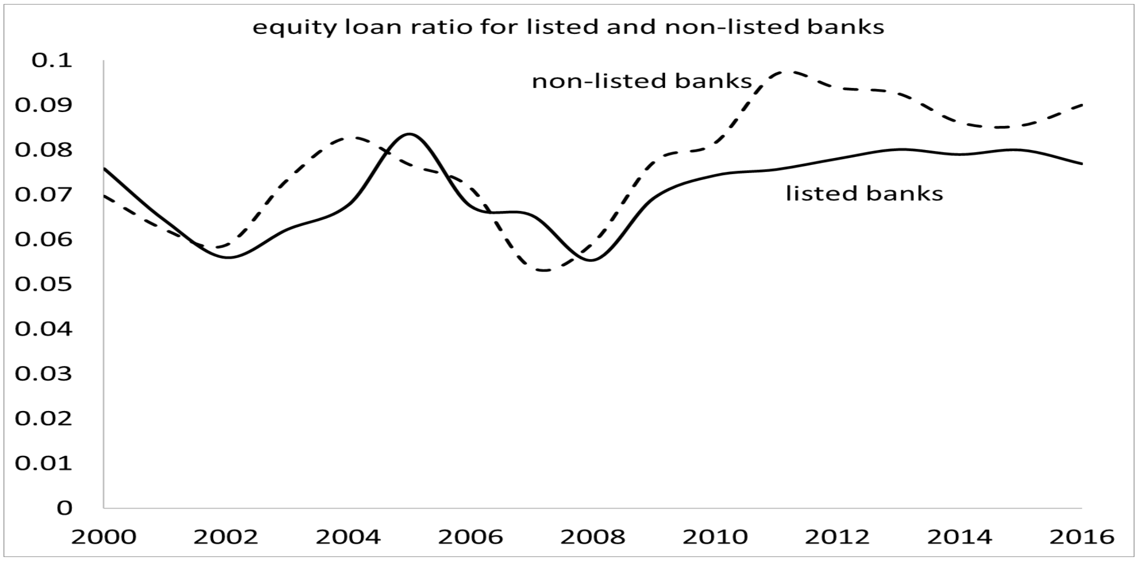
A key interest of this paper is the equity capital ratio of the banking system and the shadow return on equity, and the data on equity issuance and assets of the individual banks are also shown in Table 1.

Typically, the equity capital to asset ratio of the listed banks and the non-listed banks is very similar over the sample period, although it should be noted that the listed banks contain a small number of banks that are extremely large relative to the rest of the sample, while the distribution of the non-listed banks is less skewed by the presence of relatively large institutions. To understand the nature of re-capitalization it is more important to focus on the equity to loans ratio rather than the equity to total assets ratio, since one response of the banks to financial crisis may be to switch out of loan-based assets into security-based assets. In Figure 2 we identify the movements in the mean equity to loan ratio for both the listed and the non-listed banks separately, solid and dashed lines respectively. We use the level of total assets to weight the calculation of the mean for each group in the sample. We can see that the period beginning in 2002 signalled increases in the equity to loan ratio (deleveraging) for both listed and non-listed banks, but the rise was greater and more rapid for the non-listed banks. After 2005, the equity loan ratios were permitted to decline, but recapitalization i.e., deleveraging became the norm again during and after the global financial crisis of 2008. Again, the non-listed banks showed the more rapid and greater deleveraging ending the sample period with a higher equity loan ratio than for nearly all of the previous years. The listed banks maintained the higher equity loan ratio that they adopted in 2008 through to the end of the sample period.

It is these effects that we wish to model using the dual cost function approach described above. We first tested the data for extreme observations by looking carefully at all the series and eliminating individual banks with unexplained entries such as periods where zero securities holding were recorded, we then supplemented this with a filter of the data to eliminate extreme outliers (pooled standardised OLS residual greater than 2.25

in absolute value)[11]. All the applied filters resulted in removal of 4.5 per cent of the observations so that having started with a raw sample of 1956 observations, we worked with a final sample of 1869 observations for estimation. Variables were expressed in logged-mean-deviation form so that the elasticity estimates at the sample mean are directly estimated by the first order translog coefficients.

Figure 2: Equity to loans ratio



5. Empirical results and discussion

The results reported in tables 2 and 3 are the final outcome after a number of robustness and sensitivity tests. The robustness of the model in each of the two broad cases of asset-based cost function and the income-based cost function is tested by applying and comparing three different estimation methodologies. These are (i) the Feasible Generalised Least Squares (FGLS) estimator for the seemingly unrelated regression (SUR) model which converges to the maximum likelihood estimator under classical error assumptions; (ii) the one-way panel Fixed Effects (FE) estimator using the within regression procedure or least squares dummy variables; (iii) the one-way panel Random Effects (RE) estimator using generalised least squares. As we noted above, the choice of these different estimators is dictated by the need to allow for different banks to respond differently to the characteristics of the banking market in Japan and in particular to allow for different attitudes to risk-bearing. In the case of (i) SUR model, which has three system equations representing the cost function and two of the input demand equations, we added fixed effects for different bank-types, and applied the cross-equation restrictions on regression coefficients implied by the relationship between the cost function parameters and the share equation parameters.

[11] We also eliminated two further long-term credit institutions each observed only once in 2000 whose behaviour seemed anomalous and which did not fit the description of the commercial banks.

In cases (ii) and (iii) where we used the one-way panel data models, each individual bank has a separate fixed or random effect. To test the difference between the consistent FE estimator which permits the fixed bank effect to be correlated with the error terms, and the consistent and efficient RE estimator which assumes independence of the individual bank effects we used the Hausman test. This confirmed the superiority of the FE models.

Table 2. Estimation of the Asset-based model

Asset based cost	***SUR with bank type fixed effects***	***Individual Bank Fixed Effects***	***Individual Bank Random Effects***
Loans	0.7***	0.243***	0.225***
Securities	0.5***	0.255***	0.302***
Off balance sheet income	0.020***	0.021***	0.028***
Non-desirable outputs	0.5***	0.023	0.109***
Price of funds	0.117***	0.118***	0.114***
Price of capital	0.117***	0.118***	0.117***
Price of labour (interpolated)	0.766	0.764	0.769
Time	-0014***	-0.009***	-0.013***
Equity	0.36***	0.020**	0.041***
Equity interaction with loans	0.3***	-0.179***	-0.133***
Equity interaction with securities	-0.7**	0.114***	0.099***
Equity interaction with off balance sheet income	-0.0	0.044***	0.033**
Equity interaction with Non-desirable outputs	-0.066***	-0.024	-0.041***
Equity interaction with price of funds	0.4	-0.022**	-0.024**
Equity interaction with price of capital	-0.087***	0.006	0.004
Credit risk	-3.195***	0.144	-0.813*
Liquidity risk	-0.047	0.127***	0.053**
Market risk	*0.728**	-1.083***	-1.333***
No of observations	1869	1869	1869
R-squared	0.985	0.950	0.981
Root mean squared error	0.104	0.053	0.058
σ_u	n.a.	0.235	0.075
σ_e	n.a.	0.053	0.053
AIC	-17361.492	-5776.834	Hausman chi-sq (42 df)
BIC	-17068.235	-5527.842	335.84

Note: ***: p-value < 0.01; **: p-value < 0.05; *: p-value < 0.10

Our first set of sensitivity tests apply to these regressions. They concentrated on the extent to which the critical shadow return on equity estimates were constrained by the specification and dynamics of the model. Extensive testing was carried out particularly on the role of the credit risk, liquidity risk and market risk variables. In terms of dynamics, the preferred models allowed the shadow rate of return to be correlated with the inputs and outputs but without constraining its correlation with time, so that we were able to plot the time pattern of the shadow rate of return for each individual bank as an unrestricted relationship. After making our choices of estimators, choosing between estimates was done on the basis of root mean squared error and the information criteria (AIC, BIC) which are transformations of the log-likelihood function values. From the way that the cost function models have been constructed the robustness of the estimates of the shadow rate of return on equity in the Asset based model and the marginal cost of equity in the Income based model follows directly from the robustness of the parametric significance tests and this is confirmed by the large sample sizes and the strongly significant goodness of fit tests.

In Table 2, we report in the column one, the results of our SUR regressions for the most general asset-based four output model, where heterogeneity amongst the banks is picked up by fixed effects for bank type in five location categories together with a dummy for non-listed banks. In columns two and three, we report the panel fixed effects and panel random effects results. We report only the first order effects estimated at the sample mean from the log-mean-corrected data in order to conserve space[12], except for the impact of the equity level where interaction effects are shown as well. In Table 3 we report the results for the income-based model of cost using the same conventions.

The asset-based model that we concentrate on here has as output variables: loans, securities, off-balance sheet income and non-performing loans treated as non-desirable outputs. The non-desirable outputs add to total cost so have the same sign as the other desirable outputs. The input prices are the price of borrowed funds and the price of physical capital, both normalised by the price of labour. These variables are used in levels, squared and full interaction terms to satisfy the weakly separable translog cost function. Non-neutral technical progress is proxied by time and time interaction terms with the outputs and input prices. Equity is treated as the fixed input constraint for the short run cost function, but we do not assume that its impact on the cost elasticity or shadow price estimate is simply linear. The interactions of equity capital with the outputs and the input prices are included to allow for non-linearity in the shadow price formula. Three measures of the risk environment are used in these preliminary results: credit risk, liquidity risk and market risk. Their impacts may be ambiguous. For example, liquidity risk, may increase the observed total cost despite lowering the bank's exposure to the risk of deposit default. Or, for example market risk, may lower the risk of asset portfolio default for a bank, but could raise the total cost of operation above the efficient level. On the other hand, in circumstances of very high private asset price volatility there may be times when government bonds offer competitive returns compared with other assets.

In general, considering the root mean squared error terms and the information criteria, the panel data models with individual bank fixed or random effects perform better than the SUR estimates with bank type fixed effects in both the asset-based and the income-based models. The Hausman specification test favours the fixed effects model over the random effects model in both models.

[12] There are numerous second order coefficients in each set of results which are used to compute the elasticity results and productivity decompositions – these are available from the authors.

Table 3. Estimation of the Income-based model

Income based cost	***SUR with bank type fixed effects***	***Individual Bank Fixed Effects***	***Individual Bank Random Effects***
Interest income	0.443***	0.36***	0.534***
Non-interest income	0.176***	0.025***	0.068***
Price of funds	0.116***	0.076***	0.055***
Price of capital	0.116***	0.106***	0.106***
Price of labour (interpolated)	0.768	0.818	0.839
Time	0.002**	0.006***	0.002***
Equity	0.141***	0.079***	0.116***
Equity interaction with interest income	-0.065*	-0.040	-0.044
Equity interaction with non-interest income	0.05*	0.041*	0.046*
Equity interaction with price of funds	-0.006	-0.028**	-0.034***
Equity interaction with price of capital	-0.062***	0.006	0.019
Credit risk	0.749***	0.536***	0.497***
Liquidity risk	0.096***	0.300***	0.226***
Market risk	0.309***	0.013	0.074
No of observations	1867	1867	1867
R-squared	0.975	0.913	0.975
Root mean squared error	0.132	0.065	0.075
σ_u	n.a.	0.361	0.085
σ_e	n.a.	0.065	0.065
AIC	-16807.22	-4995.81	Hausman chi-sq (27 df)
BIC	-16613.60	-4840.91	429.53

Note: ***: p-value < 0.01; **: p-value < 0.05; *: p-value < 0.10

We can interpret these results as follows, using the sample mean as the point of interest. The coefficients are consistent in magnitude across all the models, and all of the cost function monotonicity conditions are satisfied for the output and input price variables. Table 4 provides the summary statistics on the elasticity functions for the fixed effects estimation for both the asset-based model and the income-based model. In the asset-based model, on which we concentrate here, Loans and security investment account for 50-60 percent of costs, but non-performing loans also add up to 25 percent to costs. Nevertheless, the results indicate significant economies of scale remaining in the sample. At the sample mean the Panzar-Willig elasticity of scale is 1.845 with a standard error of 0.017, while across the sample the average of the Panzar-Willig scale elasticities is 2.054 and the average of the Brauetigam-Daughety capital adjusted scale elasticities is 1.982. These results immediately suggest the scope for considerable consolidation but also turn out to have an impact on the deleveraging experience as we shall see below.

Table 4. Elasticity function values summarized across the sample

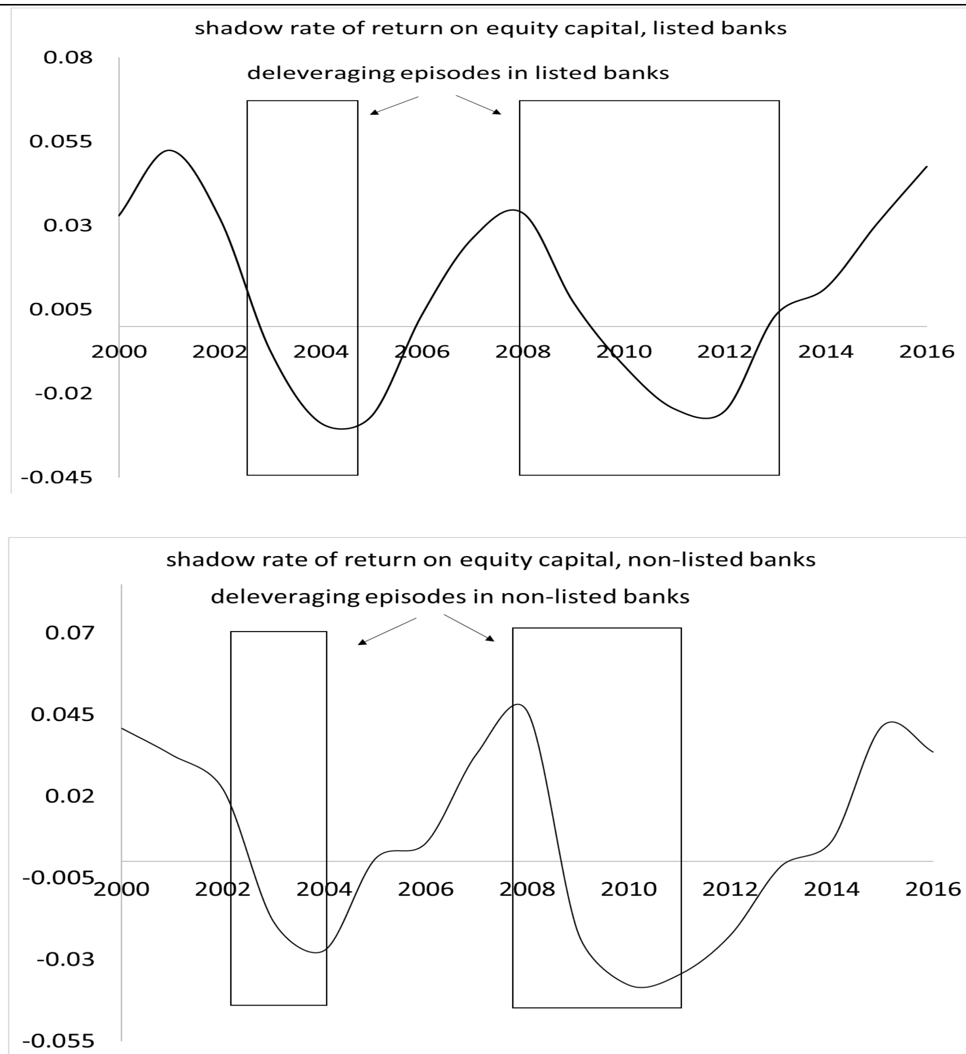
Estimated cost-elasticity functions across the sample: Asset-based model	***Obs***	***Mean***	***Std. Dev.***	***Min***	***Max***
Loans	1,869	0.240	0.246	-0.444	1.200
Securities	1,869	0.256	0.071	-0.034	0.457
Off-balance sheet income	1,869	0.022	0.036	-0.122	0.147
Non-performing loans	1,869	0.023	0.050	-0.168	0.169
Price of funds	1,869	0.117	0.059	-0.044	0.356
Price of capital	1,869	0.116	0.043	0.009	0.319
Price of labour	1,869	0.767	0.071	0.412	0.959
Time	1,869	-0.009	0.009	-0.041	0.016
Equity capital	1,869	0.021	0.059	-0.246	0.183

Estimated cost-elasticity functions across the sample: Income-based model	***Obs***	***Mean***	***Std. Dev.***	***Min***	***Max***
Interest income	1,867	0.360	0.239	-0.230	1.127
Non-interest income	1,867	0.025	0.205	-0.356	0.418
Price of funds	1,867	0.076	0.038	-0.025	0.205
Price of capital	1,867	0.105	0.044	-0.001	0.313
Price of labour	1,867	0.820	0.050	0.557	0.945
Time	1,867	0.006	0.019	-0.065	0.073
Equity capital	1,867	0.080	0.021	0.010	0.157

Going back to Table 2 and the asset-based model, the three risk environment variables are significant in affecting costs in general. In the fixed effects model, credit risk raises costs but the effect is negative in the random effects model. A different finding applies to liquidity risk, positively affecting costs in the fixed effects model and negatively in the random effects model. Market risk negatively affects costs in both of these models suggesting that a concentration on loan business is less costly than concentration on other asset output. Focusing on the Table 3 and the income-based model, credit risk liquidity risk and market risk raise costs for all models.

At the sample mean the shadow return on equity (i.e., the negative log derivative of the cost function) in the asset-based model is between -2 per cent (fixed effects mode) and -4.1 per cent (random effects model). This shadow cost varies widely form negative to positive values across individual banks over the sample period, but at the sample mean, it suggests that deleveraging behaviour by banks in financial distress has been a characteristic of this sample. Based on the overall statistical criteria, we proceed with the panel individual bank fixed effects estimation framework for the asset-based model. We first analyse the shadow return on equity capital across the whole sample. From equation [14] we know that the shadow return on equity is the negative of the elasticity function for the elasticity of total asset-based cost with respect to the level of equity capital: $-e_{z_0}(\mathbf{y}, \tilde{\mathbf{w}}, t, z_0)$. In general, this will vary by bank, by each of the output levels, and by each of the input prices and across the whole of the time period covered.

Figure 3: Shadow rate of return on equity capital (listed and non-listed banks)



In Figure 3, we plot the estimated shadow return on equity capital from the asset-based model for both listed and non-listed banks over the years in the sample. We used the asset-weighted mean of the estimated rates of return. The first result is to note that for part of the period the shadow return on equity capital did turn negative for both listed and unlisted banks indicating strong efforts at deleveraging and recapitalization. We superimpose on Figure 3 the deleveraging episodes identified by the rise in the equity loan ratios in Figure 2. We see immediately that deleveraging episodes coincide with years in which the shadow return on equity capital is falling and becomes negative. The negative correlations between the shadow return on equity and the current, lagged and forward equity-loan ratio are all statistically significant at the 1 per cent level.

The required periods of recapitalization and deleveraging were different for listed and non-listed banks and for the two major deleveraging episodes. In the first episode from 2003-06, both for listed and non-listed banks the shadow return on equity falls from a weighted average of around 2 percent to -2 percent during the deleveraging episode and begins to rise (although initially still negative) as deleveraging ends. In the second episode following the global financial crisis (GFC), the deleveraging lasts from 2008 to 2014 for listed banks but ends in 2011 for non-listed banks. During the post-GFC deleveraging, the shadow return on equity falls from 3 percent to -2.5 percent and the deleveraging continues for another two years until the shadow rate has turned positive once again. For non-listed banks deleveraging starts while the shadow return on capital is still positive at 4.5 percent and continues while it declines to -3.5 percent and as with the listed banks deleveraging still continues until the rate has turned upwards again, although deleveraging for the non-listed banks ends a little earlier before the shadow rate of return has completely turned positive again.

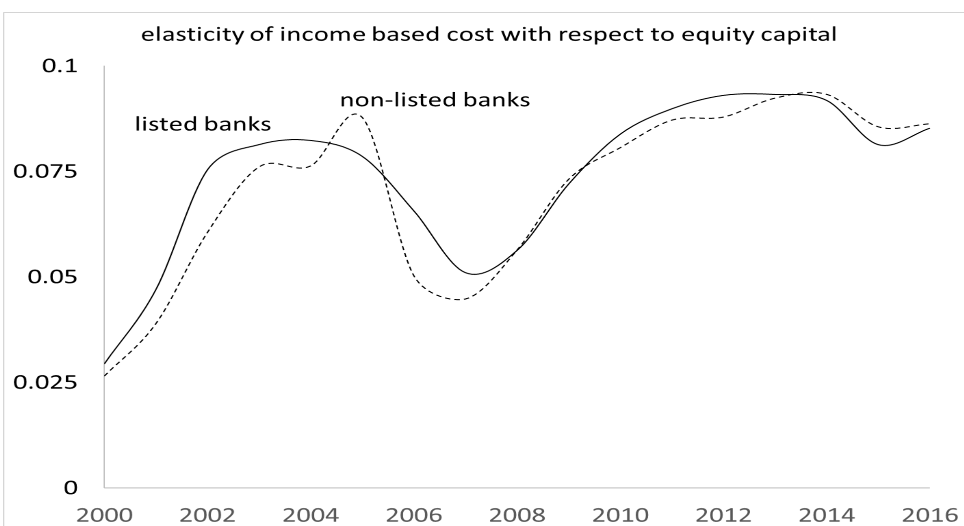
Earlier we hypothesised the following likely results:

$$\varepsilon_{C^A,equity} = \partial \ln c^A(assets, equity, input\ prices)/\partial \ln equity = -shadow\ return\ on\ equity$$
$$= \begin{cases} < 0, in\ normal\ times \\ > 0, in\ deleveraging \end{cases} \quad [32]$$

$$\varepsilon_{C^Y,equity} = \partial \ln c^Y(income, equity, input\ prices)/\partial \ln equity > 0 \quad [33]$$

Figure 3 confirms the first of these suppositions and we investigate the statistical significance of the confirmation of hypothesis 1 in detail in section 5.1 below. In Figure 4 and the second part of Table 4, we confirm the second. Figure 4 plots the asset-weighted cost elasticity of equity capital in the income-based model. Since equity capital is not permitted in this case to have an asset-related benefit as the loss absorbing capacity for non-performing assets, it acts simply as an additional constraint on earning income and will have a positive shadow cost as the figure shows across the sample. During both deleveraging episodes this income-based marginal cost of holding equity rises to show the impact on the banks' earnings of the build-up of costly equity.

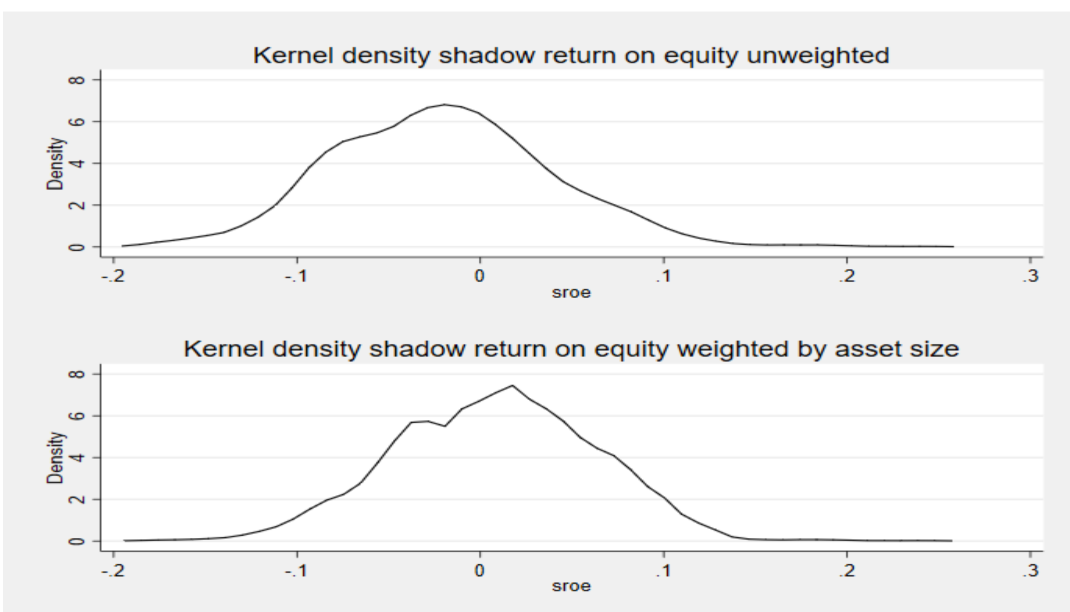
Figure 4: Elasticity of income-based cost with respect to equity capital asset weighted average



One issue that could be important is the relative size of the different banks in terms of their overall assets. As we have already seen, there are strong grounds for consolidation amongst the banks based on the findings of economies of scale across the sample. However, it is clear that there is a wide dispersion in the size of the banks in term of assets where the coefficient of variation exceeds 200 percent and there is a very long right tail in the distribution. We can see the effect of the asset size of the banks by comparing the kernel density graphs for the unweighted and the asset-weighted shadow return on equity, as in Figure 5. Clearly, as the rightward shift in the mode for the density distribution of the shadow returns on equity demonstrates, it is the largest banks in terms of asset size that are mainly responsible for the positive values of the shadow return on equity during this long volatile period in Japanese banking.

Two lessons stand out from these results: firstly, the banking system in Japan has been through a very difficult phase of operation during the sample period. There was an initial short-lived episode of deleveraging from 2003 to 2006 but following the global financial crisis in 2008 there has been widespread and long-lasting deleveraging as indicated by the fall into negativity of the shadow return on equity capital for most of the banks in the system. Secondly, it appears that only the largest banks have escaped with a positive shadow return on equity capital and this further reinforces the case for consolidation already apparent from the measured economies of scale. To verify these findings and resolve some of the issues highlighted in the literature, we formulated our hypotheses 1 and 2, equations [32] and [33] above. We show that both hypothesis 1 (the asset-based model displays both positive and negative shadow returns on equity depending on the deleveraging period) and hypothesis 2 (the income-based model displays only positive elasticity of cost with respect to equity capital in all periods) are confirmed to a high degree of statistical significance.

Figure 5: Shadow return on equity with and without asset-size weighting



5.1. Interpretation of shadow rate of return results

We now investigate in detail the evolution of the estimated shadow return on equity capital, $sroe$, in the asset-based model over the sample period and across different bank types both for listed banks and for non-listed banks. Using the sub-periods identified previously we classify the sample into either deleveraging sub-periods or balance sheet equilibrium sub-periods. By balance sheet equilibrium we simply mean that there was no systemic large-scale deleveraging as there was in the deleveraging periods. Our sub-periods include 2000-02: balance sheet equilibrium; 2003-06: deleveraging disequilibrium; 2007: balance sheet equilibrium; 2008-14: deleveraging disequilibrium; and 2015-16: balance sheet equilibrium period. There are 5 identified subperiods: $T^k, k = 1 \dots 5$, and there are 5 identified bank types: $I^s, s = 1 \dots 5$:

$$\{T^1, \dots, T^5\} = \{2000 - 02, 2003 - 06, 2007, 2008 - 14, 2015 - 16\} \quad [34]$$

$$\{I^1, \dots I^5\} = \{City, R1, R2, RI\_1, RI\_2\} \quad [35]$$

Table 5. Mean shadow rates of return on equity capital by bank type and subperiod

Mean shadow rates of return on equity, all banks/ subperiod

		2000-02, balance sheet equilibrium	2003-06, deleveraging disequilibrium	2007, balance sheet equilibrium	2008-14, deleveraging disequilibrium	2015-16, balance sheet equilibrium
	city	0.063	0.003	0.040	0.008	0.065
	R1	-0.016	-0.048	-0.004	-0.026	-0.013
	R2	-0.025	-0.045	-0.006	-0.034	-0.023
	RII_1	-0.012	-0.043	0.003	-0.025	-0.028
	RII_2	0.004	-0.013	0.026	-0.005	0.010

Mean shadow rates of return on equity, listed banks/ subperiod

		2000-02, balance sheet equilibrium	2003-06, deleveraging disequilibrium	2007, balance sheet equilibrium	2008-14, deleveraging disequilibrium	2015-16, balance sheet equilibrium
bank type	city	0.068	0.005	0.046	0.020	0.079
	R1	-0.019	-0.052	-0.007	-0.026	-0.010
	R2	-0.031	-0.052	-0.012	-0.040	-0.028
	RII_1	-0.013	-0.051	-0.0004	-0.023	-0.026
	RII_2	-0.013	-0.018	0.029	0.003	0.019

Mean shadow rates of return on equity, non-listed banks/ subperiod

		2000-02, balance sheet equilibrium	2003-06, deleveraging disequilibrium	2007, balance sheet equilibrium	2008-14, deleveraging disequilibrium	2015-16, balance sheet equilibrium
bank type	city	0.026	-0.002	0.017	-0.020	0.045
	R1	0.003	-0.027	0.012	-0.026	-0.027
	R2	0.012	-0.007	0.032	-0.001	0.011
	RII_1	-0.011	-0.035	0.008	-0.029	-0.030
	RII_2	0.017	-0.008	0.021	-0.018	-0.004

If it is possible to identify zombie banks, then the shadow rate of return on equity must be expected to vary across different deleveraging subperiods and possibly across different bank types which have different asset structures and balance sheets. This sets up a test framework: if ρ_{sk} is the true shadow rate of return on bank type $s \in I^s$ in subperiod $k \in T^k$, then the null and alternative hypotheses are:

$$H_0: \rho_{sk} = \rho, constant\ \forall s, k \Rightarrow \rho_{sk} = \rho + \varepsilon_{sk}, E(\varepsilon_{sk}) = 0$$
$$H_1: \rho_{sk} is\ not\ constant\ \forall s, k$$

[36]

Under very weak assumptions on ε_{sk}, an appropriate non-parametric test is the Kruskal-Wallis (KW) test based on the rankings associated with each of the sample values, by which $KW \sim \chi^2_{m-1}$ if the null hypothesis is true where m is the degrees of freedom equal to the number of bank types or subperiods being compared. In the Kruskal Wallis test we compare each single factor, i.e., bank type or subperiod, separately. With stronger distributional assumptions, i.e., normally and independently distributed errors with constant variance, $\varepsilon_{sk} \sim NID(0, \sigma^2)$, an appropriate test of the null hypothesis is analysis of variance, ANOVA. In one-factor ANOVA, each factor, bank type or subperiod, is tested separately, but ANOVA can be extended to multiple factors and to their interactions. ANOVA F-tests are robust to departures from normality assumptions, although we found that there was limited departure from normality in the data.

In addition to the robustness analysis of the cost functions, a second set of sensitivity and robustness results concerned the hypotheses about the shadow rate of return on equity in the Asset based model. Here the critical assumption for the ANOVA tests on the identifiability of different shadow rates of return on bank types and subperiods that is required for the existence of zombie banks is that the errors of measurement and sampling in the ANOVA procedures are normally distributed, and we carried out a range of advanced normality tests for this to confirm the validity of our test procedures. We carried out tests for departures from normality in the observed shadow rates of return over all banks, and over listed and non-listed banks separately. In all cases, the normal-overlaid histogram, the quantile (Q-Q) plot and the cumulative probability (P-P) plot all indicated minimal departure from normality and the Kolmogorov-Smirnov test confirmed normality. The joint skew-kurtosis, Shapiro-Wilk and Shapiro-Francia tests also confirmed normality for the smaller sample of non-listed banks, but not for the much larger sample of listed banks. However, these last tests which work well in small samples are thought to be particularly sensitive in the case of large samples. On balance therefore, ANOVA is valid[13].

A convenient procedure for carrying out the ANOVA tests is to set up indicator, i.e., binary or dummy variables:

$$DI_s = \begin{cases} 1\ if\ bank\ is\ of\ type\ s \\ 0\ otherwise \end{cases}$$

and

[13] All results are available upon request from the authors.

$$DT_k = \begin{cases} 1\ if\ bank\ is\ observed\ in\ subperiod\ k \\ 0\ otherwise \end{cases} \tag{37}$$

Then ANOVA F-tests are simply the goodness of fit F-tests from the general regression against types and subperiods after dropping an indicator variable from each set to avoid perfect multicollinearity with the intercept, e.g., the first indicator variable in each set:

$$sroe_{sk} = a + \sum_{s\geq 2} b_s DI_s + \sum_{k\geq 2} c_k DT_k + \sum_{s\geq 2}\sum_{k\geq s} d_{sk}(DI_s \times DT_k) \tag{38}$$

If the null hypothesis is not rejected then $\hat{a}$ is our estimate of the shadow rate of return, ρ, on bank type $s = 1$ in subperiod $k = 1$, which is then treated as the constant rate of return across all types and subperiods. It must be emphasised that this is not an explanatory equation in which the indicator variables cause the shadow rate of return observations, it is simply a procedure for carrying out ANOVA tests. One-factor ANOVA for the bank type corresponds to: $d_{sk} = 0\ \forall s,k, c_k = 0\ \forall k$ with a corresponding restriction for one-factor subperiod ANOVA; two-factor ANOVA corresponds to $d_{sk} = 0\ \forall s,k$ and without the restrictions we have multi-factor ANOVA with interactions, which we have reported for completeness.

Overall, the results suggest the existence of different rates of return on equity by bank type and reject the null hypothesis that the expected value of the shadow rate of return on equity is constant across bank types and deleveraging subperiods. Table 6 reports the Kruskal Wallis chi squared and ANOVA F-test values to confirm this rejection of the null hypothesis.

We can use the regression form of the ANOVA tests to identify the role of bank type and deleveraging subperiod in more detail. For example, in the two-factor model with interactions we find the results in table 7.

The estimate of the expected shadow rate of return for city banks in 2000-02 a period of balance sheet equilibrium taking account of the impact of the other banks and subperiods is 6.3 percent. This would be the expected value of the shadow rate of return across all banks if it was not possible to identify banks' rates of return by bank type and subperiod, i.e., if the shadow rate of return had been constant over all periods and bank types as embodied in the null hypothesis in [36]. The coefficients on the other bank types and subperiods indicate how this expected shadow rate of return varies, and it is this variation that allows the possibility of identifying zombie banks. Each of the other banks types has a significantly negative impact on the shadow rate of return. Where the negative coefficient exceeds 6.3 percent in absolute value indicates that the expected shadow rate of return will be negative; this is the case for the bank types identified as R1, R2, RII_1. Type RII_2 has a lower but still positive shadow rate of return, the net effect being [6.3-5.9] percent. For subperiods, we identify a negative effect, statistically significant at the 5 percent level, on the expected shadow rate of return for city banks in the deleveraging subperiod 2003-6 compared with 2000-02 and a shift back to a high positive rate of return of 4.0 percent in the balance sheet equilibrium subperiod 2007. We find similar negative and restored positive effects on the expected shadow rate of return for city banks in the deleveraging subperiod 2008-14 and balance sheet equilibrium subperiod 2015-16, respectively.

Table 6. Tests of the null hypothesis [36] using the Kruskal Wallis (KW) chi-squared statistic and the analysis of variance ANOVA F statistic

factor	*bank type*				*deleveraging subperiod*			
sample	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*
listed banks	KW (4) = 122.299	0.0001	ANOVA F(4, 1376) = 32.18	0.0000	KW(4) = 61.48	0.0001	ANOVA F(4, 1376) = 16.01	0.0000
non-listed banks	KW (4) = 23.443	0.0001	ANOVA F(4, 1376) = 5.07	0.0005	KW(4) = 25.275	0.0001	ANOVA F(4, 1376) = 6.23	0.0005
all banks	KW (4) = 137.355	0.0001	ANOVA F(4, 1376) = 32.00	0.0000	KW(4) = 75.812	0.0001	ANOVA F(4, 1376) = 19.60	0.0000

factor	*bank type and deleveraging subperiod*				*bank type and deleveraging subperiod with interactions*			
sample	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*	*test statistic (df)*	*p-value*
listed banks	na	na	ANOVA F(8, 1372) = 25.64	0.0000	na	na	ANOVA F(24, 1356) = 9.28	0.0000
non-listed banks	na	na	ANOVA F(4, 479) = 6.02	0.0000	na	na	ANOVA F(24, 463) = 2.21	0.0009
all banks	na	na	ANOVA F(8, 1860) =27.01	0.0000	na	na	ANOVA F(24, 1844) = 9.67	0.0000

Null hypothesis: Expected shadow rate of return on equity is constant across bank types and deleveraging subperiods

We can now concentrate on the distribution of the positive and negative values of the shadow rate of return over the different bank types and subperiods since we argue that this is the key to identifying zombie banks. In Figure 6 and Tables 8 and 9 we describe the behaviour of the sign of the shadow return on equity in different periods for the banks in the sample. We start by looking at positive and negative values for the shadow return on equity. For each subperiod and each bank we identify the sequence of positive or negative values of the shadow return on equity capital and convert these to relative frequencies as follows.

For each bank j in year t we record the number of positive values of the shadow return on capital, m_{jt}, using an indicator function of the shadow return on equity, $sroe$:

$$m_{jt} = I(sroe_{jt}) = \begin{cases} = 1 \; if \; sroe_{jt} \geq 0 \\ = 0 \; if \; sroe_{jt} < 0 \end{cases} \quad [39]$$

We sum these across the whole group of banks of type I^s in subperiod T^k i.e.

$$\sum_{j \in I^s} \sum_{t \in T^k} m_{jt} \quad [40]$$

Table 7. Deviations from the base estimate of the expected shadow rate of return for different bank types and subperiods

1st order regression coefficients from two factor model with interactions for all banks:

Coefficient	estimate	t-value	change to base: city banks expected rate in 2000-02
$\hat{a}$, shadow rate of return for city banks 2000-02	0.063	4.77	equilibrium: estimate of expected shadow rate of return on equity for city banks 2000-02 is 6.3 percent
b_2, R1 regional banks	-0.079	-5.45	R1 banks: rate shifts down by 7.9 percent compared to city banks, becoming negative
b_3, R2 regional banks	-0.088	-6.08	R2 banks: rate shifts down by 8.8 percent compared to city banks, becoming negative
b_4, RII_1 regional banks	-0.076	-5.12	RII_1 banks: rate shifts down by 7.6 percent compared to city banks, becoming negative
b_5, RII_2 regional banks	-0.059	-3.99	RII_2 banks: rate shifts down by 5.9 percent compared to city banks staying just positive
c_2, deleveraging 2003-06	-0.060	-3.44	deleveraging: rate shifts down by 6.0 percent compared to 2000-02 staying positive at 0.3 percent
c_3, balance sheet equilibrium, 2007	-0.023	-0.82	equilibrium: city banks' rate = 4 percent, i.e., slightly lower but a non-significant drop and rate is still positive
c_4, deleveraging 2008-2014	-0.055	-3.3	deleveraging: city bank rate drops to 0.8 percent compared to 2000-02: significant drop but still positive
c_5, balance sheet equilibrium	0.002	0.08	equilibrium: city bank expected rate is 6.5 percent but not significantly different from 2000-02

We do the same for an indicator function of the number of negative values of the shadow return on capital, n_{jt}, i.e.

$$n_{jt} = J(sroe_{jt}) = \begin{cases} = 1 \; if \; sroe_{jt} < 0 \\ = 0 \; if \; sroe_{jt} \geq 0 \end{cases} \quad [41]$$

We sum these across the whole group of banks of type I^s in subperiod T^k i.e.

$$\sum_{j \in I^s} \sum_{t \in T^k} n_{jt} \quad [42]$$

The relative frequencies of positive and negative values of the shadow return on capital for banks in group $I^s$and subperiod T^k are therefore:

$$f_{sk}^{+} = \sum_{j \in I^s} \sum_{t \in T^k} m_{jt} \Bigg/ \left(\sum_{j \in I^s} \sum_{t \in T^k} m_{jt} + \sum_{j \in I^s} \sum_{t \in T^k} n_{jt} \right) \quad [43]$$

$$f_{sk}^{-} = \sum_{j \in I^s} \sum_{t \in T^k} n_{jt} \Bigg/ \left(\sum_{j \in I^s} \sum_{t \in T^k} m_{jt} + \sum_{j \in I^s} \sum_{t \in T^k} n_{jt} \right) \quad [44]$$

These terms must sum to unity and hence we are able to compare the relative frequency of positive and negative values of the shadow return on capital for banks of type I^s in period T^k. By separating the bank types and subperiods we are able to take account of the unbalanced nature of the sample panel data. We then report these relative frequencies in histogram format in Figure 6. We separate these results by type of bank. The sample is all banks, both listed and non-listed.

In Figure 6, firstly we report the results for City banks, which is numerically the smallest group in the sample. Figure 6 shows for each of the critical subperiods the relative frequency of a positive shadow return on equity, represented by clear blocks in the figure, and the relative frequency of a negative shadow return on equity, represented by the shaded blocks in the figure. For City banks we can see that over all subperiods the number of positive values of the shadow return exceeds the number of negative values. In 2000-2002 there is a positive shadow return in 100 percent of the sampled City banks. This percentage drops in the two deleveraging periods, 2003-06 and 2008-14, but is 80 percent in the short-lived balance sheet equilibrium of 2007, after the first deleveraging and before the financial crisis. In each deleveraging subperiod and in the final subperiod the percentages of positive and negative values for the shadow return on equity are roughly the same. We conclude that deleveraging did reduce the shadow return on equity for the City banks with about half of the sample becoming negative in those subperiods, but in general about half of the City banks were also able to maintain a positive shadow return on equity even in the deleveraging subperiods, and of course most, if not all maintained strongly positive shadow return on equity during 2000-02, and 2007. Secondly, focusing on

Regional Bank Association in both groups we can observe that a different picture emerges. In this category the relative frequency of negative shadow rates of return on equity exceeds in general the frequency of the positive shadow return on equity, suggesting that the weakness in the banking system in this sample of subperiods is more apparent in the Regional Bank Association. This is even more apparent when looking across different subperiods, where both R1 and R2 category results indicate a clear negative shadow return on equity. This outcome of a dominant negative shadow return on equity even in balance sheet equilibrium periods indicates the strong presence of 'zombie' banks in the R1 and R2 category. Thirdly, focusing on the Second Association of Regional Banks in both groups we can see that in both of these cases, the phenomenon of zombie banking is again present but less serious in the RII_2 category in the sense that the results display a dominance of the relative frequency of positive shadow returns on equity capital in balance sheet equilibrium but not in deleveraging subperiods. By contrast, in the RII_1 category of banks, the relative frequency of the negative values of the shadow return on equity dominates in all subperiods, so that again in this category we observe clear indications of zombie banking.

Fourthly, it could be argued that true zombie banks always display a negative shadow return on equity capital over a significant number of years. Such banks would always be in danger of capital insolvency but are kept alive in a way that allows them to focus only on the income account. This was an issue raised in the literature. To identify this, we select from the sample any banks which display a negative shadow return on equity in virtually every year of the sample, 2000-2016. There are such banks, as there are some banks with the opposite property of a positive shadow return on equity capital in virtually every year of the sample, which can be identified as well-capitalised banks. In Table 8 (Panel A), we show the total number of banks with at most one missing observation (i.e., having 16 out of 17 data points) in each category. We then report the relative frequency of banks having at most one occurrence of a negative sign in at least 16 observations – these are the well capitalised banks. We also show the relative frequency of banks having all negative values of the shadow return in at least 16 observations – these are the true zombie banks. The contrast we observed above between City banks and the other categories stands out once again. City banks dominate in the well-capitalized banks, while the other bank types, in particular Regional Bank Association (R1) account for the true zombie banks.

Finally, in Table 8 (Panel B) we examine our measure of medium run and long run of zombie banks based on the occurrence of negative values of the shadow return on equity for three or four consecutive years (medium run) and for five or more consecutive years (long run). We have already established from Table 8 (Panel A) that in the short run (one year) very few banks fail to avoid at least one year's negative value for the shadow return on equity. Recall that in Panel A we saw that in the City bank category two out of the three banks present in the full sample maintained a positive shadow return, while in the other categories only between 5 and 10 percent of the sample did so. In Table 8 (Panel B), we show the proportion of the banks in the sample with negative values for the shadow return on equity for three or four consecutive years and for five or more consecutive years. We do this separately for each of the two subperiods, 2000-06 and 2008-14. Apart from the

City banks category, these proportions are relatively high, once again strongly suggesting that the zombie banking phenomenon has been widespread in the banking sector in Japan.

Lastly, we isolate the performance of the non-listed banks in the sample by restricting the analysis reported in Table 8 to the non-listed banks only. In Table 9 (Panel A) we show the split of well-capitalized banks and true zombie banks for only the non-listed banks in the sample. We see immediately that the non-listed banks with a full range of 16 observations each in category R1 are almost all true zombie banks with a negative value for the shadow return on equity over the whole sample period. Other categories of non-listed banks are more securely capitalized with 2 of the non-listed banks having always a positive value for the shadow rate of return. In Table 9 (Panel B), we apply our medium run and long run measures to the non-listed banks only. Again, City banks perform well, with zombie behaviour being concentrated in the regional banks, in particular categories R1 and R2. Overall, our findings are consistent across different definitions of outputs, variety of measurement and across different sampling distributions. As our statistical testing indicated we have been able to confirm two hypotheses: 1. that in the asset-based model of banks, the shadow rate of return varies from positive to negative with the intensity of deleveraging and 2. that when the model is re-specified as an income-based approach, the elasticity of cost with respect to equity is always positive in all periods reflecting the fact that equity no longer offers a loss-absorbing benefit. The income-based approach therefore becomes appropriate for banks which, thanks to the authorities' support, no longer have to take account of their balance sheet constraint and that can focus only on the income account. This illuminates the debate in the literature about the different ways that the issue of bank viability is measured during financial crises. We used hypothesis 1 to identify banks with long term negative shadow returns on equity capital and categorised these as zombie banks. Various studies (Goddard et al., 2009; Cipollini and Fiordelisi, 2012; Fu et al., 2014) proposed other measures based on various issues at the bank level such as profitability, productivity, efficiency and distance to default.

Figure 6: Positive and negative values for the shadow return on equity across various bank types

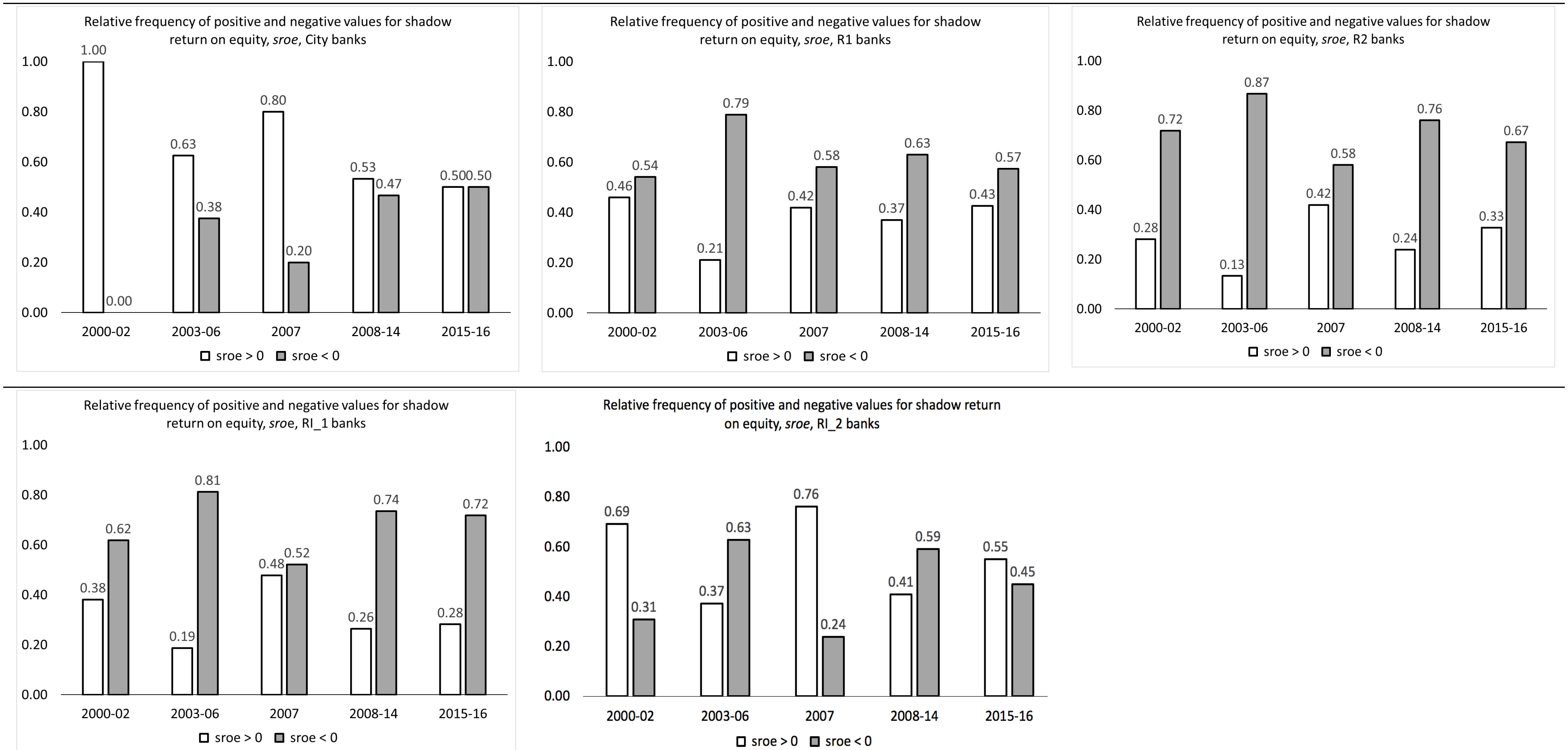


Table 8

Panel A. Well-capitalized and true zombie banks

Number of banks in category	Total banks with data for at least 16 years in sample	Proportion of banks that are well-capitalised	Proportion of banks that are true zombie banks
City Banks	3	0.67	0.00
Regional Bank Association (R1)	29	0.10	0.76
Regional Bank Association (R2)	29	0.07	0.38
Second Association of Regional Banks (RII_1)	19	0.05	0.37
Second Association of Regional Banks (RII_2)	18	0.06	0.17

Panel B. Sequences of zombie banks

Number of banks in category	Total banks in sample after all filters	Proportion of sample with negative shadow return for 3 or 4 consecutive years, 2000-2006	Proportion of sample with negative shadow return for 5 or more consecutive years, 2000-2006	Proportion of sample with negative shadow return for 3 or 4 consecutive years, 2008-2014	Proportion of sample with negative shadow return for 5 or more consecutive years, 2008-2014
City Banks	11	0.09	0	0.18	0.09
Regional Bank Association (R1)	32	0.34	0.41	0.06	0.50
Regional Bank Association (R2)	32	0.31	0.50	0.03	0.66
Second Association of Regional Banks (RII_1)	27	0.22	0.44	0.07	0.44
Second Association of Regional Banks (RII_2)	27	0.22	0.22	0.07	0.37

Table 9

Well-capitalized and true zombie (non-listed banks only)

Number of banks in category	**Total banks with data for at least 16 years in sample**	**Proportion of non-listed banks that are well-capitalised**	**Proportion of non-listed banks that are true zombie banks**
City Banks	1	0	0
Regional Bank Association (R1)	4	0.25	0.75
Regional Bank Association (R2)	4	0	0.25
Second Association of Regional Banks (RII_1)	15	0	0.27
Second Association of Regional Banks (RII_2)	10	0.10	0.10

Sequences of non-listed zombie banks (non-listed banks only)

Number of banks in category	**Total non-listed banks in sample after all filters**	**Proportion of non-listed banks with negative shadow return for 3 or 4 consecutive years, 2000-2006**	**Proportion of non-listed banks with negative shadow return for 5 or more consecutive years, 2000-2006**	**Proportion of non-listed banks with negative shadow return for 3 or 4 consecutive years, 2008-2014**	**Proportion of non-listed banks with negative shadow return for 5 or more consecutive years, 2008-2014**
City Banks	1	0	0	0	1.00
Regional Bank Association (R1)	4	0	0.25	0	0.25
Regional Bank Association (R2)	4	0.50	0.50	0	0
Second Association of Regional Banks (RII_1)	15	0.20	0.40	0.13	0.20
Second Association of Regional Banks (RII_2)	16	0.38	0.25	0.13	0.50

6. Summary and conclusion

In this paper, we set out to model the behaviour of banks meeting targets for their loan portfolios when there are different states of the world with different associated risks of loan defaults by borrowers. We emphasized the idea of the loss-absorbing capacity of the bank's equity capital. To implement these ideas, we constructed a cost minimizing model of bank behaviour for multiple outputs and inputs. In particular, we permitted the technology of the bank lending process to display the existence of a non-economic region of the production set in which the shadow price of one or more inputs can become negative when that input is increased significantly relative to the others. We treated the bank's equity capital as a quasi-fixed input due to the nature of bank regulation and therefore it entered the short-run cost function as the input level of equity, whereas other inputs entered in the form of input prices. We showed how the envelope theorem ensured that the negative of the elasticity of cost with respect to the quasi-fixed input level can be interpreted as the shadow rate of return on the input.

We estimated the dual cost function model using several estimation methods applied to a panel dataset of listed and non-listed banks in Japan over the period 2000-2016. We were able to identify periods when the shadow return on capital for both listed and non-listed banks was falling or negative, and we showed that these coincided with periods when the equity-loan ratio was increasing rapidly. This period was longer for the non-listed banks than for the listed banks. We argued in the theoretical analysis that deleveraging pushed the banks away from the long run allocative efficiency equilibrium.

Our paper therefore contributes to the debate on the costs and benefits of recapitalizing the banking system after a financial crisis. The benefits are well understood and relate to the financial stability of the economy, but the costs are less well documented. While the case against recapitalization put forward by the banks themselves often hinges on weak arguments about the weighted average cost of capital, there must nevertheless be costs to the process of recapitalization otherwise it would be painless. In this paper, we suggest that the impact can be measured by the reduced profitability of the intermediation business embodied in the fall in the shadow return on equity as the equity to loans ratio rises and deleveraging continues. In a weakly disposable technology this shadow return may even become negative. This fall in the shadow return on equity and its impact on productivity growth in banking as deleveraging and recapitalization take place is, we argue, one useful way of measuring the cost of the deleveraging that follows financial crisis. After deleveraging is complete, the return to efficiency in a seriously traumatised banking system like that of Japan, may still be insufficient to offset the impact of negative efficiency change.

Several lessons are available from this study of the banking system in Japan over the period 2000 to 2016. We show that deleveraging did reduce the shadow return on equity for the City banks with about half of the sample becoming negative in those subperiods, but in general about half of the City banks were also able to maintain a positive shadow return on equity even in the deleveraging subperiods, and of course most, if not all maintained strongly positive shadow return on equity during 2000-02, and 2007. We also provide evidence that the presence of 'zombie' banks was concentrated and large among the smaller less diversified Regional Banks.

Behind our new empirical evidence for Japanese banks, our paper has a very important policy implication since it provides policy makers (as banking regulators and supervisors) a new framework to identify "zombie" banks that rely on a core corporate finance principle (shareholders expect to receive positive returns and banks systematically failing to achieve this topic are "zombie" firms). Our approach is objective and replicable: we focus on Japanese banks (since these banks have been experiencing a deep financial crisis from the late 1990s and there is a serious problem of zombie banks), and it can be easily applied to other countries in future studies.

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