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On the Independence of Assets and Liabilities: Evidence from U.S. Commercial Banks, 1990-2005*

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Abstract: Traditional asset-liability management techniques limit banks' abilities to structure their balance sheets—but more recently, financial innovations have allowed banks the chance to manage interest rate risk without constraining their asset-liability choices. Using canonical correlation analysis, we examine how the relationships between asset and liability accounts at U.S. commercial banks changed between 1990 and 2005. Importantly, we show that asset-liability linkages are weaker for banks that are intensive users of risk-mitigation strategies such as interest rate swaps and adjustable loans. Perhaps surprisingly, we find that asset-liability linkages are stronger at large banks than at small banks, although these size-based differences have diminished over time, both because of increased asset-liability linkages at small banks and decreased linkages at large banks.

Key words: asset-liability management, canonical correlation, commercial banks, deregulation, technological change.

JEL codes: G21, G32

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1. Introduction

The savings and loan crisis of the 1970s and 1980s was the largest financial disruption in the United States since the Great Depression of the 1930s, and stood as the largest financial disruption in the United States until the subprime lending crisis of 2007-2008. While the crisis unfolded in several increasingly complicated stages and took over a decade to run its course, the initial cause of the crisis was quite simple: savings and loans (or thrifts) funded long-term fixed rate mortgage loans with short-term certificates of deposit and demandable deposit accounts. Under normal credit market conditions—that is, an upward sloping yield curve—this maturity mismatch was quite profitable, but it left thrifts vulnerable to interest rate risk. When U.S. interest rates spiked in the late 1970s thrifts' cost of funds also spiked, resulting in negative interest margins which—coupled with capital losses from discounted loan sales, loan defaults in markets with falling real estate values, and imprudent risk-taking by thrift owner-managers desperate to generate profits—consumed the equity capital of hundreds upon hundreds of thrift institutions. Over a thousand thrifts became insolvent, with the ensuing bailout of the government safety net costing U.S. taxpayers approximately $125 billion.

The thrift crisis was a wake-up call to U.S. banks and thrifts underscoring the importance of asset-liability management (ALM) for mitigating interest rate risk. In its most simple form, ALM requires banks to select a liability structure that matches the expected maturity or duration of their existing assets, thus immunizing bank earnings from interest rate movements. More recently, a variety of developments have allowed banks to mitigate interest rate risk without having to practice this strict form of ALM. Financial innovations such as interest rate derivatives, adjustable rate loans, and asset securitization have expanded the methods banks can use to manage interest rate risk both on and off the balance sheet, and have reduced the costs of doing so. Geographic deregulation has allowed banks of all sizes to grow larger, providing a wider set of investment and funding options for small banks and allowing midsized banks easier access to off-balance sheet risk-management tools and tactics. Expansion into non-traditional banking services securities brokerage and insurance sales, as well as a general shift away from portfolio lending and toward securitized lending and contingent credit contracts, have generated streams of off-balance sheet income which, in some cases, has reduced banks' reliance on interest-based income and lessened the importance of asset-liability mismatch to their overall risk positions.

Because these developments have arguably reduced the need for banks to practice strict ALM, the composition of banks' assets and liabilities should have become measurably more independent over the past two decades. We ask and attempt to answer two basic questions related to the development and application of these potential risk-mitigation tools: Have bank assets and liabilities become measurably more independent over time? And if so, is the application of interest rate derivatives, adjustable rate loans, and other off-balance sheet tools empirically associated with increased asset-liability independence? While conventional wisdom suggests that the answer to both of these questions is "yes," we are not aware of any systematic empirical investigation of these phenomena.

We apply canonical correlation analysis to balance sheet data for U.S. commercial banks between 1990 and 2005. Although canonical correlation analysis is seldom used in financial or banking research, it is a most appropriate tool for our purposes. Developed by Hotelling (1935, 1936), canonical correlation is a multivariate version of the familiar linear correlation analysis—more exactly, linear correlation is a special case of canonical correlation analysis in which the two vectors being examined each contain just a single variable. The technique measures the degree to which one set of correlated variables (say, the portfolio of loans, investments, and other assets held by banks) is useful for explaining the variance in another set of correlated variables (say, the mix of liabilities and equity capital used to fund bank assets). As such, the technique captures—in a single, summary measure—the essence of traditional asset-liability management: whether the maturity mix of banks' liability accounts reflects the maturity mix of banks' asset accounts. Moreover, the technique also identifies the most important underlying relationships between and among the individual elements in the two vectors, which allows us to infer which assets banks tend to match with which liabilities in the course of performing ALM. Finally, canonical correlation imposes no structure on the data and makes no assumptions about the causal direction between the two vectors; this flexibility is essential for our experiment, since some commercial banks have strong deposit franchises and search for profitable lending opportunities, while other commercial banks have strong lending programs and must search for funding.

We have four main findings. First, we find that the strength of asset-liability linkages is positively related on average to bank size. This is a surprising result, as one may easily have expected that small banks would be the stalwart practitioners of on-balance sheet ALM. This result (a) suggests that small size and local geographic focus impart a granularity to individual loans and an inflexibility to deposit mix, both of which constrain on-balance sheet ALM, and (b) offers an explanation for the relatively low levels of financial leverage typically found at small banks, i.e., these banks hold extra capital against risk they cannot otherwise hedge on the balance sheet.

Second, we find that overall asset-liability linkages have become systematically less correlated over time for large banks, but systematically more correlated over time for small banks. The former result is a sensible one, given that large banks (a) have easier access than small banks to many of the new tools for risk mitigation, (b) have accounted for the bulk of banking industry consolidation and thus have benefited more from size-related reductions in risk, and (c) have lately derived an increased portion of their income from fee-based activities which *may potentially* generate activity-based reductions (diversification) in risk.[1] The latter result likely reflects the increasing size of banks during our 1990-2005 time period, which for small banks relaxes to some extent the constraints associated with asset granularity and deposit mix inflexibility. Regardless of the factors driving these changes, our evidence shows that the degree of asset-liability dependence has converged over time, i.e., different-sized banks have become more alike.

Third, we find evidence that asset-liability correlations are weaker at banks that are disproportionate users of risk-mitigation tools such as interest rate swaps and/or adjustable rate loans, consistent with off-balance sheet risk-mitigation. We also find that asset-liability linkages are weaker at

[1] According to industry wisdom, banks can reduce risk by replacing interest income with non-interest income, due to greater diversification, reduced exposure to interest rate movements, and less exposure to credit risk. However, researchers have found little evidence of such gains. For example, see DeYoung and Roland (2001), DeYoung and Rice (2004), and Stiroh (2004a, 2004b).

banks that have relatively strong supervisory safety and soundness ratings, consistent with extant evidence that bank supervisors allow well-managed and/or safe-and-sound banks more risk-taking leeway (DeYoung, Hughes, and Moon 2001).

Fourth, we find a number of systematic and economically intuitive relationships among individual asset and liability accounts at commercial banks. For instance, we find especially strong positive relationships between short-term loans and purchased funds financing, and between long-term loans and core deposit funding. These results are consistent with Song and Thakor (2007) which provides a theoretical basis for asset-liability matching at banking institutions. In their model, banks that offer liquidity services to depositors maximize their profits by making relationship loans, while banks making non-relationship loans or marketable "transactions" loans are better off using purchased fund financing—thus, long-term assets and liabilities (relationship loans, core deposits) tend to appear together on the balance sheets of relationship lenders, while short-term assets and liabilities (transactions loans, purchased funds) gravitate toward the balance sheets of transactions lenders.

The remainder of the paper proceeds as follows. In Section 2 we discuss some important background issues, including the finance literature on asset-liability independence, the incompleteness of financial markets, the asset-liabilities linkages that make financial institutions special, and how recent financial innovations and deregulations arguably make financial markets more complete and reduce asset-liability linkages in all firms, but especially in financial intermediaries. In Section 3 we provide a basic outline of canonical correlation analysis, the statistical methodology we employ in this study to measure the strength of asset-liability linkages at commercial banks. In Section 4 we describe our data on U.S. commercial banks between 1990 and 2005. In Section 5 we present the basic results of our analysis, and in Section 6 we derive some additional results regarding banks that are heavy users of risk-mitigation techniques. Section 7 summarizes our findings and their implications for the theory of financial intermediation, the risk-return tradeoff in banking, and public policy toward banking institutions.

2. Background

A number of theories have been advanced to explain why banks exist. In most of these theories, banks exist because they solve a host of problems that otherwise prevent the flow of funds from agents with excess liquidity (depositors) to agents in need of liquidity (borrowers). These problems arise because of informational asymmetries, contracting costs, and scale mismatches between liquidity suppliers and liquidity demanders. Intermediation-based theories of financial institutions see banks as the solution to these problems because: banks have a comparative advantage at gathering information on borrower creditworthiness; banks are better able than individual lenders to monitor borrowers; banks provide increased liquidity by pooling funds from many households and businesses and by issuing demandable deposits in exchange for these funds; banks diversify away idiosyncratic credit risk by holding portfolios of multiple loans; and banks are able to exploit inter-temporal production synergies that exist between deposit supply and credit demand.[2]

Banks earn a profit from the financial flows fundamental to the intermediation process (e.g., interest paid on deposits, interest received from loans and securities, and the resulting net interest margins) but the nature of these flows exposes the bank to risk. Some of these risks are associated solely or primarily with items on just one side of the balance sheet and are independent of items on the other side of the balance sheet, e.g., credit risk is associated primarily with loans, while market risk is associated primarily with investments in long-term fixed income securities. This independence suggests that a substantial amount of the risk inherent in banking is unrelated to the intermediation process. In contrast, *interest rate risk* is associated with the interaction of items on the right-hand side (e.g., the maturities of various loans and securities) and left-hand side (e.g., the maturities of various deposit accounts) of a bank's balance sheet, and as such is a direct outgrowth of the intermediation process. Thus, the value of a traditional commercial banking company will depend systematically on its financing

[2] Seminal theoretical studies in this area include Gurley and Shaw (1960), Pyle (1971), Benston and Smith (1976), Leland and Pyle (1977), Fama (1980), Diamond and Dybvig (1983), Diamond (1984), Boyd and Prescott (1986), James (1987), Gorton and Pennacchi (1990), and Kashyap, Rajan, and Stein (2002). See Saunders and Cornett (2006, chapter 1) and Freixas and Rochet (1999, chapter 2) for general discussions of why banks exist and overviews of the theoretical literature.

decisions, even in a world without taxes or other frictions absent from the simplest Modigliani and Miller (1958) framework.[3]

The degree to which commercial banking companies rely on the traditional intermediation business model has declined over time. Two decades of innovations in information processing, communications technologies, and financial markets (e.g., credit bureaus, computers, the Internet, adjustable-rate loans, credit scoring, asset securitization, financial derivatives), plus a wave of industry deregulation that abolished barriers to diversification across geographic and product market boundaries, have allowed banks to (a) expand into non-intermediation activities, (b) alter the nature of their intermediation processes, and (c) adopt new methods of managing the risks inherent in intermediation. Collectively, these changes have reduced the degree of association between assets and liabilities that has traditionally been necessary for banks to operate profitably. In this paper, we employ canonical correlation analysis to document the increased independence of bank assets and bank liabilities over time, to demonstrate that the degree of asset-liability dependence has grown more similar across banks over time, and to test whether and how differences in bank size, business strategy, risk management practices, and financial performance may have influenced these changes.

Commercial bank business models have evolved over the past two decades, and today banks generate an increased portion of their income from non-intermediation and/or non-interest activities. For example, between 1980 and 2001 non-interest income in the U.S. commercial banking system increased from 0.77% to 2.39% of aggregate banking industry assets, and increased from 20.31% to 42.20% of aggregate banking industry operating income (DeYoung and Rice 2004). This is not just a U.S. phenomenon: Kaufman and Mote (1994) found that non-interest income ratios increased in the banking sectors of virtually all developed countries between 1982 and 1990, while Choi, DeYoung, and Hasan

[3] Imagine a bank with a $100 loan that matures in one year, that is funded by either (a) a $100 one-year CD or (b) a $100 six-month CD. The maturity-matched financing scheme (a) generates less interest rate risk than financing scheme (b), and hence results in higher bank value. (Note: With an upward-sloping yield curve, the cash outflows associated with short-run financing scheme (b) would be less than those associated with long-run financing scheme (a), and these savings could potentially offset some or all of the value-reducing effect of the interest rate risk. However, there is no guarantee that such conditions will obtain in credit markets; moreover, a downward sloping yield curve would exacerbate the value-reducing effect of interest rate risk in the short-run financing scheme.)

(1997) show that non-interest income increased on average from 1.6% to 2.4% of assets at a sample of 41 non-U.S. banking sectors between 1995 and 2002. On its face, the rapid growth in non-interest income at commercial banks suggests that intermediation activities have become a less important part of banking business strategies. (At least) two studies suggest that this would be a false conclusion. DeYoung and Rice (2004) showed that the correlation between return-on-equity and net interest margin in the U.S. banking system grew stronger between 1984 and 2001, and Boyd and Gertler (1994) showed that although the share of U.S. financial assets held by commercial banks was in decline, the amount of intermediation in which these banks participated was not. Both of these studies suggest a *different*, rather than *declining*, role for banks in financial intermediation which features off-balance sheet activities that generate fee income rather than, or in addition to, portfolio lending that generates interest income.

If intermediation has indeed remained central to the profitability of commercial banks over the past two decades, there is no doubt that the manner in which banks intermediate has changed. Perhaps the most fundamental change in the intermediation process has been the securitization of consumer loans—home mortgage loans in particular, but also credit cards, auto loans, and even more recently small business loans. Rather than holding these loans as on-balance-sheet investments, banks bundle the loans into loan pools, and sell these pools into an investment trust that is financed by the sale of securities (e.g., mortgage-backed securities). The security holders receive cash flows based on the interest generated by the pooled loans, as well as some protection from credit risk (the bank often takes a first-loss position). The bank earns fees when the loans are originated and fees for servicing the loans (or, alternatively, sells the servicing rights), but since the loans are not held on the balance sheet, the bank earns no interest income and economizes on equity capital. Securitized lending exhibits large scale economies, partly because banks use automated credit scoring models—a technology with a low ratio of variable costs to fixed costs—to evaluate loan applications.

Loan securitization has led to a strategic dichotomy in the banking industry, with large banks and small banks having quite different approaches to intermediation (DeYoung, Hunter, and Udell 2004). Small community banks are more likely to evaluate credit applications based on “soft” information about the borrower that cannot be used in an automated underwriting model, hold the loan in its portfolio, and fund the loan with core deposits. This is a traditional, relationship-based approach to intermediation, which generates potential interest rate risk. Loans to small businesses are the quintessential example of the relationship loan, due primarily to the idiosyncratic nature of small businesses. In contrast, large retail banks have become more likely to evaluate consumer credit applications using automated credit scoring models that rely on "hard" quantitative information, treating the loans as financial commodities rather than customer relationships. Because consumer loan applications exist in large numbers and the applicants tend to be more homogeneous than commercial borrowers, credit scoring and securitization are almost exclusively applied to this lending sector. This transactions-based approach to intermediation generates little if any interest rate risk, because the assets are not on the bank's books.[4]

Banks' intermediation activities were also disrupted by the loss of commercial lending business to non-bank competitors (e.g., insurance companies, pension funds) and business borrowers' increased access to financial markets (e.g., commercial paper, bonds) over the past two decades. The volume of commercial lending assets on banks' balance sheets has declined, but banks have been able to retain some of the commercial lending cash flows by exploiting their comparative advantage in evaluating borrower creditworthiness. For a fee, commercial banks provide loan commitments and back-up credit lines to commercial firms—without these endorsements of creditworthiness, most firms would not be able to access credit inexpensively in financial markets. These credit references are also contingent liabilities for the banks, because firms are likely to draw down these lines of credit under adverse circumstances. A recent strand of the literature (Kashyap, Rajan, and Stein 2002; Gatev and Strahan 2005; Gatev, Schuerman, and Strahan 2006) points out that the liquidity risk created by credit commitments on the left-hand side of the balance sheet (in effect, banks have sold call options to their business customers) will tend to offset the liquidity risk created by transactions deposits on the right-hand side of the balance sheet (in effect, call options in the hands of depositors). This is because these two sets of call options tend to be

[4] Under some recourse arrangements, the investors can put nonperforming loans back onto the bank's balance sheet. In this eventuality, the primary risk facing the banks is credit risk, not interest rate risk.

executed at different times: When market liquidity is tight, firms tend to draw down their available bank credit lines, and depositors tend to hold large balances. This literature provides yet another theory for why banks exist as intermediaries—holding both transactions deposits and unused loan commitments is a "natural hedge" that can reduce a bank's liquidity risk, and by doing so reduces the bank's need to hold otherwise unproductive cash balances.

For banks with business strategies that generate fewer natural hedges, "maturity" or "duration matching" is a traditional way to mitigate interest rate risk.[5] But this is a potentially costly way to mitigate interest rate risk. Matching the durations of its existing loans can require a bank to purchase deposits in maturities that carry higher interest rates than the bank's current deposits; similarly, matching the durations of its existing deposits can require a bank to forego some otherwise profitable lending opportunities. Duration matching can be less costly for banks with long-lasting relationships on both sides of the balance sheet—for example, traditional relationship banks use core deposits with long durations to fund repeat lending business—but many banks do not enjoy these types of natural strategic hedges against interest rate risk. The huge growth in the market for interest rate swaps (as well as other interest rate derivatives) over the past two decades has provided banks with an alternative approach for managing their interest rate risk, and as such has likely reduced the necessary link between assets and liabilities on banks' balance sheets. These off-balance sheet risk-mitigation tools have been used mostly by larger banks, suggesting either that larger scale or a greater amount of financial expertise is needed to profitably deploy this risk-mitigation strategy, and/or that large banks simply practice business strategies with fewer natural interest-rate-risk hedges.

We test whether changes in the intermediation environment at commercial banks over the past two decades (e.g., adjustable rate loans, interest rate derivatives) have reduced the degree of asset-liability linkage at commercial banks. We also examine whether differences across banks (e.g., bank size and

[5] While the *duration* of a financial asset is shorter than the *maturity* of the asset, these two concepts are positively correlated by construction. Given that (a) we have little information about the rates and maturities of bank assets and liabilities, and (b) by necessity we must group assets and liabilities into very broadly defined buckets, the difference between these two concepts is immaterial for the purposes of this study.

financial performance) influence asset-liability linkages. Our primary goal is to discern whether exogenous financial, regulatory, and technological changes that have arguably made markets more complete have weakened the relationships between assets and liabilities in commercial banks, and as such have moved these firms closer to a theoretical Modigliani-Miller (MM) world in which the financing and investment decisions are independent for value-maximizing firms.

3. Canonical correlation analysis

A *canonical correlation* is the maximum correlation between linear functions of two vectors of variables, where linear weights are selected that maximize the correlation. As such, canonical correlation is an especially appropriate tool for analyzing the inner workings of financial intermediaries like commercial banks that transform multiple types of liabilities with different characteristics (e.g., demand deposits, household checking and savings accounts, long-term certificates of deposit, purchased funds) into multiple types of assets with different characteristics (e.g., short-term loans, long-term loans, investment securities, cash and liquid reserves).[6]

Surprisingly, canonical correlation analysis has been applied only sparingly to describe asset-liability relationships. Simonson, Stowe, and Watson (1983) used it to analyze a cross section of data for large U.S. commercial banks. Similarly, Obben and Shanmugam (1993) used canonical correlation analysis to analyze the incidence of maturity matching among Malaysian commercial banks, finance companies, and merchant banks. Prior to these two studies, Stowe, Watson, and Robertson (1980) applied the technique to non-financial firm balance sheet relationships. These studies have all been static in nature, and we are not aware of any studies using canonical correlation analysis to illustrate the evolution of asset-liability relationships across time. More recently, canonical correlation analysis has been used to study topics in finance other than asset-liability relationships. Duru and Iyengar (2001) used the technique to investigate the relationship between multiple CEO compensation measures (e.g., salary, bonus, present value of options grants) and multiple firm performance measures (e.g., return on equity,

[6] Note that the results of canonical correlation analysis are unaffected by this inferred causation. The causation could just as well run in the opposite direction—banks having investment opportunities of various characteristics could then select liability funding with various characteristics.

earnings growth, stock market returns). Hasbrouck and Seppi (2001) used canonical correlation analysis to examine the relationships between short-run (15-minute intervals) stock order flows and short-horizon stock returns (15-minute intervals) for the 30 stocks in the Dow Jones Industrial Average.

The relationships between asset accounts and liability/capital accounts are not simple ones. (From this point forward, we use "liabilities" as a generic term to describe any of the accounts on the right-hand side of the balance sheet, including both liabilities and equity.) For example, the optimal balance of traditional home mortgage loans at a bank will depend not only on the liability account balances that fund those loans (say, long-term deposits and equity), but will also depend on the balances in other asset accounts with expected returns that co-vary with the expected returns of mortgage loans, as well as on the liability account balances that fund those other assets (say, checking accounts and purchased funds). Although canonical correlation analysis cannot directly consider return variances and co-variances, it considers them indirectly through the movements and co-movements in the relative levels of those balances.[7] More explicitly, canonical correlation analysis determines linear combinations of the various asset accounts that are most highly correlated with linear combinations of the various liability accounts. Moreover, because the complex relationships between and among asset and liability accounts are unlikely to be fully captured by a single set of linear functions, multiple canonical correlations are usually considered, based on multiple pairs of linear combinations that are orthogonal to each other.

We make a brief presentation of the canonical correlation technique here; additional technical details are available in Appendix A. Let the asset variables be denoted $X = [X_1, X_2, \ldots, X_p]$ and the liability variables be $Y = [Y_1, Y_2, \ldots, Y_q]$. The X and Y variables are expressed as a proportion of total assets. From these variables we can construct linear combinations of X and Y:

$$A = B^{'}X = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_p X_p \tag{1}$$

$$L = C^{'}Y = \gamma_1 Y_1 + \gamma_2 Y_2 + \gamma_3 Y_3 + \ldots + \gamma_q Y_q \tag{2}$$

[7] We assume that there is some risk-based return maximization strategy in place that is generating these movements and co-movements in the relative levels of these asset balances.

where $B' = [\beta_1, \beta_2, \ldots, \beta_p]$ and $C' = [\gamma_1, \gamma_2, \ldots, \gamma_q]$ are vectors of scalars to be estimated. We refer to the scalars that comprise the vectors B′ and C′ as *canonical coefficients*, and we refer to the linear combinations A and L as *canonical variables*. The canonical coefficients are chosen to maximize the *canonical correlation* between the canonical variables A and L:

$$r_{AL} = \frac{\sum al}{\sqrt{\left(\sum a^2\right)\left(\sum l^2\right)}} \tag{3}$$

where a and l denote mean differences for the variables A and L, respectively. Importantly, because (assuming $p \geq q$) there are up to p different ways to pair up each asset and liability variable, the maximization process generates p-1 separate canonical correlations, based on p-1 distinct and orthogonal linear combinations A and L.[8]

The size and strength of the canonical correlation forms the basis for identifying relationships between specific asset and liability accounts. For example, if we observe that actual core deposits (Y_{CORE}) are strongly correlated with the constructed canonical variable L, and we also observe that actual long term loans ($X_{LTLOANS}$) are strongly correlated (in the same direction) with the constructed canonical variable A, then we can surmise that banks with high levels of core deposits will also tend to have large amounts of long term loans as long as the correlation r_{AL} is strong. In other words, long term loans and core deposits share a common factor which is captured in r_{AL}. This indirect relationship between Y_{CORE} and $X_{LTLOANS}$ is illustrated in Figure 1, and depends entirely on the direction and strength of the maximized correlation between the two canonical variables A and L.

The nature of the relationships between asset and liability accounts can be studied by examining more detailed information from the *canonical loadings*. Canonical loadings are the correlations between

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[8] The process generates p-1, rather than p, canonical correlations because one asset and one liability variable is dropped to avoid singularity in the maximization process. We use an F-test proposed by Bartlett (1947) to determine the statistical significance of the p-1 canonical correlations.

the actual variables and their own canonical variables. For instance, a canonical loading of the variable X_1 with the first canonical variable A_1 is the simple correlation between X_1 and A_1:

$$Corr(X_1, A_1) = Corr\left(X_1\ ,\ \beta_1^1 X_1 + \beta_2^1 X_2 + \ldots + \beta_p^1 X_p\right) = \beta_1^1 \sigma_{x,11} + \beta_2^1 \sigma_{x,12} + \ldots + \beta_p^1 \sigma_{x,1p} \tag{4}$$

where $\beta_1^1, \beta_2^1, \ldots, \beta_p^1$ are the first canonical coefficients for A_1, $\sigma_{x,11}$ is standard deviation of X_1, $\sigma_{x,12}$ is the correlation between X_1 and X_2, and so on. Similarly, canonical loadings can be derived for liability variables (e.g., $Corr(Y_1,L_1)$) or for higher order (p>1) canonical variables (e.g., $Corr(X_1,A_3)$). Calculating the canonical loadings allows us to implement the logic displayed in Figure 1. If the canonical correlation (3) between assets and liabilities is strong <u>and</u> the canonical loading (4) for asset *i* is strong <u>and</u> the canonical loading for liability *k* is strong, then we can surmise that a relationship exists between asset *i* and liability *k*. The canonical loadings also prove useful for measuring the total amount of variance in the actual data accounted for by the canonical variables:

$$R_{A,j}^2 = \sum_{i=1}^{p} \frac{\left(Corr\left(X_i, A_j\right)\right)^2}{p} \tag{5}$$

where $R^2_{A,j}$ is the *proportion of variance* in the asset variables accounted for by the j^{th} asset canonical variable (j=1,…, p). This measure indicates how well a canonical variable captures the total amount of variance in the X variables. For instance, if only one asset variable has high association with the asset canonical variable (i.e., a high canonical loading), the statistic $R^2_{A,j}$ will tend to be small.

Note that the canonical correlation in (3) represents the variance shared by linear combinations of asset and liability variables, and not the shared variance of the original asset and liability variables. Hence, it is possible that a very large canonical correlation could be the result of a large correlation of just one asset variable with just one liability variable, while the other asset and liability variables are uninvolved in the canonical structure. In such a case, the canonical correlation would overstate the true relationship. The *redundancy coefficient* provides a summary measure of the average ability of asset (liability) variables taken as a set to explain variation in liability (asset) variables taken one at a time:

$$R^2_{A|L,j} = \mu_j^2 R^2_{A,j}. \tag{6}$$

The first term of the product, μ_j^2, is the j^{th} squared canonical correlation (or the j^{th} eigenvalue) and measures the proportion of variance in j^{th} asset canonical variable predictable from the j^{th} liability canonical variable (see the Appendix for details). The second term, $R^2_{A,j}$, is the proportion of asset variance accounted for by its j^{th} canonical variable. The product of these two terms measures the proportion of asset variance explained by j^{th} liability canonical variable. Summing the redundancy coefficients across all the canonical correlations provides an index, $R^2_{A|L}$, of the proportion of variance of asset variables predictable from liability variables, or the redundancy in asset variables given liability variables.

4. Data

We analyze asset-liability relationships and trends for FDIC-insured U.S. commercial banks between 1990 and 2005, using year-end data from the Reports of Condition and Income (call reports).[9] We place a special emphasis on four separate cross sections of data in 1990, 1995, 2000, and 2005. Examining the data in five-year intervals allows sufficient time to pass between observations for asset-liability relationships to react (or not react) to changes in financial markets, new risk mitigation tools, industry deregulation, etc. We begin our analysis in 1990 because changes in the call report during the mid- and late-1980s make it difficult to construct consistent definitions of asset and liability accounts before 1990. This starting date comes largely before the wide-spread adoption of financial innovations (interest rate derivatives, asset securitization, adjustable rate mortgages) and the onset of regulatory

[9] Although it would have been interesting to include stock and mutual savings banks in our analysis, we are unable to do so because the financial data for these firms is formatted inconsistently with that of commercial banks during the first half of our data period.

changes (FDICIA in 1991, Reigle-Neil in 1994, Gramm-Leach-Bliley in 1999) which likely have affected the nature of asset-liability relationships. We exclude banks less than 10 years old from the analysis because the balance sheets of young banks are known to be volatile (Brislin and Santomero, 1991). We also exclude credit card specialty lenders, as well as banks for which complete information was not available for the entire 1990 to 2005 sample period.

We perform canonical correlation analysis on these data in each year from 1990 through 2005; each set of annual calculations is independent from the others. The models are estimated only for "survivor banks" that appear in the data every year during the sample period; this ensures that our findings will reflect the impact of changes in financial markets, information technology, and industry regulations on asset-liability dependence, while holding (as best possible) bank management and business strategy constant. Each of the survivor banks is assigned to one of four asset size categories, or quartiles, based on its average assets over the entire sample period; this ensures that our sub-sample canonical correlation measures will be based on the same number of banks, making comparisons across sub-samples more valid. (Because the asset-size distribution of banks is skewed upward, we also construct a data sub-sample consisting of the largest ten percent (largest decile) of banks, and run selected tests on this data sub-sample.) Table 1 displays summary statistics for the variables we use to calculate the canonical correlations, arrayed separately for each of the four data cross sections and for four asset size quartiles.

We subdivide bank assets into six accounts (cash, short-term securities, long-term securities, short-term loans, long-term loans, and other assets) and bank liabilities and equity into five accounts (demand deposits, purchased funds, core deposits, other liabilities, and equity). Each of these accounts is expressed as a percentage of total assets. Care was taken to use consistent definitions of each asset and liability account across time.[10] A priori, there is no "right" way to subdivide the right-hand and left-hand sides of the balance sheet prior to applying canonical correlation analysis, and we make these choices

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[10] The one small exception to this was "open account time deposits greater than $100,000," which due to changes in the call reports are included in core deposits in 1990 and 1995, and in purchased funds in 2000 and 2005.

based primarily on the maturity characteristics of the accounts: Cash, short-term securities, short-term loans, demand deposits, and purchased funds tend to have shorter maturities, while long-term securities, long-term loans, core deposits, and equity tend to have longer maturities. Exact definitions of the balance sheet items included in each of these accounts appear in the notes to Table 1.

The individual accounts exhibit some trends over time, reflective of the changing nature of banking technologies and financial markets, as well as increasing competitive pressures in the consolidating industry. Both cash and short-term securities holdings declined on average for all size banks, the implication being that increased competition forced banks to economize on low-yielding assets, and/or that innovation in payments clearing or increasingly liquid markets for bank-owned securities reduced the size of precautionary balances. By-and-large, the data indicate a lengthening of loan maturities, as long-term loans increased as a percent of bank assets while short-term loans tended to decline. These shifts reflect multiple changes in the banking environment between 1990 and 2005, two of the more important being the decline in (mostly short-term) business lending as business borrowers increasingly accessed funding directly in capital markets, and the increased importance of (mostly long-term) home mortgage lending in the intermediation activities of commercial banks, either by originating and holding mortgage loans or by purchasing mortgage-backed securities. Historically, holding longer maturity mortgage loans (or securities backed by these mortgages) would have necessarily exposed banks to increased interest rate risk; however, this remains true only to the extent that these loans carry fixed interest rates, which today need not be the case due to the growth in adjustable rate mortgages.

Trends on the right-hand side of the balance sheet illustrate ways in which small banks and large banks have grown less alike over time. At the three smallest quartiles of banks, core deposits declined while demand deposits (predominantly non-interest bearing commercial accounts) increased, emphasizing the continuing importance of small business customers at small banks, and perhaps indicating that small banks are having increased difficulty competing for core (mostly consumer) deposits against the large banks expanding into their local markets. These trends differ among the largest banks, however, with demand deposits falling but core deposits increasing or holding steady, patterns that are consistent with large banks' increasing(decreasing) emphasis on consumer(business) banking during our sample period. Hence, the effective maturity of deposit funding has lengthened on average for the largest banks, but has gotten shorter on average for the smaller banks. Purchased funds financing increased for banks of all sizes, but especially for the smaller banks, additional evidence that small banks are losing core deposit funding to large banks and non-bank financial institutions. Finally, banks of all sizes increased their equity holdings as strong industry profits were retained and stricter government supervision (i.e., FDICIA in 1991) required them to hold higher levels of capital.

Table 2 displays simple correlations between individual asset and liability accounts (i.e., a special case of canonical correlation), by asset size group in each of the four main years of our analysis. The table displays only "strong" asset-liability correlations, which we define in ad hoc fashion as correlations greater than 0.30 in absolute value. One pattern in these data is immediately apparent: strong asset-liability correlations happen more often for large banks than at small banks. This implies that large banks are better able and/or more likely to practice on-balance sheet asset-liability management than are small banks. However, this result could also be caused by within-group heterogeneity among small banks that introduces noise into the correlation measures, or may indicate that the asset and liability categories that we impose on the data reflect large bank business models better than small bank business models.

Looking more closely at Table 2 reveals economically sensible patterns in the pair-wise correlations. Excluding for the moment the "extra" data in the bottom panel of the table, we find that 11 of the 32 strong correlations show a positive relationships between cash and demand deposits (i.e., banks with large amounts of transactions accounts need to hold higher balances of cash as a precaution against a large volume of payments presentments on any given day) while an additional 3 of the 32 show a negative correlation between cash and core deposits (banks with stable deposits face lower liquidity risk and hence can hold lower cash balances). Long-term loans are positively associated with core deposits in 7 of the 32 strong correlations (banks match long-term credits with long-term deposits) and long-term securities are positively related to equity capital balances in 5 of the 32 (banks with large retained earnings "park" the funding in liquid but relatively high-yielding securities until profitable lending opportunities arise;

alternatively, especially risk-averse banks *both* hold higher capital cushions *and* hold assets in safer investments).

We now move from simple pair-wise correlation analysis, which completely ignores the movements and co-movements of other asset and liability accounts, to canonical correlation analysis, which considers simultaneously the economic complexities both within and across the two sides of the balance sheet.

5. Main Results

Table 3 displays the canonical correlations (3), arrayed in twenty cells according to the five bank sizes and four main years in our data. We calculate five canonical correlations for each of the cells, the maximum allowable given the manner in which we group the asset and liability accounts.[11] The asset and liability variables exhibit a relatively high degree of collective dependence. For example, the first canonical correlation in the table (for the smallest asset quartile group in 1990) is 0.42, which indicates that the first pair of canonical variables (A_1 and L_1) share 17.6% of their variance with each other; stated differently, the first factor extracted from the asset accounts data and the first factor extracted from the liability accounts data have a linear correlation of 0.42. The second canonical correlation is 0.19, indicating a common factor that accounts for 3.65% of the shared variance between the second pair of canonical variables (A_2 and L_2). Moving down each column, the canonical correlations tend to decline in explanatory power, as well as in statistical significance. In the first column, the first approximate F-value of 16.74 allows us to reject the null hypothesis that all five canonical correlations are zero; similarly, the second F-value of 5.75 rejects the null hypothesis that second, third, fourth, and fifth canonical correlations are zero. The third F-value is also statistically significant, but the fourth F-value is not, and as such we conclude that three or fewer canonical pairs are necessary to represent the asset-liability relationship. The asset and liability canonical variables are more strongly correlated—that is, the

[11] That is, p = 6 liability accounts, with one variable deleted to avoid perfect collinearity.

numerical magnitudes tend to be bigger—for the larger banks, a result similar to the simple pair-wise correlations displayed above in Table 2.

The statistics displayed in Table 3 represent relationships between linear combinations of asset variables and linear combinations of liability variables, and these canonical correlations may or may not indicate systematic relationships between or among the underlying asset and liability variables. To get at this question, we report information for the proportion of variance coefficients (5) and the redundancy coefficients (6) in Table 4. To reduce the amount of space necessary to display these diagnostics, each cell in the table displays a straight-line average based on the values of (5) or (6) from each of the four bank asset quartiles and four main years of our data. These averages are calculated separately for each of the five canonical loadings; the sixth column is the sum of the first five entries, and represents the total proportion of asset or liability variance explained by the canonical variables.

By construction, the proportion of variance statistics (5) in the top half of the table must sum to 100% across the five loadings. About 90 percent of the variation in the actual liabilities data is explained by the liability canonical variables in the first three loadings—in contrast, the variation in the actual assets data is explained by the asset canonical variables in a more uniform fashion in all five loadings. All else equal, this suggests that the relationships among the various asset accounts are more complex than the relationships among the various liability accounts.

The redundancy coefficients (6) in the bottom half of the table sum to well less than 100% across the five loadings. The liability canonical variables explain only about 7% of the variation in the asset variables, while the asset canonical variables explain about 12% of the variation in the liability variables. Moreover, in both cases over 80 percent of the redundancy is accounted for in the first two loadings. We draw two informal inferences from these results: First, the calculations suggest that causation runs more strongly from assets to liabilities (i.e., banks seek funding and/or determine funding mix only after finding investment opportunities) than from liabilities to assets (i.e., banks are pools of deposits looking for lending opportunities). Second, the relatively small size of the redundancy coefficients, as well as the importance of the first two loadings in the calculation of these coefficients, suggests that the strong canonical correlations in Table 3 are driven by a relatively small number of relationships among individual asset and liability accounts.

We look more closely at links between the individual asset and liability accounts in Table 5, which focuses on the individual asset-liability relationships in the canonical loadings (4). Given our results in Table 4, we limit our analysis here to the linkages suggested by the first loading (Table 5, panel A) and the second loading (Table 5, panel B). Correlations between individual actual asset accounts and their asset canonical variables appear on the left-hand side of the cells, while correlations between individual actual liability accounts and their liability canonical variables appear on the right-hand side of the cells. By the logic of Figure 1, finding simultaneous strong canonical loadings for asset and liability accounts implies a strong relationship between the underlying asset and liability variables, because the canonical correlations in both the first and second loadings are empirically large and statistically strong (see Table 3). As above, we use a 0.30 threshold to determine a "strong" relationship between the original variables and the canonical variables (Fornell and Larcker 1980).

We find a limited number of strong and economically sensible relationships among the variables in Table 5. In panel A, the dominant relationship is between long-term loans and core deposits, which have strong canonical loadings with the same sign in all 20 of the cells, strong evidence that these two balance sheet accounts move up and down together. This is a plausible relationship: Banks with large amounts of core deposits are better able to hold large portions of their portfolios in long-term loans without incurring large amounts of interest rate risk. Panel A also contains similar evidence of a positive link between short-term loans and purchased funds: the canonical loadings for these two variables exceed 0.30 and have the same signs in 19 of the 20 cells. This is also an economically sensible result: Because purchased funds can expose banks to severe interest rate risk, the most logical use for these funds is to finance short-run investments with relatively high yields (i.e., loans rather than cash or short-term securities). Importantly, we note that this relationship was not revealed by the simple pair-wise correlations in Table 2. Finally, the canonical loadings for core deposits and purchased funds exceed 0.30 and have opposite signs in all 20 cells, consistent with (albeit merely suggestive evidence of) the conventional wisdom that banks turn to purchased funds financing in the absence of cheaper and more stable core deposit funding. All three of these results provided evidence consistent with the predictions of Song and Thakor (2007).

We find a different set of strong and systematic linkages in Panel B—not surprising, because by definition the linear combinations (1) and (2) are orthogonal across loadings. The dominant relationship here is a positive association between long-term securities and equity capital, which appears in 10 of the 20 cells, consistent with the findings pair-wise correlations in Table 2 as well as our suppositions about retained earnings and/or risk-averse bank management. The only other systematic finding is the positive association between cash holdings and demand deposits in 4 of the 20 cells, consistent with but less prevalent than the results of the simple correlation analysis in Table 2.

Importantly, we have not found any evidence so far that the linkages between assets and liabilities have declined over time: such declines are necessary to support our conjectures about the increasing independence of bank assets and liabilities due to improvements in risk mitigation, more complete financial markets, etc. As explained above, however, the indirect logic displayed in Figure 1 (quantified by the results in Tables 3 and 5) can overstate the degree of correlation between the two vectors of variables under consideration. The redundancy coefficients (6) provide a more direct summary measure of asset-liability linkage that does not suffer from the same potential for overstatement. Figures 2 and 3 plot the annual redundancy coefficients from 1990 through 2005 both for asset size quartiles (Panel A) and asset size deciles (Panel B).[12]

Figure 2 displays the degree to which the liability canonical correlations explain the variation of the actual asset account data. There is little evidence in either panel of any systematic inter-temporal trends. Moreover, in Panel A the lines cross each other repeatedly and do not reflect the systematic size-based patterns displayed in the data in Tables 2 and 3. The size-based ordering does appear in Panel B

[12] As is common practice, the redundancy measures plotted in Figures 2 and 3 are based on the summations over <u>only</u> the statistically significant *j* terms.

(where we have averaged together for deciles 1 through 5, and also for deciles 5 through 9), but still there is little evidence of inter-temporal patterns in the data.

The data provide a more systematic story in Figure 3, where the asset canonical correlations explain the variation of the actual liability account data (i.e., the converse of Figure 2). This is not surprising, given that the evidence in Table 4 that the liability data are more fully explained by asset canonical correlations than vice versa. First, the magnitudes of the redundancy coefficients are larger than in the previous figure, finishing in the 10% to 15% range as opposed to the 6% to 8% range shown in Figure 2. Second, both Panel A and B display a clear rank ordering by asset size, with asset-liability linkages stronger on average for larger banks and weaker on average for smaller banks. Third, consistent with our conjectures about the influence of new financial technologies on asset-liability linkages, there is a systematic decline in the redundancy coefficients across time for the larger banks. For example, the asset canonical variable explained a little over 20% of the variance in the liability accounts of the largest quartile of banks during the early 1990s, but no more than 15% by the early 2000s. In contrast, the data show a systematic increase in the redundancy coefficients across time for banks in the two smaller asset size quartiles. For example, this version of the redundancy coefficient increased from about 5% to 10% between 1990 and 2005 for banks in the smallest asset size quartile. Both Panels A and B show a clear and consistent convergence across time in the level of asset-liability linkage for banks of all sizes. By this measure, large and small commercial banks have become more alike over time.

It is perhaps surprising that our measures of asset-liability linkage are systematically stronger at the larger banks than for the smaller banks, both in the early and later years of our sample period. *A priori*, one might have expected to find the strongest asset-liability relationships at the smallest banks—that is, with less access to interest rate risk mitigation tools (e.g., derivatives hedges), small banks must manage interest rate risk on their balance sheets, which implies stronger rather than weaker correlations between the maturities and compositions of asset and liability accounts. One possible explanation for this unintuitive result is observable in the Table 1 summary statistics: Smaller banks have traditionally held more equity capital than larger banks (for example, in 1990 the equity-to-assets ratio for the small Group

1 banks averaged about 9%, compared to just 6% to 8% for banks in the larger groups), suggesting that small banks practiced a strategy of absorbing rather than hedging interest rate risk. This extra equity cushion may have allowed them to operate with a greater than average amount of maturity mismatches on their balance sheets. This explanation is also consistent with the convergence of the redundancy coefficients over time: By the end of our sample, the smallest banks no longer held larger equity ratios than the larger banks, with equity/assets averaging about 11% in 2005 for the banks in Group 1, compared to between 10% and 12% on average for banks in the larger groups.

Differences in operating scale and business environment provide another likely explanation for the relatively low redundancy coefficients for small banks. If profitable lending opportunities present themselves to at banks with some randomness, then small banks—which do a small number of deals in any given time period—will naturally have more difficulty managing the composition of their assets. Combine this with the fact that small banks have historically been substantially more dependent on core deposit funding than their large bank counterparts (e.g., as shown in Table 1, in 1990 core deposits provided nearly 70 percent of total financing for small banks). If loan balances change frequently and with some randomness, but deposit balances are stable and change slowly (a characteristic of core deposits), then measures of asset-liability relationships will necessarily be weak.

The convergence of strength of asset-liability linkages for banks of all sizes is illuminating. The obvious inference to be drawn from the downward drift in the redundancy coefficients for the larger banks is that the compositions of assets and liabilities at these banks have grown more independent over time. This could indicate that larger banks have been more active in adopting interest rate risk mitigation tools such as derivative hedges, adjustable rate consumer loans, and asset securitization. Also, large banks have accounted for the bulk of the geographic expansion as the banking industry has consolidated, and have also expanded more aggressively than small banks into non-interest-based (off-balance sheet) financial services—both of which may have resulted in greater diversification for larger banks and may have allowed them to accept more risk from mismatched assets and liabilities.

The upward drift in the redundancy coefficients for the smaller banks indicates that the compositions of assets and liabilities at these banks have grown less independent over time. Small banks are not intensive users of interest rate derivatives, but like their larger peers they did increase their use of adjustable rate loans over the sample period. This should weaken (rather than strengthen) the measured linkages between our long-run and short-run asset and liability categories. The quality of management (and hence better ALM) at small banks likely increased during our sample period—but this is unlikely to be driving our results, because our survivor-only sampling method should substantially control for the exit of poorly managed banks between 1990 and 2005. The more likely explanation is the tripling in the real size of small banks over time (see Table 3), a byproduct of the industry consolidation among banks of all sizes during our sample period. As these small banks got larger, constraints on ALM due to idiosyncratic loans, granularity in asset growth, and dependence on core deposit funding to which we alluded above would have naturally lessened, resulting in the stronger asset-liability linkages we observe for these banks in Figure 2.

Rapid growth—especially growth by acquisition, which combines two different balance sheets—should make ALM more difficult in the short-run, just as rapid growth hampers most operational tasks in the short-run. Since our sample includes only those banks that survived the entire sample period (i.e., banks that were acquirers during the sample period rather than targets), the data in displayed in Tables 3 and 4 and in Figures 2 and 3 are likely to understate the degree to which bank assets and liabilities are related to each other in equilibrium. Apart from these transitory effects, our results suggest that asset growth is related to higher canonical correlations in equilibrium, because the banks that have grown the most are disproportionately represented in the higher asset-size quartiles. Finally, the inter-termporal convergence of the results for these asset-size quartiles suggests that the influence of growth on our results has diminished over time.

6. Sub-sample analysis

Our analysis above indicates that the strength of asset-liability relationships, while converging over time, still varied substantially across different size banks at the end of our sample period. In this section we explore some of the possible reasons for this. For example, can derivatives securities (a predominantly large bank activity) mitigate interest rate risk enough to materially weaken asset-liability correlations? Similarly, are differences in product mix or financial condition across banks associated with stronger or weaker asset-liability relationships? We perform these analyses using data from 2005, when our measured asset-liability correlations were much more similar across banks of different sizes.

In Table 6 we test whether actively hedging against interest rate risk allowed banks to operate with greater asset-liability freedom. Panel A displays redundancy coefficients for the group of 91 banks from our sample that reported positive amounts of "total gross notional amount of interest rate swaps held for purposes other than trading where the bank has agreed to pay fixed rate" in 2005; we calculated the redundancy coefficients separately for banks above and below the median. Panel B displays redundancy coefficients for the entire sample of banks for "total loans with remaining maturity or next repricing frequency of 1 year or less" as a percentage of total bank assets, again calculated separately for banks above and below the median. In both panels, the asset canonical variables have greater explanatory power than the liabilities canonical variables, and hence we will refer to these data in our discussion here. We find suggestive evidence in both Panel A and Panel B that interest rate derivatives and adjustable rate loans allow banks to relax their on-balance sheet asset-liability management. For example, the redundancy coefficient (variance of liabilities variables explained by assets canonical variable) for more intensive users of interest rate swaps to hedge against exposure to fixed interest rate loans is just 49.60, compared to 56.70 for less intensive user of interest rate swaps. Similarly, redundancy coefficients are lower for intensive users of adjustable rate loans (9.05) than for largely fixed-rate lenders (13.76).[13]

Banks recognized by regulators as being well-managed—and especially banks recognized as being well-positioned against market risk—should feel less regulatory pressure to operate with tight asset-liability linkages. In Table 6, panels C and D display redundancy coefficients separately calculated for

[13] To control for the effects of asset size on the full-sample results in Panels B, C, and D, we first divided each of the four asset size groups into top and bottom halves in terms of adjustable rate lending, then aggregated the top and bottom halves across bank size groups, and finally calculated the redundancy coefficients separately for these two resulting asset-stratified sub-samples.

sub-samples of banks with strong, satisfactory, and weak regulatory safety and soundness ratings in 2005. The overall safety and soundness rating—known as a "CAMELS" rating for Capital Adequacy, Asset Quality, Management Quality, Earnings Quality, Liquidity, and Sensitivity to Market Risk—bear this out. The redundancy coefficients in Panel C are lowest (11.36) for banks judged to be the very safest (1-rated), and highest (12.63) for the banks judged to have substantial risk (3-rated or worse). Not surprisingly, this discrepancy is larger in Panel D where the Sensitivity to Market Risk component of the CAMELS ratings was used to construct the sub-samples; ranging from 12.21 for the 1-rated banks to 19.22 for the 3-, 4-, and 5-rated banks.[14]

We performed additional tests (not shown) similar to those shown in Table 6 in which the sub-samples were defined by non-interest income levels, reasoning that asset-liability management may be less important for banks that earn large portions of their incomes from non-interest sources. However, we found virtually no difference in redundancy coefficients between the high non-interest and low non-interest sub-samples.[15] We can think of two mutually exclusive explanations for this non-result. On-the-one-hand, much non-interest income derives from activities related to balance sheet accounts (e.g., fees charged to depositors, fees from contingent lines of credit, fees associated with loan origination and securitization), and as such the generation of this non-interest income need not affect existing asset-liability linkages. Similarly, some non-interest income, while wholly unrelated to balance sheet activities, can still be quite sensitive to changes in interest rates (e.g., brokerage services, asset management services), so that an increase in these activities will not weaken, and may actually re-enforce, existing asset-liability linkages (DeYoung and Roland 2001). On-the-other-hand, non-interest income may generate a set of risks that are orthogonal to interest rate risk and ALM, in which case we would indeed expect them to have no impact on our measures of asset-liability linkages. Although additional tests on

[14] This result is consistent with DeYoung, Hughes, and Moon (2001), who found that the national bank regulator (the Office of the Comptroller of the Currency) gave worse CAMEL ratings to risky banks in general, but did not give worse CAMEL ratings to risky banks that were efficiently run.

[15] The redundancy coefficients for banks with above median non-interest income were 6.12 (variance of asset variables explained by liabilities canonical variable) and 13.41 (variance of liabilities variables explained by assets canonical variable), compared to 6.04 and 10.66 for banks with below median amounts of non-interest income.

individual fee-based product lines may yield less ambiguous results, the availability of such data is sparse in commercial bank financial reports.

7. Conclusions

Unlike most commercial firms, banking companies have typically profited by managing their investment decisions together with their financing decisions, trading off expected profits from mismatches in the maturity of assets and liabilities (e.g., lending long and borrowing short) against increased interest rate risk. During the late 1980s, this formula resulted in mass insolvencies of U.S. thrift institutions, due to the inability of these lenders to effectively mitigate the interest rate risk. Since that time, however, deregulation has allowed banks to diversify risk by expanding into new products and new geographic markets, innovations in risk management have allowed banks to better mitigate interest rate risk, and more highly developed financial markets have allowed shareholders to better diversify their personal portfolios. In this paper, we find broad evidence that these developments have permitted banks to operate with fewer balance sheet constraints.

We use canonical correlation analysis to measure the relationships among and between asset and liability accounts at U.S. commercial banks in 1990, 1995, 2000, and 2005. We find strong and substantial evidence that bank assets and bank liabilities have indeed become more independent over time for large banks (but not for small banks). While there are many reasons that this may have happened, we show that at least some portion of this increased independence is driven by intensive use of risk-mitigation tools such as interest rate swaps and adjustable rate loans. We also find that banks with strong regulatory safety and soundness ratings have *weaker* asset-liability linkages, consistent with the idea that bank supervisors give well-run banks more risk-taking leeway (DeYoung, Hughes, and Moon 2001). Perhaps surprisingly, we find that bank size is positively related to asset-liability dependence in every year of our analysis. This may reflect the existence of scale economies in traditional asset-liability management—in particular, duration matching could be more difficult at small banks, where just a few new loan accounts could upset the duration match, and a reliance on stable core deposit funding could make fast adjustments difficult. This interpretation is consistent with the large equity cushions historically held by small banks, perhaps as an offset to their inability to effectively practice ALM. Regardless, we find that asset-liability linkages have tended to converge over time for banks of all sizes, growing weaker for larger banks, and growing stronger for smaller banks. We hypothesize that the increased size of small banks over time, and thus increased diversity of their loan portfolios, may simply make ALM more efficient.

One inference from these results is that large banks have moved closer to an abstract Modigliani and Miller (1958) world in which investment and financing decisions are more independent and thus more efficient, and that there is less need for banks to accept interest rate risk to earn profits. In other words, deregulation and financial innovation have made banking markets, and the markets to which banks have access, more complete. (See Appendix B for a brief discussion.)

Our results also suggest that banks have become better able to accept and manage interest rate risk without constraining the composition of their balance sheets; stated differently, our results suggest that banks do not need to accept as much interest rate risk as in the past in order to earn profits. However, this does not mean that banks are taking less risk. A number of previous studies of bank risk-taking indicate that banks tend to "spend" risk reductions in one area on increased risk-taking in other areas (Demsetz and Strahan 1997, Hughes, Lang, Mester, and Moon 1999, Schrand and Unal, 1998), and the reduction in asset-liability linkages that we find here may be further evidence of such behavior.

In addition, our findings highlight the challenges facing researchers estimating cost, profit, and production functions for commercial banks. Such studies typically assume that banks of all sizes use the same production technology, and rely on flexible functional forms to fit this technology to the data. Our results suggest that the relationships between liabilities (the primary inputs in such models) and assets (the primary outputs in such models) have historically been quite different across different sized banks, perhaps too different to be captured by a single, albeit flexible, parametric form. This could help explain why scale economies and scope economies at banking companies have been so difficult to measure, and why the resulting point estimates are often statistically weak or economically nonsensical. On the bright side, we find that these relationships have been converging over time for different sized banks, so perhaps future estimates of bank cost and profit functions using such techniques will deliver more accurate results.

We stress that our findings are generated using a statistical approach, canonical correlation analysis, that has been used only occasionally in financial institution research. While we argue above that this technique is completely appropriate for a first examination of these phenomena, we also stress that this technique—at least as it is employed here—can generate only broad suggestive evidence at the industry or industry subsample levels. As such, our findings here should be interpreted with some degree of caution. Further investigation into asset-liability linkages needs to generate bank-level evidence. One potential approach would be to apply canonical correlation analysis to time-series data at the bank level; such an approach would generate bank-specific estimates of canonical correlations, redundancy coefficients, etc. which could then be regressed on bank-specific arguments to test a variety of hypotheses.

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Appendix A: Details of Canonical Correlation Analysis

The reader may be interested in a more explicit presentation of the maximization process in canonical correlation analysis. Given observations of the data X and Y, we solve for the vectors of canonical coefficients B′ and C′ as follows. In equation (3), we make the substitutions $\Sigma al = B'S_{xy}C$, $\Sigma a^2 = B'S_{xx}B$, and $\Sigma l^2 = C'S_{yy}C$, resulting in:

$$r_{AL} = \frac{B'S_{xy}C}{\sqrt{(B'S_{xx}B)(C'S_{yy}C)}} \tag{A1}$$

where S_{xx} and S_{yy} are the within-set variance-covariance matrices for assets and liabilities, respectively, and S_{xy} is the between-sets covariance matrix for assets and liabilities. Since r_{AL} is invariant to the scaling of B and C, we constrain the linear combinations A and L to have zero means, E(A)=E(L)=0, and unit variances, $B'S_{xx}B = C'S_{yy}C = 1$. These constraints normalize the denominator in (3′) to 1.0, while retaining in the numerator the information in which we are most interested, the asset-liability variance-covariance matrix S_{xy}. Maximizing (3′) subject to these constraints is equivalent to solving the Lagrangian:

$$L = B'S_{xy}C - \frac{\lambda}{2}(B'S_{xx}B - 1) - \frac{\mu}{2}(C'S_{yy}C - 1) \tag{A2}$$

Setting equal the expressions for λ and μ derived from the first order conditions of (4) and rearranging terms gives us the following matrix equations:

$$(S_{xx}^{-1}S_{xy}S_{yy}^{-1}S_{yx} - \mu^2 I)B = 0 \tag{A3}$$

$$(S_{yy}^{-1}S_{yx}S_{xx}^{-1}S_{xy} - \mu^2 I)C = 0 \tag{A4}$$

where I is the identity matrix. The matrix equations (5) and (6) can be rewritten as systems of p linear equations in p vectors of unknown coefficients B_i and C_i ($i = 1,2,\ldots,p$). For instance, the matrix equation (5) can be written as:

$$\begin{bmatrix} (1-\mu_i^2) & r_{12} & r_{13} & \cdots & r_{1p} \\ r_{21} & (1-\mu_i^2) & r_{23} & \cdots & r_{2p} \\ . & & & & \\ . & & & & \\ . & & & & \\ r_{p1} & r_{p2} & r_{p3} & \cdots & (1-\mu_i^2) \end{bmatrix} \cdot \begin{bmatrix} \beta_{1i} \\ \beta_{2i} \\ . \\ . \\ . \\ \beta_{pi} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ . \\ 0 \end{bmatrix}.$$

We then solve for the systems (5) and (6) for the p sets of canonical coefficients $B' = [\beta_1,\beta_2,\ldots,\beta_p]$ and $C' = [\gamma_1,\gamma_2,\ldots,\gamma_q]$. These systems of linear equations will have non-trivial solutions only if their determinants are zero:

$$\left|S_{xx}^{-1}S_{xy}S_{yy}^{-1}S_{yx} - \mu^2 I\right| = 0 \tag{A5}$$

$$\left|S_{yy}^{-1}S_{yx}S_{xx}^{-1}S_{xy} - \mu^2 I\right| = 0 \tag{A6}$$

Equations (7) and (8) are called characteristic equations (every square matrix has associated with it a characteristic equation). The characteristic equation is formed by subtracting some value μ^2 from each of the diagonal elements of the matrix. The values of μ^2, which are the roots of the characteristic equations, are chosen so that the determinant of the resulting matrix is equal to zero (i.e., the matrix is singular). Normally, for a matrix of order p, there are up to p different values for μ^2 that will satisfy the characteristic equation. In our case, there are p-1 (or q-1) different values for μ^2. This is because the asset and liability variables sum to one, and S_{xx} and S_{yy} are singular. To avoid the singularity, one variable from each set is eliminated. The largest root of the characteristic equation, μ_1^2, is also the first eigenvalue, and B_1 and C_1 are its corresponding eigenvectors. More generally, for each μ_i^2, there is corresponding vector of solutions B_i and C_i, which constitute the weights for the linear combinations:

$$A_i = B_i^{'} X \tag{A7}$$

$$L_i = C_i^{'} Y \tag{A8}$$

where both B_i and X are px1 vectors and both C_i and Y are qx1 vectors. There are p canonical variable pairs, and the corresponding p correlations $Corr(A_p,L_p)$ are all maxima, subject to the conditions that the A_p are uncorrelated with $A_1,A_2,\ldots,A_{p-1}$ and the L_p are uncorrelated with $L_1,L_2,\ldots,L_{p-1}$ (that is, the p canonical variable pairs are linear functions selected subject to the restrictions of orthogonality). Finally, the correlations of the canonical variable pairs are such that $Corr(A_1,L_1) > Corr(A_2,L_2) > \ldots > Corr(A_p,L_p)$.

Canonical correlation analysis is directionless and symmetric. The analysis is invariant to whether causation runs from assets-to-liabilities (i.e., banks with pre-existing investment opportunities looking for financing) or from liabilities-to-assets (i.e., banks with core deposit customers looking for investment opportunities). The analysis presumes that banks determine the optimal balances of asset (liability) accounts jointly with the balances of other asset (liability) accounts as well as with liability (asset) accounts, and it measures the resulting co-variations among these accounts. This approach contrasts with multiple-output production (or cost or profit) function analysis of banks, which assigns certain balance sheet accounts to be inputs and other balance sheet accounts to be outputs.[16]

[16] The typical bank production/cost/profit function approach assumes an intermediation framework that constrains all deposit accounts to be inputs and all asset accounts to be outputs.

Appendix B: Modigliani and Miller and Banks

Under strong assumptions about transactions costs, information symmetry, bankruptcy costs, and the tax code, modern finance theory postulates that a firm's financial structure does not influence the value of its assets (Modigliani and Miller, 1958). However, because these assumptions hold imperfectly in real markets, a firm's value can indeed be a function of its balance sheet structure. The most familiar theoretical treatment of "real world" considerations posits an optimal financial structure that balances the tax advantages of debt against the probability of costly bankruptcy, but additional temporal considerations such as personal income taxes and managerial agency costs have also been used to motivate theoretical value-maximizing tradeoffs between debt and equity financing (Miller 1977, Jensen and Meckling 1976). There is no unifying theory of corporate financial structure, and much of the recent empirical research attributes differences in debt-equity mix to industry-specific factors such as competitive rivalries and production technologies.[17]

The debt-equity choices of commercial banking companies are influenced by two industry-specific factors: Under-priced deposit insurance creates strong financial incentives for banks to use debt (deposit) financing, and in response to these incentives government regulators impose explicit limits on debt financing in the form of minimum capital ratios. In recent years, most commercial banking companies have used less than the maximum amount of financial leverage permitted by regulators, which suggests that banks target an optimal debt-equity mix that balances the benefits (e.g., interest deductibility, subsidized interest rates, agency considerations) and the costs (e.g., costs of insolvency, regulatory pressures) of debt finance.[18] Moreover, the value of banking companies depends not only on their debt-equity financing choices, but also on their choices of debt maturity structure. For financial intermediaries, an important profit driver is the maturity mismatches between assets and liabilities—for

[17] Other important theoretical explanations of firms' financial structure decisions include the "pecking order" and "signaling" hypotheses (Donaldson 1961, Myers 1984). A full review of the theoretical and empirical literature on optimal financial structure is beyond the scope of this paper. Some recent empirical investigations include Frank and Goyal (2001), Fama and French (2002), and MacKay and Phillips (2002).

[18] Berger, DeYoung, Flannery, Lee, and Oztekin (2008) show that the vast majority of publicly traded U.S. bank holding companies hold equity capital ratios that are hundreds of basis points in excess of levels required to be "adequately capitalized" or "well-capitalized" by regulatory standards.

example, borrowing short for which interest rates paid are typically low, and lending long for which interest rates received are typically high. Thus, when choosing the optimal amount of maturity mismatch in its debt structure, banks must perform a second balancing act, weighing the benefits of wider profit margins against the interest rate risk generated as these mismatches increase (e.g., increased probability of insolvency and the attendant costs of regulatory intervention).

In a strict Modigliani-Miller (MM) world, a bank's value would be invariant to its debt maturity structure: Investors in a bank that uses a high proportion of short-maturity debt (e.g., borrowing short and lending long) would be able to undo the interest rate risk associated with this debt structure by borrowing long-term and using the proceeds to lend short. However, this is an unprofitable maneuver outside the strict assumptions of MM, because investors do not have access to the same interest rates as banks, and under normal market conditions would be borrowing at long rates (say, mortgaging their homes) that exceed their lending rates (say, making bank deposits) after taxes.

Table 1

This table displays the mean values for asset and liability/equity account items. All variables are expressed as a percentage of total assets. Asset size groups are in 2005 dollars. *Cash balances* include cash at the bank, deposits at other banks, and reserves at the Federal Reserve. *Short-term securities* include all investment securities with maturities of less than one year. *Long-term securities* include all investment securities with maturities of more than one year. *Short-term loans* include all loans with maturities of less than one year and federal funds sold and securities purchased under agreements to resell. *Long-term loans* are obtained by subtracting short-term loans from the sum of total loans and leases and federal funds sold and securities purchased under agreements to resell. *Other assets* include all other assets not described. *Equity* includes all common stock, perpetual preferred stock, surplus, retained earnings, other equity capital, and subordinated notes and debentures. *Demand deposits* include all demand deposit accounts. *Core deposits* include NOW accounts, money market deposit accounts, savings deposits, time certificates of deposits in amounts less than $100,000, fixed rate time certificates of deposits in amounts of $100,000 or more with a remaining maturity of over 1 year, time deposit open accounts in amounts greater than $100,000 with a remaining maturity of over 1 year, demand notes issued to the U.S. Treasury, and other borrowed money such as Federal Home Loan Bank advances. *Purchased funds* include fixed rate time certificates of deposits in amounts of $100,000 or more with a remaining maturity of 12 months or less, floating rate time certificates of deposits in amounts of $100,000 or more with a repricing frequency of 12 months or less, and federal funds purchased. *Other liabilities* include all other liabilities not described. All variables are based on year-end data from the Reports of Income and Condition (call reports).

	1990	1995	2000	2005
Group 1 – Bottom Quartile (N = 1315)				
Assets (in $1000s)	11,729	15,546	22,654	33,569
Asset accounts				
Cash balances	8.24	6.11	5.67	6.23
Short term securities	12.16	9.32	5.43	5.02
Long term securities	24.53	25.05	23.50	20.90
Short term loans	35.14	35.64	33.34	33.73
Long term loans	17.19	21.45	29.23	30.77
Other assets	2.74	2.43	2.82	3.35
Liability/Equity accounts				
Equity	10.15	11.39	11.53	11.56
Demand deposits	12.17	12.89	13.33	15.22
Core deposits	69.05	67.45	64.16	62.52
Purchased funds	6.74	6.71	9.82	10.10
Other liabilities	1.89	1.55	1.16	0.59
Group 2 – Second Quartile (N = 1316)				
Assets (in $1000s)	23,472	33,102	50,858	78,544
Asset accounts				
Cash balances	7.13	5.14	4.71	4.87
Short term securities	10.99	7.66	4.24	4.22
Long term securities	24.48	26.43	24.29	21.94
Short term loans	35.37	35.01	31.47	32.51
Long term loans	19.08	23.08	32.06	32.52
Other assets	2.95	2.67	3.23	3.93
Liability/Equity accounts				
Equity	9.45	10.74	10.75	10.77
Demand deposits	11.20	12.22	12.45	14.44
Core deposits	69.63	68.05	65.02	63.56
Purchased funds	7.90	7.44	10.62	10.57
Other liabilities	1.82	1.56	1.16	0.65

Table 1 (continued)

	1990	1995	2000	2005
Group 3 – Third Quartile (N = 1316)				
Asset (in $1000s)	41,617	62,205	101,145	163,801
Asset accounts				
Cash balances	6.08	4.68	4.21	4.19
Short term securities	10.34	6.98	3.66	3.72
Long term securities	24.19	26.48	23.42	21.18
Short term loans	36.79	35.82	31.81	33.58
Long term loans	19.56	23.32	33.57	33.14
Other assets	3.04	2.72	3.33	4.18
Liability/Equity accounts				
Equity	9.24	10.52	10.38	10.44
Demand deposits	11.43	12.48	12.60	14.12
Core deposits	68.49	67.40	64.37	63.47
Purchased funds	9.09	8.10	11.59	11.31
Other liabilities	1.75	1.50	1.07	0.65
Group 4 – Top Quartile (N = 1316)				
Asset (in $1000s)	241,569	431,672	1,013,934	1,956,61 3
Asset accounts				
Cash balances	6.39	5.04	4.36	3.93
Short term securities	8.44	6.12	3.21	3.10
Long term securities	20.44	23.76	21.69	20.26
Short term loans	39.26	36.41	32.33	35.02
Long term loans	22.24	25.76	34.96	32.87
Other assets	3.23	2.90	3.45	4.82
Liability/Equity accounts				
Equity	8.37	9.67	9.52	9.99
Demand deposits	13.00	13.91	11.68	10.04
Core deposits	65.20	65.18	63.92	65.89
Purchased funds	11.36	9.39	13.45	12.93
Other liabilities	2.07	1.85	1.43	1.16
Extra Group – Top Decile (N = 526)				
Asset (in $1000s)	491,476	906,006	2,220,178	4,331,55 5
Asset accounts				
Cash balances	7.31	5.63	4.49	3.68
Short term securities	7.79	5.81	3.19	3.09
Long term securities	18.59	22.98	20.60	19.84
Short term loans	40.95	37.48	33.96	36.20
Long term loans	22.00	25.07	34.14	31.81
Other assets	3.36	3.04	3.62	5.38
Liability/Equity accounts				
Equity	8.02	9.20	9.29	10.11
Demand deposits	13.69	14.55	10.42	8.31
Core deposits	13.08	10.98	15.13	14.08
Purchased funds	62.64	62.80	63.15	65.68

Other liabilities	2.58	2.47	2.01	1.83

Table 2

"Pair-wise" or "simple" correlations between asset accounts and liability accounts that exceed 0.30 in absolute value. Asset size groups are defined in terms of 2005 dollars.

1990			1995			2000			2005		
Group 1 – Bottom Quartile											
						Cash	0.34	DD			
Group 2 – Second Quartile											
Other asset	-0.31	Equity	Cash	0.36	DD	Cash	0.37	DD	Other asset	0.46	Other liab
			LT secs	0.33	Equity	LT secs	0.34	Equity	LT loans	0.39	Core
									Cash	0.32	DD
Group 3 – Third Quartile											
Cash	0.34	DD	Cash	0.46	DD	Cash	0.45	DD	Cash	0.37	DD
LT secs	0.34	Equity	LT secs	0.32	Equity	LT secs	0.34	Equity	LT loans	0.32	Core
			LT loans	0.32	Core	LT loans	0.33	Core			
Group 4 – Top Quartile											
Cash	0.47	Other liab	Cash	-0.45	Core	Cash	0.42	DD	Other asset	0.69	Equity
Cash	-0.42	Core	Cash	0.42	DD	Other asset	0.35	Equity	LT loans	0.32	Core
Cash	0.32	DD	Cash	0.41	Other liab	Cash	-0.30	Core			
			LT loans	0.37	Core	LT loans	0.30	Core			
Extra Group – Top Decile											
Cash	0.58	Other liab	Cash	0.52	Other liab	Cash	0.38	DD	Other asset	0.67	Equity
Cash	-0.49	Core	Cash	-0.50	Core	LT loans	0.36	Core	Cash	0.46	Other liab
LT loans	0.39	Core	Cash	0.45	DD	Cash	-0.34	Core	LT loans	0.38	Core
			LT loans	0.33	Core				Cash	-0.30	Core

Table 3

This table displays the 1st through the 5th canonical correlations for asset size groups of U.S. commercial banks in 1990, 1995, 2000, and 2005. The F-statistics (Rao's F-ratio approximation) tests whether there is any association between the p pairs of canonical variables.

	1990		1995		2000		2005	
Loadings	Canonical Correlation	F-statistic	Canonical Correlation	F-statistic	Canonical Correlation	F-statistic	Canonical Correlation	F-statistic
Group 1 – Bottom Quartile								
1	0.42	16.74***	0.39	20.58***	0.40	24.57***	0.39	17.24***
2	0.19	5.75***	0.32	15.43***	0.36	21.05***	0.27	12.63***
3	0.11	3.09***	0.17	6.95***	0.21	10.30***	0.22	10.96***
4	0.05	1.86	0.04	1.08	0.03	0.52	0.15	7.91***
5	0.00	.	0.00	.	0.00	.	0.05	3.41*
Group 2 – Second Quartile								
1	0.49	23.47***	0.46	29.15***	0.44	28.72***	0.52	33.06***
2	0.22	6.63***	0.37	19.99***	0.39	22.56***	0.40	23.48***
3	0.11	2.67**	0.17	7.17***	0.18	8.24***	0.26	14.28***
4	0.02	0.41	0.07	3.28**	0.07	2.84*	0.15	7.98***
5	0.00	.	0.00	.	0.00	.	0.00	0.01
Group 3 – Third Quartile								
1	0.50	28.02***	0.52	38.60***	0.49	37.40***	0.43	23.38***
2	0.27	12.23***	0.41	26.24***	0.42	29.26***	0.29	18.68***
3	0.18	8.15***	0.20	11.24***	0.22	12.65***	0.28	19.78***
4	0.05	1.80	0.11	7.59***	0.08	4.60**	0.22	17.31***
5	0.00	.	0.00	.	0.00	.	0.03	1.43
Group 4 – Top Quartile								
1	0.61	42.69***	0.64	49.78***	0.49	38.71***	0.72	72.38***
2	0.26	14.01***	0.34	18.86***	0.44	31.73***	0.38	26.78***
3	0.22	12.73***	0.20	10.74***	0.23	12.35***	0.28	18.26***
4	0.08	4.55**	0.09	4.89***	0.06	2.14	0.06	2.04
5	0.00	.	0.00	.	0.00	.	0.00	.
Extra Group – Top Decile								
1	0.69	23.69***	0.69	24.40***	0.52	12.05***	0.72	38.46***
2	0.31	7.45***	0.36	7.71***	0.31	5.66***	0.57	23.62***
3	0.23	5.88***	0.18	3.19***	0.16	2.39**	0.30	9.32***
4	0.10	2.74*	0.07	1.35	0.01	0.04	0.10	2.81*
5	0.00	.	0.00	.	0.00	.	0.00	.

Table 4

This table displays the average proportion of the variance in asset and liability variables explained by the canonical variables, for each of the five canonical loadings. The averages are un-weighted means across 20 separate calculations (5 size groups by 4 time periods).

			1st loading	2nd loading	3rd loading	4th loading	5th loading	total
Proportion of variance (5):								
Asset variables variance	explained by:	Assets canonical variable	17.76	19.48	26.65	20.00	16.12	100.00
Liabilities variables variance		Liabilities canonical variable	30.07	28.27	32.08	8.92	0.66	100.00
Redundancy coefficient (6):								
Assets variables variance	explained by:	Liabilities canonical variable	3.88	2.19	1.23	0.15	0.01	7.46
Liabilities variables variance		Assets canonical variable	7.57	2.96	1.46	0.08	0.00	12.07

Table 5a (Varimax Rotated)

Correlations from the first canonical loadings. The left-hand part of each cell displays correlations between actual asset account data and the assets canonical variable. The right-hand part of each cell displays correlations between actual liabilities account data and the liabilities canonical variable. The correlations are ranked in order of declining absolute value, up to the fourth largest correlation.

1990				1995				2000				2005			
Group 1 – Bottom Quartile															
LT loans	0.95	PF	-0.90	LT loans	0.92	PF	-0.93	LT loans	0.94	PF	-0.84	LT loans	0.93	Core	0.84
LT Secs	-0.45	Core	0.71	ST loans	-0.66	Core	0.70	ST loans	-0.66	Core	0.77	ST loans	-0.55	PF	-0.78
ST loans	-0.27	Equity	-0.27	Cash	0.13	Equity	-0.16	LT Secs	-0.24	Equity	-0.30	LT Secs	-0.40	Equity	-0.41
Other	-0.13	DD	-0.14	LT Secs	-0.11	DD	-0.12	Other	-0.15	Other	0.13	ST Secs	0.14	DD	-0.15
ST Secs	-0.10	Other	-0.03	Other	-0.11	Other	-0.03	Cash	0.03	DD	-0.09	Other	0.04	Other	-0.05
Cash	0.04			ST Secs	-0.06			ST Secs	0.01			Cash	0.00		
Group 2 – Second Quartile															
LT loans	0.96	PF	-0.91	LT loans	0.95	PF	-0.95	ST loans	0.86	PF	0.92	LT loans	0.98	Core	0.95
ST loans	-0.52	Core	0.87	ST loans	-0.59	Core	0.76	LT loans	-0.86	Core	-0.81	ST loans	0.44	Equity	0.57
LT Secs	-0.22	DD	-0.23	LT Secs	-0.24	Other	0.13	ST Secs	-0.09	DD	0.13	LT Secs	0.41	PF	0.56
Other	-0.21	Equity	-0.21	Other	-0.17	DD	-0.12	LT Secs	0.06	Equity	0.03	ST Secs	0.07	DD	0.34
ST Secs	-0.18	Other	-0.06	Cash	0.08	Equity	-0.10	Cash	-0.06	Other	-0.01	Other	0.02	Other	0.11
Cash	0.09			ST Secs	0.02			Other	0.03			Cash	0.01		
Group 3 – Third Quartile															
LT loans	-0.91	PF	0.98	LT loans	0.96	PF	-0.97	LT loans	0.93	PF	-0.91	LT loans	0.96	PF	-0.86
ST loans	0.74	Core	-0.84	ST loans	-0.64	Core	0.78	ST loans	-0.73	Core	0.83	ST loans	-0.63	Core	0.83
Other	0.02	DD	0.21	LT Secs	-0.21	DD	-0.17	LT Secs	-0.24	DD	-0.19	LT Secs	-0.26	Equity	-0.20
LT Secs	0.01	Equity	0.11	ST Secs	0.02	Equity	-0.12	ST Secs	0.08	Equity	-0.10	ST Secs	0.08	DD	-0.18
Cash	0.01	Other	0.05	Other	0.02	Other	-0.01	Other	-0.06	Other	0.07	Other	0.06	Other	-0.03
ST Secs	-0.01			Cash	0.00			Cash	0.01			Cash	0.00		
Group 4 – Top Quartile															

LT loans	-0.90	PF	0.98	LT loans	0.97	PF	-0.98	LT loans	0.97	PF	-0.96	LT loans	0.95	PF	-0.97
ST loans	0.78	Core	-0.79	ST loans	-0.62	Core	0.77	ST loans	-0.58	Core	0.82	ST loans	-0.68	Core	0.79
Cash	0.10	DD	0.18	LT Secs	-0.19	DD	-0.13	LT Secs	-0.34	Other	-0.21	LT Secs	-0.11	Other	-0.23
ST Secs	-0.06	Equity	0.04	ST Secs	-0.09	Other	-0.11	Cash	-0.09	Equity	-0.11	ST Secs	-0.10	Equity	-0.09
LT Secs	-0.04	Other	0.00	Cash	-0.06	Equity	-0.02	ST Secs	-0.06	DD	0.01	Other	0.05	DD	-0.01
Other	-0.01			Other	0.01			Other	0.05			Cash	0.04		

Table 5b (Varimax Rotated)

The Second canonical loadings. The left-hand part of each cell displays correlations between actual asset account data and the assets canonical variable. The right-hand part of each cell displays correlations between actual liabilities account data and the liabilities canonical variable. The correlations are ranked in order of declining absolute value, up to the fourth largest correlation.

1990				1995				2000				2005			
Group 1 – Bottom Quartile															
Cash	0.92	DD	0.93	LT Secs	0.96	Other	0.84	LT Secs	0.93	Other	0.85	Cash	0.99	DD	0.97
LT Secs	-0.54	Core	-0.66	ST loans	-0.64	Equity	0.52	ST loans	-0.71	Equity	0.44	ST loans	-0.17	Core	-0.53
ST loans	0.13	Other	0.30	LT loans	-0.24	Core	-0.30	ST Secs	-0.11	Core	-0.22	LT loans	-0.15	PF	-0.28
LT loans	-0.12	PF	-0.11	ST Secs	-0.10	PF	-0.14	LT loans	-0.11	PF	-0.18	LT Secs	-0.06	Other	-0.08
ST Secs	0.04	Equity	0.10	Cash	-0.08	DD	-0.06	Cash	-0.06	DD	-0.02	ST Secs	-0.03	Equity	-0.06
Other	-0.02			Other	0.06			Other	0.04			Other	0.02		
Group 2 – Second Quartile															
LT Secs	-0.86	Other	0.91	LT Secs	0.95	Equity	0.85	LT Secs	0.98	Equity	0.88	Cash	1.00	DD	0.93
ST loans	0.64	Equity	-0.30	ST loans	-0.75	Other	0.34	ST loans	-0.50	Core	-0.32	LT loans	0.14	Equity	0.41
LT loans	0.17	Core	-0.25	Other	-0.29	Core	-0.29	LT loans	-0.45	PF	-0.06	LT Secs	0.10	Core	0.28
Cash	-0.17	DD	0.25	LT loans	-0.19	PF	-0.12	Other	-0.12	DD	-0.03	ST loans	0.09	PF	0.26
ST Secs	0.13	PF	-0.05	ST Secs	0.12	DD	-0.11	ST Secs	0.07	Other	0.00	ST Secs	0.05	Other	0.04
Other	-0.09			Cash	-0.06			Cash	-0.07			Other	0.03		
Group 3 – Third Quartile															
LT Secs	0.98	Equity	0.94	LT Secs	0.96	Equity	0.82	LT Secs	0.96	Equity	0.83	Cash	1.00	DD	0.95
ST loans	-0.59	Other	0.26	ST loans	-0.75	Other	0.43	ST loans	-0.68	Core	-0.28	ST Secs	0.13	Core	-0.54
LT loans	-0.36	PF	-0.16	Other	-0.20	Core	-0.25	LT loans	-0.23	DD	-0.09	LT loans	-0.13	PF	-0.15
Other	-0.25	DD	-0.11	LT loans	-0.18	DD	-0.15	Other	-0.11	Other	0.07	LT Secs	-0.07	Equity	-0.10
ST Secs	0.18	Core	-0.20	ST Secs	0.13	PF	-0.10	ST Secs	0.09	PF	0.01	ST loans	-0.05	Other	0.05
Cash	-0.04			Cash	-0.08			Cash	-0.04			Other	-0.01		
Group 4 – Top Quartile															
LT Secs	0.99	Equity	0.96	LT Secs	0.94	Equity	0.96	LT Secs	-0.93	Other	0.90	ST	0.96	DD	0.94

												Secs			
ST loans	-0.54	PF	-0.14	ST loans	-0.78	DD	-0.36	ST loans	0.78	Equity	-0.21	Cash	0.27	Core	-0.47
LT loans	-0.34	Core	-0.09	ST Secs	0.22	Other	0.17	Other	0.20	DD	-0.17	Other	-0.18	Other	-0.32
ST Secs	0.19	Other	-0.07	Cash	-0.14	PF	-0.09	Cash	0.14	Core	-0.09	ST loans	-0.13	Equity	0.13
Other	-0.10	DD	-0.04	LT loans	-0.12	Core	-0.05	LT loans	-0.04	PF	-0.03	LT Secs	-0.12	PF	-0.09
Cash	-0.07			Other	0.00			ST Secs	0.00			LT loans	-0.10		

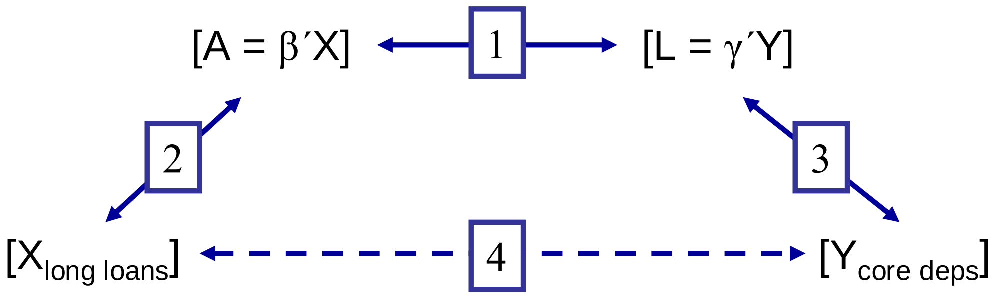
Table 6

Redundancy Coefficients: Interest Rate Hedging and Regulatory Ratings.

Panel A displays separate results for high and low halves of banks that reported non-zero values for "Total gross notional amount of interest rate swaps held for purposes other than trading where the bank has agreed to pay fixed rate" in 2005. Panel B displays results for the aggregated high and low halves of the sample bank in 2005, stratified across the five size groups, for "Total loans with remaining maturity or next repricing frequency of 1 year or less" as a percentage of total bank assets. Panels C and D display separate results for banks with strong (1-rated), good (2-rated), and poor (3-, 4-, or 5-rated) regulatory safety and soundness ratings in 2005.

A. Interest Rate Swaps, Bank Pays Fixed Rate.			
Top 50% (46)			
Asset variables variance	Explained by	Liabilities canonical variable	30.36
Liabilities variables variance		Assets canonical variable	49.60
Bottom 50% (45)			
Asset variables variance	Explained by	Liabilities canonical variable	27.67
Liabilities variables variance		Assets canonical variable	56.70
B. Adjustable Rate Loans, Repricing in One Year or Less.			
Top 50% (2632)			
Asset variables variance	Explained by	Liabilities canonical variable	4.88
Liabilities variables variance		Assets canonical variable	9.05
Bottom 50% (2631)			
Asset variables variance	Explained by	Liabilities canonical variable	7.77
Liabilities variables variance		Assets canonical variable	13.76
C. Composite CAMELS Rating			
Composite CAMELS = 1 (2,196)			
Asset variables variance	Explained by	Liabilities canonical variable	5.27
Liabilities variables variance		Assets canonical variable	11.36
Composite CAMELS = 2 (2,840)			
Asset variables variance	Explained by	Liabilities canonical variable	5.84
Liabilities variables variance		Assets canonical variable	11.65
Composite CAMELS = 3, 4, or 5 (227)			
Asset variables variance	Explained by	Liabilities canonical variable	5.29
Liabilities variables variance		Assets canonical variable	12.63
D. Component Market Sensitivity Rating			
Market Sensitivity Component = 1 (2,157)			
Asset variables variance	Explained by	Liabilities canonical variable	5.45
Liabilities variables variance		Assets canonical variable	12.21
Market Sensitivity Component =2 (2,917)			
Asset variables variance	Explained by	Liabilities canonical variable	6.28
Liabilities variables variance		Assets canonical variable	11.41
Market Sensitivity Component = 3, 4, or 5 (189)			
Asset variables variance	Explained by	Liabilities canonical variable	10.75
Liabilities variables variance		Assets canonical variable	19.22

Figure 1



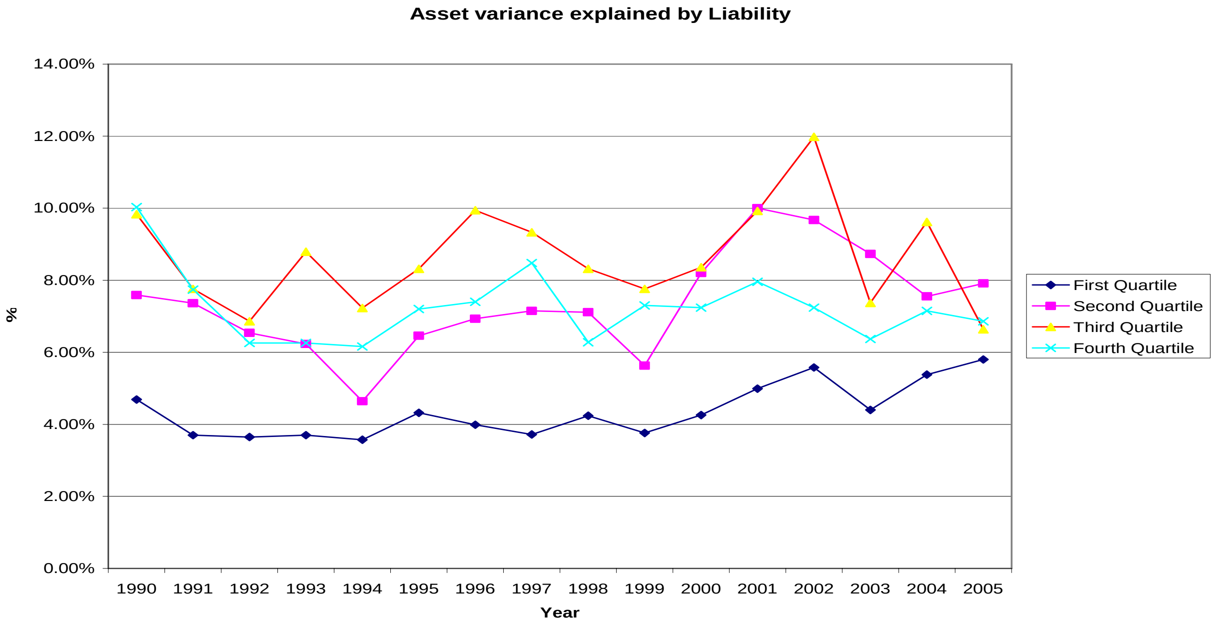
The following three conditions:

1. A strong canonical correlation between Assets and Liabilities (equation 3, Table 3).
2. A strong canonical loading between Long-term Loans and Assets (equation 4, Table 5).
3. A strong canonical loading between Core Deposits and Liabilities (equation 4, Table 5).

Imply the following fourth condition:

4. There is a strong relationship between Long-term Loans and Core Deposits, after considering the correlations among all of the other asset and liability accounts.

Figure 2
Redundancy Coefficients, 1990-2005
Liabilities explaining Assets
Panel A: Size Quartiles



Panel B: Size Deciles

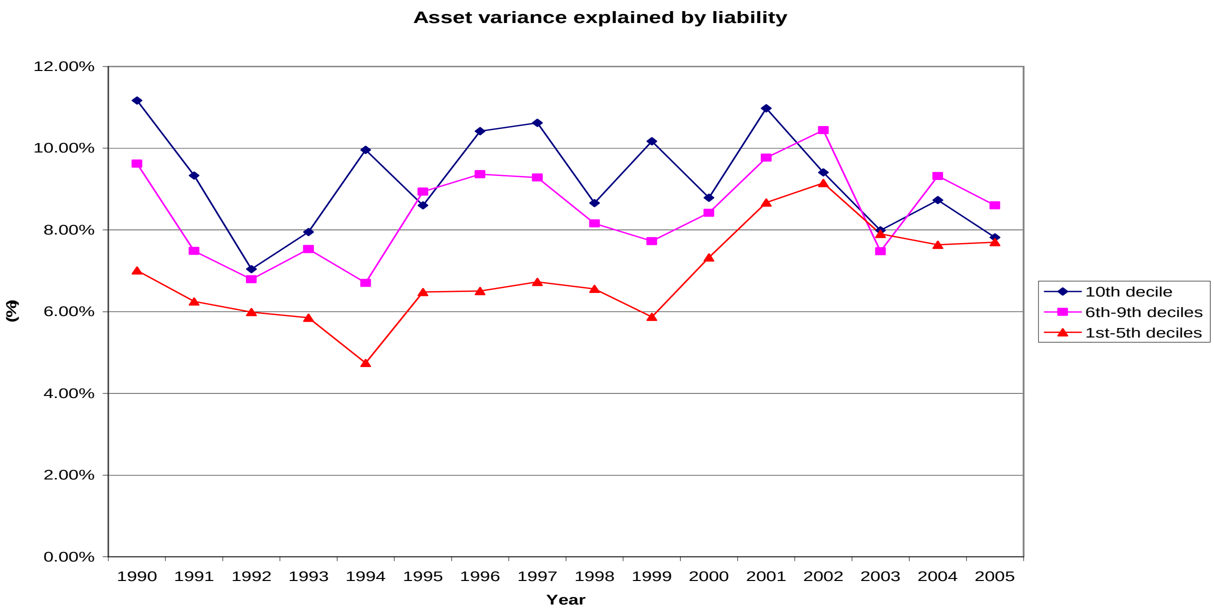
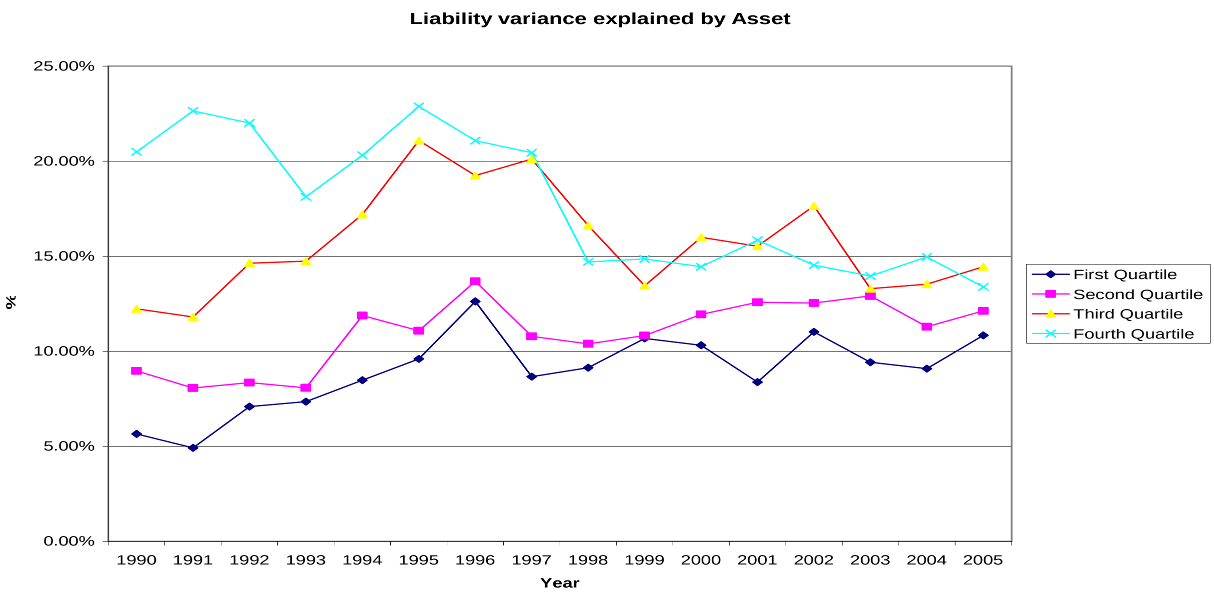


Figure 3
Redundancy Coefficients, 1990-2005
Assets explaining Liabilities
Panel A: Size Quartiles



Panel B: Size Deciles