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

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Abstract: In a highly abstract world (no taxes, costless bankruptcy, complete financial markets), firms' investment decisions and financing decisions are independent (Modigliani and Miller, 1958). In the real world, traditional banking institutions provide a strong counter-example to this abstract theory—indeed, banks have traditionally profited by managing the relationships between assets and liabilities. But changes in the banking industry during recent years—e.g., industry deregulation, advances in risk mitigation, innovations financial markets—have allowed banks to operate profitably with fewer balance sheet constraints. In this paper, 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 become more independent over time, especially for the largest banks. We find (perhaps surprisingly) that asset-liability dependence historically has been stronger at large banks, but has steadily converged over time for banks of all sizes. Finally, we show that asset-liability linkages are indeed weaker for banks that are intensive users of risk-mitigation strategies like interest rate swaps and adjustable loans. These findings imply that deregulation and financial innovation have made markets more complete, thus moving the industry closer to the predictions of an abstract Modigliani and Miller world.

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

JEL codes: G21, G32

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1. Introduction

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 been used to motivate other theoretical value-maximizing tradeoffs between debt and equity financing (Miller 1977, Jenson 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.[1]

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 regulatory maximum amount of debt financing, which suggests an optimal debt-equity mix for banks 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.[2] But unlike commercial firms, 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,

[1] 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).

[2] For example, in 2006 over three-quarters of all publicly traded bank holding companies in the U.S. had "leverage ratios" of 8 percent or more (higher than the 5 percent ratio necessary to be considered "well capitalized") and had "Tier 1 ratios" of 10 percent or more (higher than the 6 percent ratio necessary to be considered well capitalized). See Berger, DeYoung, and Flannery (2007).

an important profit driver is the maturity mismatches between assets and liabilities—for 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 by these mismatches increases (e.g., increased probability of insolvency and the attendant costs of regulatory intervention).[3]

To mitigate the costs associated with interest-rate risk, banks have traditionally practiced on-balance sheet asset-liability management (ALM), attempting to match the maturities of their assets and liabilities without foregoing profitable lending opportunities or substantially driving up their funding costs. Although ALM is a key part of all banks' risk management practices, for many banks (especially small and mid-sized banks) these risks cannot be costlessly or even inexpensively hedged. A number of developments in recent years have provided new ways for banks to mitigate interest rate risk and/or have diluted the impact of asset-liability maturity mismatch on banks' risk positions. New financial technologies—including 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. And the expansion of banks' powers to offer securities and insurance products, as well as a shift from portfolio lending to 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.

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[3] 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 (i.e., 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.

These developments have arguably made the asset and liability markets in which banks operate more complete. If this is the case, then the composition of banks' assets and liabilities should have become measurably more independent over the past two decades. In this paper, we offer evidence consistent with this conjecture. Applying canonical correlation analysis to balance sheet data for all U.S. commercial banks between 1990 and 2005, we show that the composition of bank assets and bank liabilities have become systematically less correlated with each other over time.

We find that the weakening of the asset-liability relationships has been most dramatic for large banks, a reasonable result given that large banks (a) have easier access than small banks to many of the new developments and 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 generate activity-based reductions (diversification) in risk. Perhaps surprisingly, we find weaker asset-liability correlations as banks get smaller, which suggests that small size and local geographic focus imparts a granularity on asset and liability accounts that constrains asset-liability management, and also helps account for the relatively low levels of financial leverage at small banks. However, we also find that these size-based differences in asset-liability linkages have converged substantially over time. Finally, we provide evidence of weaker asset-liability correlations at banks that are disproportionate users of interest rate swaps and/or adjustable rate loans (consistent with off-balance sheet risk-mitigation) and at 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).

This is the first preliminary version of our paper, and as such we stress that these findings are tentative. 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 offers some preliminary conclusions based on our results.

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.[4]

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, 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

[4] 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 (2000, chapter 6) and Freixas and Rochet (1999, chapter 2) for general discussions of why banks exist and overviews of the theoretical literature.

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 decisions, even in a world without taxes or other frictions absent from the simplest Modigliani-Miller framework.[5] [6]

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 use an unorthodox statistical approach (i.e., 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.

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[5] 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. 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 exactly offset 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.)

Commercial bank business models have evolved over the past two decades, and today banks generate an increased portion of their income from nonintermediation 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.

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. If this is indeed the case, then it stands to reason that the correlation between bank profitability and bank net interest margin would have grown weaker over time. Figure 1, reproduced from DeYoung and Rice (2004), displays the average correlation of ROE and net interest margin each year between 1984 and 2001, and shows no such weakening—if anything, the figure indicates a strengthening inter-temporal relationship between total earnings and the margin from intermediation.[7]

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

[7] Boyd and Gertler (1994) used a different method to reach a similar conclusion.

income and economizes on equity capital. Securitized lending exhibits large scale economies, partly because banks use automated credit scoring models 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.[8]

Banks' intermediation activities were also disrupted by the loss of commercial lending business to non-bank competitors (e.g., insurance companies) and direct financial markets (e.g., commercial paper and 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 direct 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

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

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 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, "duration matching" is a traditional (though potentially costly) way to mitigate interest rate risk. Matching the durations of loans and deposits can require a bank to purchase deposits in durations that carry higher interest rates than the bank's current deposits, and/or forego some otherwise profitable lending opportunities. This is less costly for banks with long-lasting relationships on both sides of the balance sheet—for example, traditional relationship banking uses core deposits to fund repeat lending business—but most banks do not enjoy this type of natural strategic hedge 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 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., asset securitization, 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, product mix, and financial performance) influence asset-liability linkages. Our primary goal is to discern whether exogenous financial, regulatory, and technological changes—changes that have arguably made markets more complete—have reduced the relationships between assts 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

Canonical correlation analysis was developed by Hotelling (1935, 1936). As opposed to the more familiar simple correlation analysis, which describes the relationship between two individual variables, canonical correlation analysis describes the relationships between and within two vectors of variables. (Indeed, simple correlation analysis is a special case of canonical correlation analysis in which the vectors each contain just a single variable.) A *canonical correlation* is the maximum correlation between linear functions of the 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 that, like commercial banks, 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).[9]

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

[9] 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. Canonical correlation is a non-causal concept.

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, 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 the term "liability accounts" to include all 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 covary 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 the canonical correlation analysis that we apply to bank asset and liability balances does not directly consider return variances and covariances, it considers them indirectly through the movements and co-movements in the relative levels of those balances.[10] 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.

[10] 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.

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:

$$A = B'X = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_p X_p \qquad (1)$$

$$L = C'Y = \gamma_1 Y_1 + \gamma_2 Y_2 + \gamma_3 Y_3 + \ldots + \gamma_q Y_q \qquad (2)$$

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 correlation between the canonical variables A and L:

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

where a and l denote mean differences for the variables A and L, respectively.

The size and strength of this correlation (3) 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 *if r_{AL} is strong* we can surmise that banks with high levels of core deposits will also tend to have large amounts of long term loans. Note that the surmised relationship between Y_{CORE} and $X_{LTLOANS}$ is an indirect one—as illustrated in Figure 2a—as it depends entirely on the direction and strength of the (maximized) correlation between the two canonical variables A and L. In other words, long term loans and core deposits share a common factor, which is captured in r_{AL}.

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 covariations among these accounts. This approach contrasts with production/cost/profit function analysis, which typically assumes an intermediation framework that constrains all deposit accounts to be inputs and all asset accounts to be outputs.

3.1. Technical Details

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:

$$r_{AL} = \frac{B^{'}S_{xy}C}{\sqrt{\left(B^{'}S_{xx}B\right)\left(C^{'}S_{yy}C\right)}} \qquad (3')$$

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:

$$L = B^{'}S_{xy}C - \frac{\lambda}{2}\left(B^{'}S_{xx}B - 1\right) - \frac{\mu}{2}\left(C^{'}S_{yy}C - 1\right) \qquad (4)$$

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:

$$\left(S_{xx}^{-1}S_{xy}S_{yy}^{-1}S_{yx} - \mu^2 I\right)B = 0 \qquad (5)$$

$$\left(S_{yy}^{-1}S_{yx}S_{xx}^{-1}S_{xy} - \mu^2 I\right)C = 0 \qquad (6)$$

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,…,p). For instance, the matrix equation (5) can be written as:

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

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:

$$\left|S_{xx}^{-1}S_{xy}S_{yy}^{-1}S_{yx} - \mu^2 I\right| = 0 \qquad (7)$$

$$\left|S_{yy}^{-1}S_{yx}S_{xx}^{-1}S_{xy} - \mu^2 I\right| = 0 \tag{8}$$

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:

$$A_i = B_i' X \tag{9}$$

$$L_i = C_i' Y \tag{10}$$

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 $Corr(A_1,L_1) > Corr(A_2,L_2) > \ldots > Corr(A_p,L_p)$.

3.2. Interpreting the results

The first significance test of interest is whether there are any significant linear relationships between the asset and liability variables. We test for associations between the p pairs of canonical variables using Rao's F-ratio approximation of Wilks's Λ,

$$R = \frac{1-\Lambda^{1/s}}{\Lambda^{1/s}} * \frac{(N-3/2-(p+q)/2)s - pq/2+1}{pq}$$

where Wilks's Λ is

$$\Lambda = \prod_{i=1}^{p}\left(1-\mu_i^2\right)$$

and s is

$$s = \sqrt{\frac{p^2q^2-4}{p^2+q^2-5}}\ .$$

Since each μ_i^2 is a squared correlation between corresponding pairs of canonical variables, the Wilks's Λ is inversely related to the strength of relationship between two sets of variables. These F-ratio approximations are used to determine whether canonical correlations are significant. If the first (i.e., p=1) F-ratio approximation is significant, then there is at least one significant canonical correlation. After removing the first canonical correlation, the test is repeated to see whether there is at least one significant canonical correlation in the residual (consisting of the second through p^{th} canonical correlations). This test is repeated on successive residuals until the residuals are no longer statistically significant.

If the F-tests show that there are significant canonical correlations, the nature of the relationships between asset and liability accounts can be studied by examining the *canonical loadings*. Canonical loadings are the correlations between 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:

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

where β_1^1, β_2^1, …, β_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 canonical variables (e.g., $Corr(X_1,A_3)$). The canonical loadings indicate which variables are most closely associated with the canonical variable, and are used to identify the links between asset and liability accounts.

It is possible that the canonical correlation is large yet be based on a relatively small proportion of each set's variance. For instance, if only one asset variable has high association with the asset canonical variable (i.e., a high canonical loading), the total amount of variance in the asset variables accounted for by the canonical variable can be small. The canonical loadings can be used to measure the total amount of variance in the actual data accounted for by the canonical variables:

$$R_{A,j}^2 = \sum_{i=1}^{p} \frac{\left(r_{Ai}^j\right)^2}{p} = \sum_{i=1}^{p} \frac{\left(Corr\left(X_i, A_j\right)\right)^2}{p} \qquad (12)$$

where $R_{A,j}^2$ is the *proportion of variance* in the asset variables accounted for by the j^{th} canonical variable, and r_{Ai}^j is the canonical loading of the variable X_i on the j^{th} canonical variable A_j.

Similarly, it is possible that a very large canonical correlation could be the result of a large correlation of just one variable of one set with just one variable of the other set, while the other variables of the two sets 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:

$$R^2_{A|L,j} = \mu_j^2 \sum_{i=1}^{p} \frac{\left(r_{Ai}^j\right)^2}{p} = \mu_j^2 R^2_{A,j} \quad (13)$$

where the redundancy coefficient $R^2_{A|L,j}$ is the portion of the variance in the actual asset variables that is accounted for by the liability variables, μ_j^2 is the j^{th} squared canonical correlation (or the j^{th} eigenvalue), and $R_{A,j}^2$ is the proportion of asset variance accounted for by its j^{th} canonical variable.

It is important to note that $R^2_{A|L,j}$, the portion of the variance in the actual asset variables that is accounted for by the liability variables, is not equal to $R^2_{L|A,j}$, the portion of the variance in the actual liability variables that is accounted for by the asset variables. The variance extracted by A from X is not the same as the variance extracted by L from Y. Suppose A is a major factor of X while L is a trivial factor of Y. If such is the case, the redundancy of X given Y as packaged in A should be much greater than the redundancy of Y given X as packaged in L, and indeed it will be true that $R^2_{L|A,j} < R^2_{A|L,j}$.

4. Data

We analyze asset-liability relationships and trend for U.S. commercial banks between 1990 and 2005, using year-end data from the Reports of Condition and Income (call reports). We place a special emphasis on four separate cross sections of data from 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. 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 changes (FDICIA in 1991, Reigle-Neil in 1994, Gramm-Leach-Bliley in 1999) which may have affected the nature of asset-liability relationships. Because the balance sheet composition of young banks is known to be volatile, we exclude banks less than 10 years old from the analysis (Brislin and Santomero, 1991). Stock and mutual savings banks are deleted from the sample because these institutions do not have maturity information for loans and purchased funds that are consistent with other types of institutions in 1990 and 1995.

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 five different asset size groups. The asset size thresholds separating these five groups of banks are $100 million, $500 million, $2 billion, and $10 billion, expressed in 2004 dollars. The number of observations in each of the four data cross sections reflects the consolidation of the U.S. banking industry. The smallest banks decline in number by nearly two-thirds, from 8,373 in 1990 to 2,754 in 2005. In contrast, the number of banks in each of the other four size groups increases over time. Overall, there are about 4,000 fewer commercial banks today than in 1990, and the asset-size distribution of those banks has shifted up. Only about 10 percent of this population decline is due to bank failures (mostly between 1990 and 1995), and these trends primarily reflect mergers and acquisitions that combined assets of existing banks into fewer, larger banks.

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.[11] 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 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.

[11] 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.

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. Cash 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 innovations in payments clearing reduced the size of precautionary balances. By-and-large, the data indicate lengthening bank asset maturities: Both long-term securities and long-term loans increased while both short-term securities and short-term loans tended to decline. These shifts have many causes, with 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 larger banks, demand deposits fell but core deposits rose, indicating a shift from business banking to consumer banking, as well as a lengthening of the effective maturities of transactions account liabilities. At small banks, these trends have gone in the opposite direction, emphasizing the continued importance of small business customers at small banks, and perhaps indicating that small banks are having increased difficulty competing for core deposits with large banks that have expanded into their local markets. Consistent with this last point, small banks increased their use of purchased funds across time. Finally, banks of all sizes increased their equity holdings—a long-term source of funding—as the industry profits were retained and changes in regulations (FDICIA, 1991) required them to hold higher levels of capital.

These trends suggest, albeit crudely, relationships among different asset accounts, among different liability accounts, and between asset accounts and liability accounts. Importantly, these correlations appear to involve complex combinations of multiple accounts on both sides of the balance sheet. We apply canonical correlation analysis to reveal the nature and strength of these relationships, and changes in these relationships over time.

5. Results

Table 2 displays the canonical correlations (3), arrayed by bank size and year. We calculate five canonical correlations for each of the five bank sizes and four time periods, the maximum allowable by our data.[12] For example, for the small bank group (assets less than $100 million) in 1990 the first canonical correlation is 0.409, which indicates that the first pair of canonical variables (A_1 and L_1) share 16.7% of their variance with each other—in other words, the first factor extracted from the asset accounts data and the first factor extracted from the liability accounts data have a linear correlation of 0.409. The second canonical correlation is 0.235, i.e., the second pair of canonical variables (A_2 and L_2) share 5.5% of their variance with each other. Moving down each column, the canonical correlations tend to decline in explanatory power (lower correlation magnitudes) and statistical significance (weaker F-tests). The canonical correlations also tend to be larger (greater explanatory power) for the larger banks, a result we will discuss below.

Table 3 displays the proportion of the variance in the actual assets and liability data accounted for by the canonical variables. To reduce the amount of space necessary to display these results, each cell contains the average across 20 (5 size groups, 4 years) separate calculations of (12) for each canonical loading. The first canonical loadings tend to explain substantially more of the variance in the data than do later loadings. For example, the liabilities canonical variables explain 8.2% of the variance in the actual assets variables in the 1st loading (compared to only 4.8% and 1.8% in the 2nd and 3rd loadings), while the assets canonical variables explain 19.8% of the variance in the actual liabilities variables in the 1st loading

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

(compared to only 5.6% and 2.2% in the 2nd and 3rd loadings). Thus, we limit the more detailed portion of our analysis to the measures generated from only the first two canonical loadings.

We are interested chiefly in the relationships between the right-hand and left-hand sides of the balance sheet, and whether these relationships have grown stronger or weaker over time. One way to gauge the ongoing strength of asset-liability relationships is to follow the logic displayed in Figure 2: If [1] the canonical correlation between assets and liabilities is strong, and [2] asset *i* is strongly correlated with the asset canonical variable, and [3] liability *j* is strongly correlated with the liability canonical variable, then [4] we can surmise that a relationship exists between asset *i* and liability *j*. Tables 4a and 4b display the individual canonical loadings (11) that represent the second and third links in this logical chain. Correlations between individual actual asset accounts and asset canonical variables appear on the left-hand side of the cells, while correlations between individual actual liability accounts and liability canonical variables appear on the right-hand side of the cells.

The patterns in Tables 4a (correlations based on the 1st canonical loadings) and 4b (correlations based on the 2nd canonical loadings) provide evidence of four fundamental asset-liability banking relationships. First, the correlations of cash holdings and demand deposits with their respective canonical variables typically have the same signs (15-of-20 times in Table 4a; 9-of-20 times in Table 4b), suggesting that these two balance sheet accounts move up and down together. This is a plausible relationship: Banks with large amounts of demand deposits (a pure transactions account) will naturally need to hold higher balances of cash and reserves as a precaution against a large volume of payments presentments on any given day. We note that this positive cash balances-demand deposit relationship shows up less often in the data for the larger banks—in particular, the correlations between demand deposits and the liabilities canonical variable are low—perhaps because large banks have been more likely to sweep demand deposits balances into overnight investments for their clients. In general, the magnitudes of these correlations tend to decline over time in Table 4a—our first, albeit tenuous, evidence of increased independence of assets and liabilities over time.

Second, the correlations of long-term loans and core deposits with their respective canonical variables usually have the same sign (16-of-20 times in Table 4a; 13-of-20 times in Table 4b), suggesting that these two balance sheet accounts also move up and down together. Again, 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. The magnitudes of these correlations are roughly similar for all sizes of banks, and there is little evidence that they decline over time.

Third, the correlation the asset canonical variable with short-term loans, and the correlation of the liability canonical variable with purchased funds and/or demand deposits, very often have the same sign (8-of-20 times in Table 4a; 9-of-20 times in Table 4b). Banks that practice maturity-match financing would prefer to fund short-term loans with something other than core deposits (e.g., large CDs, fed funds). Moreover, commercial borrowers with short-term loans and/or lines of credit often hold compensating balances in demand deposit accounts. These correlations are less systematic in the data, especially for the largest banks, and show up less frequently over time—additional evidence consistent with increasing independence of bank assets and liabilities.

Finally, for the two groups of banks with less than $500 million in assets, the correlations of short-term securities holdings and equity capital with their respective canonical variables often have the same sign (5-of-8 times for banks under $100 million in Tables 4a and 4b; 3-of-4 times for banks between $100 and $500 million in Table 4b). Small banks with less access to capital markets allow unexpected increases in net income to build up in retained earnings (part of equity capital), which can be used to fund future lending opportunities; in the interim, the banks invest these proceeds in liquid short-term securities. We find no similar evidence in larger banks, which have easier access to external funding.

Another way to gauge the ongoing strength of asset-liability relationships is to follow either of the more straightforward logic paths displayed in Figure 3: [1] Measuring the correlations of actual asset account data with the liability canonical variable or [2] measuring the correlations of actual liability account data with the asset canonical variable. In other words, refer to the redundancy coefficients (13), which measure the proportion of variance in the account data explained by the canonical variables. The redundancy coefficients are displayed on the second and fourth lines of Table 5. For clarity and comparison, we have graphed the redundancy coefficients for annual data in Figures 4 and 5.

We find systematic and economically meaningful reductions in the magnitudes of the redundancy coefficients over time. For the largest banks in Group 5, the liability canonical variable explained 49.80% of the variance in the asset account data in 1990, but only 15.44% in 2005. We find similarly large reductions in this redundancy coefficient for banks in Groups 3 and 4, both of which declined by about half between 1990 and 2005. The smaller banks in groups 1 and 2 exhibit smaller declines over time, but the redundancy coefficients for these banks were quite low to start out, at less than 10% in 1990. We find somewhat similar results for the size and direction of the converse redundancy coefficients that measure the proportion of the liability account data explained by the asset canonical variable—the only qualitative difference being that this redundancy coefficient increased over time for banks with less than \$100 million in assets, from 7.44% in 1990 to 11.02% in 2005.

The obvious inference to be drawn from the downward drift in the redundancy coefficients is that the compositions of assets and liabilities at commercial banks have grown more independent over time. We make two additional observations from these data. First, and perhaps surprisingly, the "redundancy" among the composition of assets and liabilities is systematically stronger for larger banks, in both the early and later time periods. One might have expected *a priori* 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 the larger banks—suggesting that small banks practiced a strategy of absorbing, rather than hedging, interest rate risk. This extra cushion may have allowed them to operate with a greater than average amount of maturity mismatches on their balance sheets. [Note that 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 smaller 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 (high) redundancy coefficients for small (large) banks. If profitable lending opportunities present themselves to at banks with some randomness, then small banks—which do a smaller 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—for example, in 1990 core deposits provided nearly 70 percent of total financing for small banks (see Table 1). 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.

Second, the redundancy coefficients have clearly converged over time, and the degree of this convergence is both substantial and rapid. For example, in Figure 4 the spread in the redundancy coefficients between the smallest and largest banks was 6.85% versus 49.80% in 1990, but this spread shrank to just 5.92% versus 15.44% in 2004. By this measure, large and small commercial banks have become more alike. The convergence is driven mainly by declines—i.e., more independence of assets and liabilities—and the declines are approximately proportional to bank size, perhaps because 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 fully into non-interest-based (off-balance sheet) financial services—both of which have diversified larger banks' income streams and hence allowed them to accept more risk from mismatched assets and liabilities.

6. Sub-sample analysis

Our analysis above indicates that the strength of asset-liability relationships, while converging over time, continue to vary substantially across different size banks. In this section we explore some of the possible reasons for this. For example, as posited above, does the use of derivatives securities (almost exclusively a 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 126 banks 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, calculated separately for banks above and below the median. Panel B displays redundancy coefficients for the entire sample of bank 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. The results indicate that hedging interest rate risk (a) with interest rate derivatives and/or (b) by holding adjustable rate loans does allow banks to relax their on-balance sheet asset-liability management. For example, the redundancy coefficients for intensive users of interest rate swaps to hedge against exposure to fixed interest rate loans are just 16.51 (variance of asset variables explained by liabilities canonical variable) and 27.22 (variance of liabilities variables explained by assets canonical variable), compared to 20.29 and 44.77 for less intensive user of interest rate swaps. We found similar, though not as dramatic, differences for intensive users of adjustable rate loans (5.60 and 9.95) compared to largely fixed-rate lenders (7.43 and 14.73).[13]

[13] To control for the effects of asset size on the full-sample results in Panel B, we first divided each of the five 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 then calculated the redundancy coefficients separately for these two resulting asset-stratified sub-samples.

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 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 A are lowest (5.05 and 11.18) for the banks judged to be the safest (1-rated), and and highest (8.70 and 13.89) for the banks judged to have substantial risk (3-rated or worse). Not surprisingly, this discrepancy was somewhat larger in Panel B where the Sensitivity to Market Risk component of the CAMELS ratings was used to construct the sub-samples; ranging from 5.44 and 11.82 for the 1-rated banks to 9.58 and 17.79 for the 3-, 4-, and 5-rated banks.[14]

We performed additional tests similar to those shown in Table 6 in which the sub-samples were defined by non-interest income levels (not shown), 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

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[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 amounts of 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.

asset-liability linkages. 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 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 at most commercial firms, the investment decisions and financing decisions at banking companies are inter-independent. Banks have traditionally profited by managing the relationships between assets and liabilities, and in many cases have become insolvent due to their inability to manage the resulting interest rate risk. In recent years, 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. It is likely that these developments have permitted banks to operate with fewer balance sheet constraints—if so, then the banking industry has moved closer to an abstract Modigliani and Miller world, in which investment and financing decisions are more independent and thus more efficient, and there is less need for banks to incur interest rate risk to earn profits.

In this paper, 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 2004. We find strong and substantial evidence that bank assets and bank liabilities have indeed become more independent over time, especially for the largest 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. Perhaps surprisingly, we find that large banks have historically exhibited the strongest asset-liability dependence, while small banks have historically exhibited the weakest asset-liability dependence—likely reflecting scale economies in traditional asset-liability management. Regardless, we show that the degree to which the composition of assets and liabilities are dependent on each other has steadily converged over time for banks of all sizes.

These findings imply that deregulation and financial innovation have made markets more complete, i.e., more consistent with a Modigliani and Miller world. Importantly, these findings also imply a declining need over time for banks to incur interest rate risk to earn profits. However, this does not mean that banks' overall appetite for taking risk has declined; 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).

Our results also 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 findings 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 note that this is a first draft of our research. Hence, the empirical results are preliminary, as are any implications drawn from those results.

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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, including federal funds sold. *Long-term loans* include all loans with maturities of more than one year. *Other assets* include all other assets not described. *Demand deposits* include all demand deposit accounts. *Core deposits* include all checkable transactions accounts (other than demand deposits), and savings accounts. *Small CDs* include certificates of deposits in amounts less than $100,000. *Purchased funds* include federal funds purchased and certificates of deposit in amounts greater than $100,000. *Other liabilities* include all other liabilities not described. *Equity* includes all common stock and paid-in capital. All variables are based on year-end data from the Reports of Income and Condition (call reports).

	1990	**1995**	**2000**	**2005**
Group 1 -- Assets less than $100M				
No. of observations	8373	6499	4198	2754
Asset accounts				
Cash balances	7.08	5.45	5.16	5.78
Short term securities	10.29	7.50	4.52	4.68
Long term securities	22.42	24.31	22.96	21.83
Short term loans	36.98	36.80	33.13	33.01
Long term loans	20.12	23.13	31.03	31.09
Other assets	3.12	2.81	3.20	3.62
Liability/Equity accounts				
Equity	9.00	10.52	10.94	11.34
Demand deposits	12.17	13.18	13.15	15.18
Core deposits	29.25	32.75	31.77	36.57
Small CDs	39.32	34.22	32.30	26.11
Purchased funds	8.45	7.76	10.68	10.19
Other liabilities	1.81	1.56	1.16	0.62
Group 2 -- Assets between $100M and $500M				
No. of observations	1484	1851	2303	2545
Asset accounts				
Cash balances	6.35	5.19	4.45	4.17
Short term securities	7.71	5.91	3.11	3.25
Long term securities	17.78	23.10	21.12	19.23
Short term loans	41.67	36.76	33.26	35.58
Long term loans	23.32	26.07	34.68	33.46
Other assets	3.17	2.97	3.38	4.30
Liability/Equity accounts				
Equity	7.70	9.45	9.52	10.03
Demand deposits	13.35	14.36	12.65	13.20
Core deposits	31.64	35.74	36.09	41.73
Small CDs	33.00	29.42	27.59	22.13
Purchased funds	12.48	9.41	13.00	12.17
Other liabilities	1.84	1.61	1.16	0.73

(OVER)

	1990	1995	2000	2005
Group 3 -- Assets between $500M and $2B				
No. of observations	255	314	400	634
Asset accounts				
Cash balances	8.22	5.85	4.30	3.67
Short term securities	5.52	5.37	3.23	2.82
Long term securities	15.46	20.53	20.67	17.30
Short term loans	43.29	38.23	34.40	39.02
Long term loans	24.03	26.98	33.70	32.41
Other assets	3.48	3.04	3.70	4.77
Liability/Equity accounts				
Equity	6.71	8.92	9.09	9.90
Demand deposits	15.10	14.80	9.60	8.46
Core deposits	31.69	35.62	41.12	48.62
Small CDs	27.29	23.91	22.67	17.41
Purchased funds	16.86	14.06	15.85	14.46
Other liabilities	2.36	2.69	1.68	1.15
Group 4 -- Assets between $2B and $10B				
No. of observations	132	147	121	159
Asset accounts				
Cash balances	10.56	7.64	5.27	4.08
Short term securities	3.59	2.63	2.37	2.25
Long term securities	13.94	17.46	20.19	19.57
Short term loans	46.45	42.22	36.66	38.93
Long term loans	21.95	26.45	30.84	28.90
Other assets	3.51	3.60	4.67	6.25
Liability/Equity accounts				
Equity	6.29	8.76	9.04	10.89
Demand deposits	15.99	16.46	8.49	7.45
Core deposits	30.43	35.81	41.37	49.81
Small CDs	21.02	18.17	18.29	12.85
Purchased funds	19.83	15.41	18.30	16.50
Other liabilities	6.45	5.39	4.50	2.50
Group 5 -- Assets greater than $10B				
No. of observations	17	38	56	58
Asset accounts				
Cash balances	13.01	8.87	5.95	4.28
Short term securities	2.03	3.12	2.18	1.67
Long term securities	13.55	15.39	17.72	20.55
Short term loans	46.31	44.95	37.33	35.87
Long term loans	19.36	23.11	30.92	29.52
Other assets	5.74	4.55	5.90	8.11
Liability/Equity accounts				
Equity	6.30	9.23	9.53	11.36
Demand deposits	15.55	16.87	8.68	6.21
Core deposits	27.01	33.45	42.74	52.10
Small CDs	13.52	14.54	13.25	9.47
Purchased funds	21.14	14.72	16.70	14.07
Other liabilities	16.48	11.20	9.10	6.78

Table 2

This table displays the 1st through the 5th canonical correlations for five 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 (less than $100 million)								
1	0.41	116.82***	0.42	113.40***	0.44	77.16***	0.44	51.91***
2	0.23	60.76***	0.29	74.14***	0.29	47.71***	0.37	40.84***
3	0.16	43.82***	0.18	51.59***	0.18	31.94***	0.21	25.21***
4	0.06	16.71***	0.12	47.78***	0.10	22.82***	0.18	23.60***
5	0.00	.	0.00	.	0.00	.	0.01	0.12
Group 2 ($100 to $500 million)								
1	0.58	48.19***	0.61	56.45***	0.49	56.76***	0.41	53.18***
2	0.32	23.23***	0.26	14.75***	0.33	37.58***	0.35	46.25***
3	0.23	18.09***	0.15	7.19***	0.27	30.29***	0.25	35.48***
4	0.13	13.66***	0.04	1.59	0.03	0.75	0.13	21.06***
5	0.00	.	0.00	.	0.00	.	0.00	.
Group 3 ($500 million to $2 billion)								
1	0.70	13.47***	0.69	19.38***	0.53	12.75***	0.61	28.42***
2	0.40	5.80***	0.49	11.83***	0.43	9.26***	0.48	18.38***
3	0.29	4.02***	0.33	7.95***	0.23	3.96***	0.26	7.99***
4	0.09	1.09	0.19	5.65***	0.05	0.57	0.05	0.91
5	0.00	.	0.00	.	0.00	.	0.00	.
Group 4 ($2 to $10 billion)								
1	0.85	11.37***	0.79	14.49***	0.71	8.60***	0.72	10.34***
2	0.28	1.91**	0.62	8.50***	0.56	5.91***	0.51	5.76***
3	0.26	2.01*	0.28	3.84***	0.37	3.71***	0.33	3.07***
4	0.15	1.55	0.27	5.45***	0.19	2.27	0.04	0.12
5	0.00	.	0.00	.	0.00	.	0.00	.
Group 5 (more than $10 billion)								
1	0.98	5.30***	0.92	7.63***	0.78	3.95***	0.87	10.12***
2	0.77	2.06*	0.68	3.83***	0.56	1.88*	0.79	6.56***
3	0.74	2.06	0.56	3.47***	0.19	0.39	0.45	2.35**
4	0.38	0.95	0.43	3.55**	0.10	0.23	0.17	0.75
5	0.00	.	0.00	.	0.00	.	0.00	.

Table 3

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**
Asset variables variance	explained by:	Assets canonical variable	16.62	21.42	23.79	20.20	17.97	100.00%
Asset variables variance		Liabilities canonical variable	8.16	4.83	1.81	0.79	0.00	15.59%
Liabilities variables variance		Liabilities canonical variable	41.66	24.31	23.10	10.81	0.12	100.00%
Liabilities variables variance		Assets canonical variable	19.84	5.62	2.16	0.35	0.00	27.97%

Table 4a

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 -- Assets less than $100M															
LT Secs	0.77	DD	-0.79	Cash	0.83	DD	0.93	Cash	0.71	DD	-0.76	Other	0.81	Other	0.80
ST loans	-0.59	Equity	0.58	LT loans	-0.44	Core	-0.83	LT loans	-0.62	Core	0.76	LT loans	-0.52	Core	-0.66
Other	-0.58	Core	0.50	Other	0.40	Other	0.22	ST Secs	0.44	Equity	0.64	ST loans	0.25	Equity	0.61
Cash	-0.49	PF	-0.30	LT Secs	-0.21	Equity	0.19	LT Secs	0.21	PF	-0.12	Cash	0.20	DD	0.31
Group 2 -- Assets between $100M and $500B															
Cash	0.92	Core	-0.81	Cash	0.90	Core	-0.93	Cash	0.93	Core	-0.77	Cash	0.68	Core	-0.82
LT loans	-0.40	DD	0.73	LT loans	-0.59	DD	0.83	LT loans	-0.51	DD	0.75	LT loans	-0.62	DD	0.72
LT Secs	-0.27	Other	0.59	Other	0.38	Other	0.45	ST loans	0.28	Other	0.58	Other	0.41	Other	0.53
ST loans	0.26	PF	0.34	ST loans	0.27	PF	0.30	Other	0.20	PF	0.17	ST Secs	0.36	Equity	0.46
Group 3-- Assets between $500M and $2B															
Cash	0.95	DD	0.84	Cash	0.96	DD	0.94	Cash	0.75	Core	-0.94	Cash	0.80	Other	0.73
LT loans	-0.41	Core	-0.71	LT loans	-0.24	Core	-0.57	LT loans	-0.65	DD	0.70	Other	0.45	Equity	0.68
LT Secs	-0.30	Other	0.38	Other	-0.09	Equity	-0.14	ST loans	0.64	PF	0.44	LT loans	-0.35	Core	-0.58
Other	0.25	PF	0.25	ST Secs	-0.06	Other	0.08	LT Secs	-0.31	Other	0.44	ST Secs	0.29	DD	0.42
Group 4 -- Assets between $2B and $10B															
Cash	-0.93	Other	-0.90	Cash	0.88	Other	0.66	Other	0.70	Equity	0.92	Other	0.87	Equity	0.96
LT loans	0.56	Core	0.67	LT loans	-0.59	Core	-0.65	Cash	0.60	DD	0.42	LT loans	-0.48	Core	-0.41
LT Secs	0.47	Equity	-0.14	Other	-0.35	DD	0.39	LT Secs	-0.60	PF	-0.40	ST loans	0.26	Other	0.21
ST Secs	-0.18	PF	0.09	ST loans	0.22	Equity	-0.18	ST loans	0.32	Other	0.32	LT Secs	-0.26	PF	-0.10
Group 5 -- Assets greater than $10B															
Other	-0.92	Other	-0.94	Cash	0.90	Core	-0.97	Cash	0.95	Core	-0.89	Other	-0.86	Equity	-0.81
Cash	-0.92	Core	0.89	LT loans	-0.86	Other	0.91	LT loans	-0.51	Other	0.88	Cash	-0.49	Core	0.65
LT loans	0.64	PF	0.47	Other	0.45	Equity	0.16	ST Secs	0.28	PF	0.49	LT Secs	0.28	Other	-0.60
LT Secs	0.48	Equity	-0.39	ST Secs	0.31	PF	0.13	LT Secs	-0.23	DD	0.33	LT loans	0.07	DD	-0.16

Table 4b

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 -- Assets less than $100M															
LT loans	-0.69	Equity	0.81	LT Secs	0.78	Equity	0.95	Cash	-0.66	Equity	0.73	Cash	0.68	DD	0.79
Cash	0.65	Core	-0.67	ST Secs	0.59	Core	-0.27	LT Secs	0.66	DD	-0.62	LT loans	-0.60	Core	-0.60
LT Secs	0.37	DD	0.58	LT loans	-0.52	DD	-0.26	LT loans	-0.46	PF	0.19	Other	-0.52	Other	-0.56
ST Secs	0.32	Other	0.06	ST loans	-0.48	PF	0.11	ST Secs	0.35	Other	-0.10	ST Secs	0.37	Equity	0.13
Group 2 -- Assets between $100M and $500B															
LT loans	-0.70	Equity	0.65	ST loans	-0.76	Equity	0.94	ST Secs	0.63	Equity	0.93	Other	-0.74	PF	0.68
ST Secs	0.59	PF	0.64	LT Secs	0.59	PF	-0.31	LT loans	-0.60	Core	-0.34	ST loans	0.59	Equity	-0.61
Other	-0.48	Core	-0.50	Other	0.49	Other	0.23	LT Secs	0.52	PF	0.21	LT loans	-0.35	Core	-0.49
LT Secs	0.35	DD	-0.31	ST Secs	0.41	DD	-0.23	Other	0.28	DD	-0.10	Cash	0.28	Other	-0.44
Group 3-- Assets between $500M and $2B															
LT loans	-0.89	PF	0.88	ST Secs	0.87	PF	0.91	Other	-0.82	Equity	-0.94	Other	-0.88	Equity	-0.69
LT Secs	0.48	Core	-0.70	LT loans	-0.61	Core	-0.79	ST Secs	-0.32	PF	0.27	Cash	0.48	Other	0.43
ST Secs	0.40	Equity	0.56	Cash	-0.18	Other	0.34	Cash	0.25	DD	0.15	LT loans	-0.21	DD	0.39
ST loans	0.20	Other	0.19	Other	-0.15	DD	-0.22	LT Secs	0.23	Other	0.08	ST loans	0.19	PF	0.20
Group 4 -- Assets between $2B and $10B															
ST loans	0.90	PF	0.61	Other	0.80	Equity	0.93	LT loans	-0.83	Core	-0.92	Cash	0.81	Core	-0.80
LT loans	-0.42	Core	-0.58	LT Secs	-0.44	Core	-0.67	Cash	0.53	Other	0.63	LT loans	-0.64	Other	0.71
LT Secs	-0.41	Equity	0.55	ST loans	0.39	Other	0.49	LT Secs	0.46	PF	0.60	Other	-0.34	DD	0.55
Cash	-0.37	DD	0.34	LT loans	-0.36	PF	0.27	ST Secs	0.36	DD	0.25	LT Secs	0.17	PF	0.33
Group 5 -- Assets greater than $10B															
LT Secs	0.81	DD	-0.97	ST loans	0.84	Equity	0.89	Other	-0.66	Equity	-0.80	Cash	0.83	Other	0.77
LT loans	-0.64	Equity	-0.58	LT Secs	-0.72	DD	0.50	LT loans	-0.58	DD	-0.59	Other	-0.48	Equity	-0.59
ST Secs	0.44	PF	0.54	ST Secs	-0.51	Other	-0.26	ST Secs	0.56	PF	-0.38	LT loans	-0.47	Core	-0.39
ST loans	-0.23	Other	0.28	Other	0.41	Core	-0.10	LT Secs	0.55	Core	0.36	ST Secs	0.34	DD	0.14

Table 5

This table displays the proportion of the variance in asset and liability variables explained by the canonical variables, for five size groups of U.S. commercial banks in 1990, 1995, 2000, and 2005.

			1990	1995	2000	2005
Group 1 -- Assets less than $100M						
Asset variables variance	explained by:	Assets canonical variable	88.43	84.73	73.07	74.13
Asset variables variance		Liabilities canonical variable	6.85	5.59	5.61	5.92
Liabilities variables variance		Liabilities canonical variable	100	100.00	100.00	97.55
Liabilities variables variance		Assets canonical variable	7.44	11.70	10.74	11.02
Group 2 -- Assets between $100M and $500M						
Asset variables variance	explained by:	Assets canonical variable	88.22	75.35	71.70	68.69
Asset variables variance		Liabilities canonical variable	8.42	8.13	8.05	6.41
Liabilities variables variance		Liabilities canonical variable	100.00	93.34	89.54	100.00
Liabilities variables variance		Assets canonical variable	19.47	23.78	13.68	12.47
Group 3 -- Assets between $500M and $2B						
Asset variables variance	explained by:	Assets canonical variable	84.79	63.52	63.51	57.62
Asset variables variance		Liabilities canonical variable	13.83	8.13	11.00	6.86
Liabilities variables variance		Liabilities canonical variable	91.99	100.00	86.99	90.61
Liabilities variables variance		Assets canonical variable	27.29	26.25	18.20	15.41
Group 4 -- Assets between $2B and $10B						
Asset variables variance	explained by:	Assets canonical variable	85.86	75.50	52.06	48.47
Asset variables variance		Liabilities canonical variable	24.18	20.13	17.94	13.08
Liabilities variables variance		Liabilities canonical variable	92.08	100.00	83.55	90.44
Liabilities variables variance		Assets canonical variable	33.48	33.20	26.57	22.34
Group 5 -- Assets greater than $10B						
Asset variables variance	explained by:	Assets canonical variable	62.42	94.63	38.75	37.23
Asset variables variance		Liabilities canonical variable	49.80	48.49	17.27	15.44
Liabilities variables variance		Liabilities canonical variable	85.03	100.00	79.57	94.16
Liabilities variables variance		Assets canonical variable	75.37	70.23	44.41	47.16

Table 6

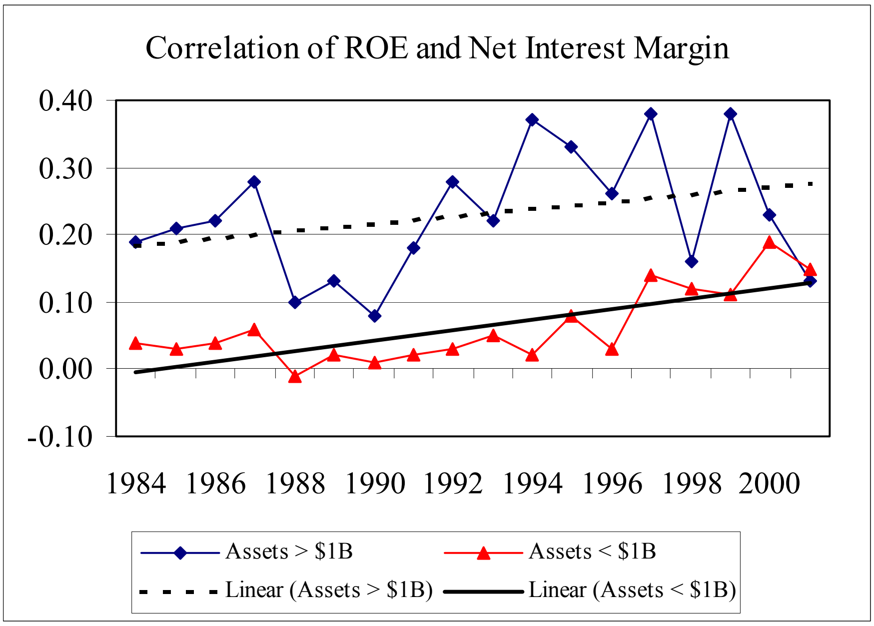
Redundancy Coefficients: Interest Rate Hedging and Regulatory Ratings.

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% (63)			
Asset variables variance	Explained by	Liabilities canonical variable	16.51
Liabilities variables variance		Assets canonical variable	27.22
Bottom 50% (63)			
Asset variables variance	Explained by	Liabilities canonical variable	20.29
Liabilities variables variance		Assets canonical variable	44.77
B. Adjustable Rate Loans, Repricing in One Year or Less.			
Top 50% (3076)			
Asset variables variance	Explained by	Liabilities canonical variable	5.60
Liabilities variables variance		Assets canonical variable	9.95
Bottom 50% (3074)			
Asset variables variance	Explained by	Liabilities canonical variable	7.43
Liabilities variables variance		Assets canonical variable	14.73
C. Composite CAMELS Rating			
Composite CAMELS = 1 (2,479)			
Asset variables variance	Explained by	Liabilities canonical variable	5.05
Liabilities variables variance		Assets canonical variable	11.18
Composite CAMELS = 2 (3,390)			
Asset variables variance	Explained by	Liabilities canonical variable	6.55
Liabilities variables variance		Assets canonical variable	12.96
Composite CAMELS = 3, 4, or 5 (281)			
Asset variables variance	Explained by	Liabilities canonical variable	8.70
Liabilities variables variance		Assets canonical variable	13.89
D. Component Market Sensitivity Rating			
Market Sensitivity Component = 1 (2,447)			
Asset variables variance	Explained by	Liabilities canonical variable	5.44
Liabilities variables variance		Assets canonical variable	11.82
Market Sensitivity Component =2 (3,496)			
Asset variables variance	Explained by	Liabilities canonical variable	6.63
Liabilities variables variance		Assets canonical variable	12.38
Market Sensitivity Component = 3, 4, or 5 (207)			
Asset variables variance	Explained by	Liabilities canonical variable	9.58
Liabilities variables variance		Assets canonical variable	17.79

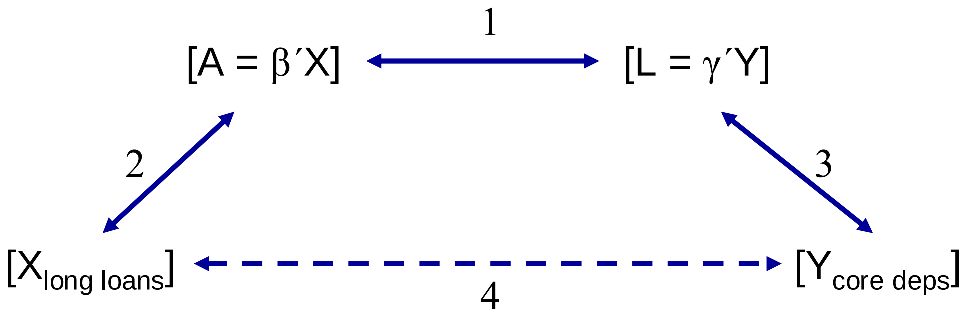
Figure 1

Average annual cross-sectional correlations between commercial bank return-on-equity and commercial bank net interest margin. OLS trend lines are superimposed over each series of correlations.



Reproduced from DeYoung and Rice (2004).

Figure 2



If all three of the following conditions obtain….

1. Strong canonical correlation between Assets and Liabilities.
2. Strong canonical loading between Long-term Loans and Assets.
3. Strong canonical loading between Core Deposits and Liabilities.

….then these three conditions imply the 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 3

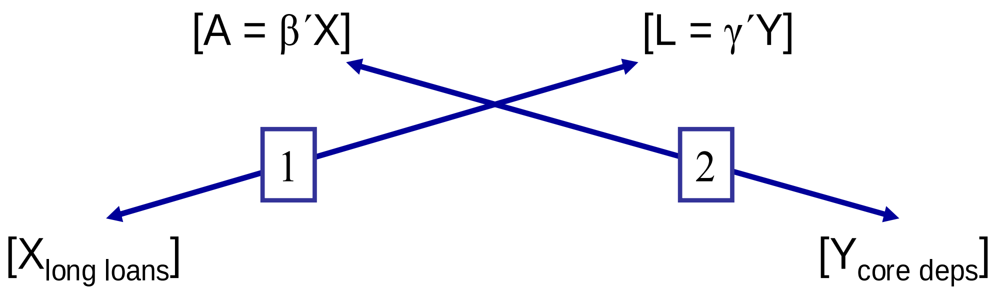


Figure 4 – Redundancy Coefficients

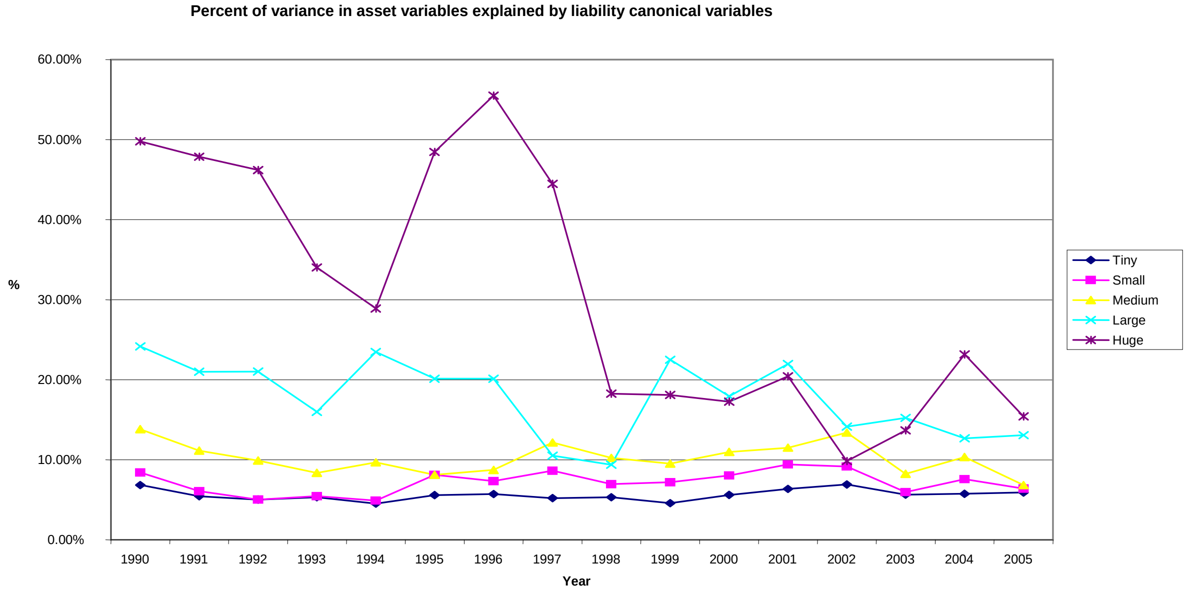


Figure 5 – Redundancy Coefficients