The Asset-Correlation Parameter in Basel II for Mortgages on Single-Family Residences

Prepared as Background for Public Comment on the Advance Notice of Proposed Rulemaking on the Proposed New Basel Capital Accord

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Summary: This paper summarizes empirical research undertaken by Federal Reserve Board (FRB) staff in support of the asset-correlation assumption implicit in the regulatory capital formula for mortgages on single-family residences (structures with up to four living units) in the proposed New Basel Capital Accord (Basel II). This analysis employs several alternative credit-risk models for residential mortgages. Among these is the FRB model, which is a multiperiod, multifactor simulation model designed to estimate economic capital for thirty-year, conforming, conventional, fixed-rate, prime mortgages. In addition, we explore the implications of models developed by various industry practitioners. We find that the 15 percent asset-correlation assumption implicit in the proposed Basel II rule falls within the range of estimates generated by these models.

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* The revision, which is minor, is explained in table 1.

I. Introduction

Banks, thrift institutions, and bank holding companies in the United States must maintain a minimum leverage ratio and two minimum risk-based ratios.[1] The current U.S. risk-based capital requirements are based on the 1988 Basel Capital Accord, an international regulatory framework for capital measurement developed by the Basel Committee on Banking Supervision. The Basel Committee has been working for several years to develop a new regulatory capital framework that recognizes developments in financial markets and risk management practices that have emerged since the 1988 accord. On April 29, 2003, the Basel Committee released for public comment "The New Basel Capital Accord," the third in a series of consultative papers.[2]

A particularly important and challenging aspect of the New Basel Capital Accord (Basel II) as it applies to the United States is the determination of minimum regulatory capital charges for single-family residential mortgages. First, mortgages on single-family residences (structures with up to four living units) constitute a significant share of the portfolios of the largest U.S. banking organizations.[3] Second, state-of-the-art practices available to evaluate mortgage credit risk employ highly sophisticated multifactor and multiperiod models using vast amounts of data. Codifying such models into relatively simple regulatory rules is quite challenging.

The focus of this paper is the Advanced Internal-Ratings-Based (A-IRB) approach proposed in Basel II for determining minimum regulatory capital charges for single-family residential mortgages. To assist the public in evaluating the Basel II proposal, we summarize empirical work undertaken by Federal Reserve Board staff that has helped shape the proposed Basel II capital function for single-family mortgages--in particular, its 15 percent asset-correlation assumption. We first summarize the A-IRB approach for determining capital charges for single-family residential mortgages and

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[1] The leverage ratio measures regulatory capital as a percentage of total on-balance-sheet assets as reported in accordance with generally accepted accounting principles (GAAP) (with certain adjustments). The risk-based ratios measure regulatory capital as a percentage of both on- and off-balance-sheet credit exposures with some gross differentiation based on perceived credit risk.

[2] The paper is available at www.bis.org/bcbs/bcbscp3.htm.

[3] At the end of 2003:Q1, the ten largest U.S. commercial banks held $500 billion, or 15.7 percent of their total assets, in such loans. In addition, according to Call Report data, we estimate that these banks held an additional $356 billion in securities backed by such loans (11.1 percent of total assets).

illustrate its use for various types of mortgages. Next we review estimates of economic capital produced by several credit risk models for residential mortgages. Last, we translate these economic capital allocations into implied asset-correlation parameters; we find these parameters to be broadly consistent with the 15 percent correlation assumption embodied in the Basel II proposal.

II. Summary of the Basel A-IRB Rule for Single-Family Residential Mortgages

A broad purpose of the IRB approach is to improve the alignment between the minimum regulatory capital requirements for specific bank investments to the economic capital for the credit risk associated with these investments. Broadly speaking, economic, or "value-at-risk" capital quantifies the expected reduction in the value of an investment due to a severe economic event. A typical and more specific definition is that economic capital is coverage for unexpected losses, where unexpected losses are the amount of losses in a severe or "tail" event less expected losses. The specified tail percentile defining the A-IRB standard does not necessarily coincide with the standard used for internal economic capital calculations by any particular banking institution. Indeed, it is expected that the internal economic capital allocations of well-managed banks will be based upon a more stringent loss-coverage target than that which underlies the A-IRB rule. As such, economic capital charges will generally exceed regulatory capital requirements.

The better alignment between regulatory and economic measures of capital is brought about by transforming credit-risk parameters specific to a particular investment into a regulatory capital charge. For an individual mortgage loan, these risk parameters are the exposure at default (EAD), probability of default (PD), loss given default (LGD), and asset correlation (ρ). In general, the EAD for a mortgage equals the outstanding loan balance. Both PD and LGD would be provided by the bank by "risk segment" subject to standards set forth in Basel II.[4] The Basel Committee has specified that ρ be set equal to 0.15 (or 15 percent) for mortgages on single-family (one- to four-unit) residences.

[4] Risk segment refers to a particular loan category distinguished by degree of risk and risk characteristics. For example, a portfolio may be divided into various segments distinguished by borrower credit history and the LTV ratio of the loan.

Given values of the above parameters, the minimum total regulatory capital requirement (k) for a residential mortgage under Basel II would be calculated (in dollars) as

$$k = \Phi\left(\frac{\Phi^{-1}(PD)+\sqrt{\rho}\,\Phi^{-1}(C)}{\sqrt{1-\rho}}\right) * LGD * EAD \qquad (1)$$

where Φ is the standard normal distribution function; Φ^{-1} is its inverse; and C is the confidence interval, which has been set by Basel II at 0.999. The risk weight for any asset is defined as the amount of regulatory capital expressed as a fraction of 8 percent.[5]

Under Basel II, the internal systems, models, and processes of banks would generate the values of PD and LGD. The proposed standards in Basel II will permit flexibility in how PD estimates may be developed, although the intent is to measure PD as the annualized average probability of default over a mortgage's expected remaining life. LGD would be measured as the expected loss severity in a period of high default rates for residential mortgages. That is, the LGD input is to represent something akin to a "recession LGD."

The Basel II A-IRB proposal does not explicitly address the question of private mortgage insurance (PMI), a form of credit-risk mitigation for residential mortgages, nor more complex insurance arrangements such as captive reinsurance, which is used by some large banks. One possibility consistent with the proposed framework is to incorporate reimbursement from PMI claims into the LGD calculation. Alternatively, PMI could be treated as a "guarantee" and be assigned a risk weight applicable to the guarantor for the guaranteed portion of the loan. Since the purpose of the present document is to review the research underlying the proposed Basel II risk-weight formula for single-family residential mortgages, attention is restricted to results pertaining to loans not covered by PMI. We note, however, that the recent Advance Notice of Proposed Rulemaking solicits comments on the question of appropriate treatment of PMI and on related issues such as the counterparty risk embodied in such insurance.

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[5] That is, $RW = 1250 \times (k/EAD)$.

Illustrative Calculations

Information quantifying PDs and recession LGDs by risk segment is not easily obtained because it is generally proprietary. We present three sets of illustrative calculations based upon information assembled from various nonproprietary sources:

1. PD estimates for newly originated loans are based on a credit risk model for residential mortgages developed by Federal Reserve Board staff (the "FRB model"), which is discussed in detail below. These estimates all pertain to prime, conventional, first-lien, fixed-rate, thirty-year mortgages.
2. PD estimates are derived from information published in a recent study of the market for jumbo prime and alt-A residential-mortgage-backed securities (RMBS).[6] The study reports that cumulative loss rates for pools of jumbo prime and alt-A mortgages originated between 1993 and 1997 are equal to 0.20 percent and 0.35 percent respectively.[7] From these data, we have constructed implied PD estimates by dividing the loss rate for each product by 5 (average life), and again by its estimated average loss given default.[8]
3. PD estimates are based upon a highly stylized, hypothetical, and highly seasoned portfolio of prime loans that enjoyed the benefits of appreciation in the price of the properties securing the loans. We choose a low PD of 0.19 percent, which is highly plausible for a portfolio with an average current loan-to-value (LTV) ratio of 60 percent or so and FICO scores averaging well above 700.

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[6] See Laurent Gauthier, "Market-Implied Losses and Non-Agency Subordinated MBS," *Journal of Fixed Income*, vol. 13 (2003), no. 1, pp. 49–74. *Jumbo prime* refers to a loan for which the borrower's credit score (or FICO score) indicates very low credit risk and the size of which is too large to qualify for purchase by Fannie Mae and Freddie Mac. *Alt-A* refers to a loan for which the borrower's credit score either is marginally below that for prime borrowers or is in the prime range but is accompanied by issues requiring special attention when underwriting (such as lack of income documentation or non-owner occupancy). Both jumbo prime and alt-A loan types constitute a sizable and growing segment of the RMBS market; $145 billion of the jumbo prime RMBS and $55 billion of the Alt-A products were issued in 2002.

[7] Only data pertaining to thirty-year mortgages are used. The pools mostly consist of fixed-rate loans that were newly originated when the pools were formed.

[8] The rates for average loss given default were selected, after discussions with Laurent Gauthier, to be 0.15 for jumbo prime loans and 0.25 for alt-A loans.

As noted above, use of the Basel II capital formula requires that a recession LGD be estimated for each risk segment (table 1). Most recession LGDs are estimated by simulating the loss severity function in the FRB model over historical periods of high mortgage default rates. These estimates apply to a loan that is not covered by private mortgage insurance (PMI). More details about the procedure for deriving these LGD estimates are provided in the appendix. The only exceptions to this approach pertain to the estimates of LGD for the jumbo prime loans, the alt-A loans, and the hypothetical seasoned portfolios. In the absence of a model for these data, the specific estimates represent plausible approximations to the LGDs appropriate for these three loan groups (table 1, column 2).

In conformance with the goal of creating a more risk-sensitive regulatory capital framework, the Basel II capital charges and their associated risk weights vary widely among risk segments. Recall that Basel I fixes the risk weight at a constant 50 percent for qualifying residential mortgages. The Basel II risk weights range from 3 percent (for a loan with a FICO score of 740 and LTV ratio of 70 percent) to 62 percent (for a loan with FICO of 620 and LTV ratio of 95 percent). The risk weights for prime jumbo and alt-A loans are in the middle of that range, at 13 percent and 19 percent respectively. The last line of table 1 applies the Basel II rule to the average statistics for a hypothetical portfolio of single-family, geographically diversified, seasoned, prime loans with low current LTV ratios and is provided to highlight the outcome of the Basel II rule for a highly seasoned portfolio of prime mortgages. The risk weight for this seasoned portfolio evaluated at mean values is 10 percent.[9]

These risk weights can be used to define the amount of additional regulatory capital required to put a qualifying residential mortgage of each type on the balance sheet. The amount of additional Tier 1 capital (common stock and preferred stock) required for such mortgages must exceed 4 percent of the risk-weighted mortgage assets. The amount of total capital, which is defined under both Basel I and Basel II as the sum of Tier 1 capital (common stock and preferred stock) and Tier 2 capital (subordinated

[9] A more accurate estimate would evaluate capital at the loan level or for larger numbers of loan buckets. Also, note that this amount of capital pertains to a nationally diversified portfolio of high-quality, seasoned loans.

debt and loss reserves), must exceed 8 percent of risk-weighted assets. Thus, for instance, the additional amount of regulatory Tier 1 capital for a mortgage is its risk weight times 4 percent of the loan balance. For example, the marginal Tier 1 regulatory capital for a mortgage with a risk weight of 25 percent equals 100 basis points, that is, 0.25 *0.04 = 0.01 = 100 basis points.

This logic leads to the final column of table 1, which shows the additional amount of Tier 1 regulatory capital in basis points needed to finance an additional dollar of exposure in a single-family residential mortgage of each type. The required amount of total capital can be obtained simply by doubling the Tier 1 amount shown in the table. The Tier 1 estimates range from 12 basis points to 248 basis points for the newly originated loans. The pool of jumbo prime loans would require 53 basis points of Tier 1 capital and the alt-A pool would require 77 basis points. The hypothetical seasoned prime pool would require Tier 1 capital of 40 basis points.

III. Evidence Regarding Economic Capital for Residential Mortgages

As noted above, the Basel II proposal sets capital charges for residential mortgages on the basis of four parameters: the bank-determined inputs PD, LGD, and EAD; and the supervisory-determined asset-correlation parameter.[10]

Because of its importance in Basel II and because state-of-the-art models of mortgage capital do not usually contain an explicit asset-correlation parameter, we offer an intuitive explanation of what the term does and does not represent. Literally interpreted, the rule assumes that year-to-year variation in default rates for a portfolio of residential mortgages (or the portfolio of all assets) is driven by changes in a single, underlying risk factor during the same time period. This commonality of response is captured by the asset-correlation parameter in a formal "regulatory" credit-risk model. A strict linkage between the asset-correlation parameter and one or more economic variables is not specified in Basel II. Neither is it presumed that the one-factor model is a

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[10] A rigorous derivation and explanation of the asset-correlation parameter in the context of the Basel II rule is contained in Michael B. Gordy, "A Risk-Factor Model Foundation for Ratings Based Bank Capital Rules," *Journal of Financial Intermediation*, vol. 12 (2003), pp. 199–233.

complete characterization of the default risk embedded in a particular exposure. Rather, it is an approximation whose accuracy may vary among exposures and over time.

In particular, the Basel II capital formula for residential mortgages is simpler than state-of-the-art models of mortgage portfolio credit risk.[11] These models view default and prepayment as competing risks that play out over a number of years. National and local market movements in house prices, interest rates, and a host of other borrower-specific and mortgage-specific characteristics, especially the borrower's initial equity investment and credit score, have been shown to significantly influence mortgage default and prepayment probabilities.[12]

In order to assess what might be reasonable asset-correlation assumptions for use in the Basel II rule, Federal Reserve Board staff has employed several state-of-the-art credit-risk models for mortgages. Estimates of asset correlations were developed through a two-step process. First, economic capital allocations for single-family mortgages were generated using these models of mortgage credit risk calibrated with industry data. Second, an asset-correlation parameter was "reverse engineered" to match as closely as possible the capital charges implied by the Basel II formula with the economic capital allocations derived in the first step.

Applying this two-step procedure raises a number of challenges. One, for instance, is calibrating sophisticated models of mortgage portfolio credit risk in the absence of loan-level mortgage performance databases directly available to Federal Reserve Board staff. Thus, indirect methods of calibration had to be used. Another challenge is to translate the economic capital results from various multiperiod, multifactor models into the asset-correlation parameter, ρ. Selection of the value for ρ poses an especially challenging assignment because no single value will ensure an exact match across the full, relevant range of PD and LGD inputs between the results of the Basel II rule and the economic capital allocations implied by various models.

The remainder of this section focuses on evidence pertaining to economic capital for residential mortgages. The section is divided into two parts. The first part reviews the

[11] This is also true for other asset categories in Basel II.

FRB credit model for residential mortgages along with estimates of economic capital produced by this model. The second part summarizes estimates of economic capital implied by other modeling approaches. In section IV, we describe the reverse-engineering of asset correlations from these estimates of economic capital.

The FRB Credit Model

The FRB credit model for residential mortgages consists of three main components: (1) behavioral equations that determine prepayment and foreclosure probabilities for thirty-year, fixed-rate mortgages as functions of changes in house prices and interest rates; (2) a loss-given-foreclosure (LGF) equation; and (3) a simulation algorithm that calculates the probability distribution of cumulative discounted losses on the basis of simulated paths for interest rates and house prices for a specified period.[13]

The model generates a probability distribution of the present value of cumulative credit losses over a given multiyear period for specified risk segments within a large portfolio of newly originated and seasoned mortgage loans. It is assumed that no single loan accounts for more than a negligible proportion of the overall portfolio. Ex ante risk characteristics of a segment include a specified initial loan-to-value ratio and borrower FICO score, as well as a distribution of loan sizes. Economic capital--or credit value-at-risk--for the risk segment equals the credit loss associated with a selected tail-percentile of the simulated credit loss distribution less the expected loss.

The model's behavioral equations were adapted from the Loan Performance Risk Model, developed by the Loan Performance Corporation (LP). The original behavioral equations in the LP model were estimated on the basis of a comprehensive database for residential mortgages that LP has compiled from the portfolios of the largest mortgage originators and investors in the country. The database includes 70 percent to 80 percent of outstanding single-family residential mortgage debt, according to LP representatives.

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[12] A recent example with a full set of references is Charles A. Calhoun and Yongheng Deng, "A Dynamic Analysis of Fixed- and Adjustable-Rate Mortgage Terminations," *Journal of Real Estate Finance and Economics*, vol. 24 (2002), pp. 9–33.

[13] The following summary of the FRB credit model is largely drawn from Paul S. Calem and Michael LaCour-Little, "Risk-Based Capital Requirements for Mortgage Loans," *Journal of Banking and Finance* (forthcoming). The article is available at www.sciencedirect.com/science/journal/03784266. Those interested in receiving a copy may also contact the authors directly.

The key determinants of default and prepayment in these equations are those used in most industry-standard models of this type. These include: (1) a measure of the incentive to refinance (coupon rate relative to current market rate); (2) the amount of equity available to the borrower (current LTV); (3) the age of the mortgage; (4) the borrower's FICO score; and (5) miscellaneous borrower-specific and mortgage-specific characteristics, such as loan size.

The data used to estimate these equations are proprietary and were not available to Federal Reserve Board staff. However, various summary statistics together with documentation of the steps taken by LP to prepare the data for estimation were provided to us on a confidential basis. We reviewed this information and conducted simulation exercises to assess the reasonableness of the behavioral equations provided by LP. Importantly, the data do not incorporate subprime mortgage pools or loans that are explicitly identified as subprime, although a wide range of borrower FICO scores are found in the data.

The LP transition model was not used directly within the FRB model. Rather, the FRB model incorporates approximations to the LP equations. The most common approach taken in the literature to modeling mortgage prepayments and foreclosures focuses upon three types of transitions for a loan that is current (but could be delinquent): (1) continue as current; (2) prepay; and (3) proceed to a terminal default state, a stage that includes foreclosure completion, deed in lieu of foreclosure, and short sale, all of which we will henceforth refer to collectively as *foreclosure completion*.[14] In contrast, the LP model includes not only the three terminal default states, but also an intermediate default state--"foreclosure initiation"--as well as earlier stages of delinquency (sixty days past due, sixty to ninety days past due, etc.). That is, the LP framework incorporates a multidimensional "roll-rate" structure in which a loan in a particular stage of delinquency can return to an earlier stage (or to being current) or can proceed to a more severe delinquency state culminating with entry into a foreclosure or an alternative-to-foreclosure process. To facilitate implementation of the FRB model and to mitigate

[14] In a short sale, a lender agrees to the sale of collateral still owned by the borrower for less than the loan amount outstanding and to accept sale proceeds, sometimes accompanied by an unsecured note in the amount of any deficiency, in satisfaction of the debt.

potential concerns regarding the effects of model complexity on the precision of the estimated parameters, we employed statistically and judgmentally based smoothing techniques to reduce the dimensionality of the state transition matrix when implementing the LP model's behavioral equations.

The final FRB model incorporates a hybrid specification that includes a single intermediate default state. The model posits five possible states for a mortgage: (1) current (but possibly delinquent); (2) full repayment (or prepayment); (3) delinquent for at least ninety days; (4) initiation of foreclosure; and (5) foreclosure completion. The probability of transitioning from any one state to another is modeled as a parametric survival function, except that full repayment and foreclosure completion are defined as terminal states from which the probability of exit was set to zero. Judgmentally, it is assumed that short sales comprise 10 percent of total short sales and foreclosure completions.[15]

Loss Given Foreclosure (LGF)

The LGF function in the FRB model is consistent with commonly employed representations of loss severity for residential mortgages, such as that underpinning the capital requirements of the Office of Federal Housing Enterprise Oversight (OFHEO) for Fannie Mae and Freddie Mac. Within the FRB model, LGF = FE + INT – NR, where FE refers to foreclosure expenses (such as sales commissions, legal costs, taxes and maintenance costs); INT refers to lost interest income at the time of foreclosure; and NR is net recovery proceeds, which is typically negative and equals gross proceeds from foreclosure less the outstanding principal balance at the time of foreclosure completion.[16]

The FRB model assumes foreclosure expenses equal to 10 percent of the mortgage balance. Unpaid interest is calculated on the basis of interest rates generated

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[15] In Calem and LaCour-Little (previously referenced), a fixed, 10 percent probability of reinstatement was assumed. This assumption was subsequently refined in the version of the model underlying the present paper, in which the probability of reinstatement was allowed to depend on the current LTV ratio and was calibrated on the basis of information provided by Mortgage Insurance Companies of America (MICA). This distinction accounts for the differences between the economic capital estimates shown in table 2 and those reported in Calem and LaCour-Little.

[16] A reduction for mortgage insurance claims (MI) would normally be included as well, but it is omitted from our definition because only loans without MI are included in this analysis.

during the simulation procedure.[17] Net recoveries are based on a regression equation relating historical net recovery to loan characteristics and housing market conditions, which was developed using an OFHEO database.[18] As is consistent with the findings of other researchers, the estimated net recovery equation implies that LGF is an increasing function of the current LTV ratio of the mortgage.[19]

Simulation Algorithm

The model yields a probability distribution of cumulative foreclosure rates and cumulative credit loss rates for a pool of thirty-year, fixed-rate mortgages over a specified period. The simulation period was set at ten years for most exercises.[20] As already noted, a pool or segment is defined in terms of its *initial* risk characteristics: specifically, initial LTV ratio and FICO score, initial loan sizes, and remaining maturity. Given the behavioral equations and the LGF function, the probability distributions are estimated through a Monte Carlo procedure in which the basic risk drivers are simulated paths for house prices and interest rates.

Rather than positing dynamic equations for interest rate and house price processes, as is often done in the literature, the FRB model's simulation algorithm draws 15,000 simulated paths for house prices and interest rates from historical data. Each of the 15,000 simulations is termed a "trial." Scenarios for these two variables are generated from the 76-quarter period 1982:Q1 through 2000:Q4. Each trial begins with a random selection of a quarter from the period 1982-91, a selection called the "starting quarter." The simulated path of interest rates is then set to that reported in Freddie Mac's quarterly interest rate survey over the ten-year span beginning with the starting quarter.

The simulation of house price paths is more complex because it seeks to preserve regional correlation in the movements of house prices among metropolitan statistical areas (MSAs). Within a given trial, each loan in the portfolio is assigned randomly to one

[17] A rate that measures the short-run cost of funds is used for both discounting and measuring lost interest.
[18] The exact specification and results are in table 3 of Calem and LaCour-Little (previously referenced).
[19] See, for example, Anthony Pennington-Cross, "Subprime and Prime Mortgages: Loss Distributions," OFHEO Working Paper 03-01 (Office of Federal Housing Enterprise Oversight, 2003).
[20] The selected period is ten years or less. A smaller number is used if capital is higher than at the ten-year horizon. For this reason, periods shorter than ten years were used for riskier loans. Calem and LaCour-Little (forthcoming) provide more detail on this point.

of nine Census regions and then to an MSA selected to be consistent with the assumed degree of regional concentration, which is either "regionally concentrated" or "nationally diversified." For expository purposes, the MSA to which the loan is assigned during the trial is termed the "designated MSA." The path for house price appreciation for a given trial and individual loan is set equal to that implied by the OFHEO house price index for the designated MSA for the period beginning with the starting quarter and ending ten years later.

The calculations are conducted using pools of 500 loans with a geographic distribution matching the distribution of either the nationally diversified or regionally concentrated portfolios. Given the draw of interest rate and house price paths for a trial and this interpretation, an expected cumulative rate of foreclosure completion and an expected cumulative discounted loss rate for the pool are computed using the empirical transition probabilities and loss-given-foreclosure relationship. Specifically, the expected cumulative default rate given a particular scenario is the sum of the predicted default rates for each of the 500 loans in the pool. The predicted default rates are simply the behavioral equations that define default evaluated at the particular scenario. Similarly, the expected cumulative loss rate given a particular scenario is the weighted-average loss rate for all 500 loans, where the weights are the predicted default rates for each loan. Upon replicating this procedure for all 15,000 trials, the full probability distributions of cumulative foreclosure rates and cumulative discounted losses are generated for the simulation horizon. Each point in the foreclosure or loss rate distribution corresponds to an expected cumulative foreclosure or, respectively, a loss rate given the draw of house prices and interest rates within the trial.

Because the calculated loss distributions are derived from calculations of conditional expected values, they do not incorporate small-portfolio idiosyncratic risk and, hence, are applicable to a very large portfolio of loans. The use of a small pool of loans for the calculations is merely a technical convenience. Given the assumption that no single loan represents more than a negligible proportion of the overall portfolio containing the pool, the calculations as well as the interpretation of them as conditional expected values are appropriate.

A variety of statistics from these distributions can be computed, but the critical ones for the purpose of estimating the implied asset-correlation parameter are the cumulative foreclosure rates and loss rates associated with a specified tail percentile. As discussed earlier, economic capital--or credit value-at-risk--equals the credit loss associated with the selected tail percentile of the simulated credit loss distribution less the expected loss. Under Basel II, a 99.9 percentile criterion is designated for calculating value-at-risk capital for a loan with one-year maturity. No criteria are specified for use with multiyear, cumulative loss distributions. A 99.9 percentile criterion corresponds roughly to the midpoint between A-minus and BBB-plus loss-coverage targets for a one-year period (one-year insolvency probabilities for A-minus and BBB-plus bonds); hence, we use an analogous criterion to select the tail percentile for calculating credit value at risk for a multiyear period when applying the FRB model. Specifically, for instance, a 98th percentile criterion was applied in the case of a ten-year cumulative loss distribution, a choice corresponding to the midpoint between A-minus and BBB-plus ten-year cumulative loss-coverage targets.

Implied Estimates of Economic Capital

The FRB model generated the economic capital allocations associated with the selected loss-coverage target (between A-minus and BBB-plus) for various FICO scores and original LTV categories (table 2). We show results for two alternative specifications of the degree of geographic diversification. The nationally diversified portfolio, which represents the relevant benchmark for the Basel II rule, is calibrated in a way that distributes the loans broadly among all regions of the country (with 40 percent of the portfolio in the two regions with the largest concentration). For comparison, we also generate results for a regionally concentrated portfolio, in which loans are distributed equally among twelve MSAs within a single Census region. The loan-size distribution for each of these calculations was calibrated using Home Mortgage Disclosure Act data to reflect a typical large portfolio of conforming-size mortgages.[21] Also shown are

[21] See Calem and LaCour-Little (forthcoming) for further details.

annualized default (180-day delinquency) probabilities, which are employed below to reverse-engineer the implied asset correlations and estimates of recession LGD.[22]

The results (table 2, column 3) indicate that the economic capital levels for newly originated thirty-year fixed-rate mortgages in a nationally diversified portfolio range from less than 20 basis points (LTV ratio = 70 percent, FICO = 740) to 396 basis points (LTV ratio = 95 percent, FICO = 620). These results are consistent with widely held views about the nature of mortgage credit risk. Namely, portfolio credit risk increases with the initial LTV ratio and decreases with FICO.

Another key finding pertains to the benefits of a nationally diversified portfolio. The benefits of national diversification in the FRB model are measured as the ratio of capital for a nationally diversified portfolio to that for a regionally concentrated portfolio (table 2, column 3 divided by column 2). The ratios range between 41 percent and 63 percent, which suggests that the credit risk for nationally diversified portfolios is substantially less than that for a portfolio limited to a single Census region.

We now summarize a number of comparisons conducted to benchmark the economic capital estimates produced by the FRB model. Each comparison has its own set of strengths and weaknesses. On balance, they suggest that the FRB model results are plausible and are likely to be within the range of estimates generated by other state-of-the-art models.

Study by Mortgage Insurance Companies of America

In collaboration with Federal Reserve Board staff, members of the Mortgage Insurance Companies of America (MICA) carried out exercises to recalibrate the FRB model's behavioral equations using their internal data (table 3). The participating companies collectively account for 85 percent of the insured loans outstanding in the United States. This benchmark is thought to be particularly valuable in the estimation of

[22] The PD and LGD estimates shown in the table are used in reverse-engineering the asset correlation from the economic capital figures. The method for determining PD is discussed in section IV, and the procedure for estimating LGD is described in the appendix.

economic capital for residential mortgages with LTV ratios in excess of 80 percent, which is the general domain of mortgage insurance companies.[23]

Much effort was made to make the results of the MICA exercise as comparable as possible to those from the FRB model.[24] One difference that cannot be readily quantified concerns the definition of the terminal default state. The MICA study defines the terminal default state as a "claim event," meaning a claim for reimbursement filed with the insurer. Although a claim event usually corresponds to a foreclosure completion, no solid estimates of the relationship between these two variables are available. The MICA study assumes that foreclosure completion and claim event are comparable, and it equates loss given a claim event to loss given foreclosure. We suspect that losses associated with claim events may often be less than those associated with completed foreclosures because claim events include workouts or other events involving relatively minor losses. This difference would tend to produce higher estimates of economic capital and higher estimates of the asset-correlation parameter. The bias, however, could go the other way to the extent that foreclosures resulting in zero loss are not reported as claim events. Note that the MICA estimates (table 3) are higher than the FRB model estimates (table 2) for both the nationally diversified and regionally concentrated portfolios. The MICA estimates of economic capital are roughly 50 percent higher in each corresponding LTV and FICO category than the FRB estimates. The two sets of PD estimates are comparable, and the LGD estimates are identical by design (the MICA exercise employed the same LGF relationship as the FRB model). Hence, the MICA behavioral equations for default prediction appear to exhibit greater sensitivity to large house price

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[23] Nearly all of the loans in the databases have original LTV ratios of 85 percent or higher because lenders generally require PMI only for high-LTV-ratio loans.

[24] Because the PMI companies' data do not indicate whether and when a loan becomes delinquent, but only the timing of prepayments and claim events, it was necessary to adapt the FRB model by eliminating the intermediate default state from the transition matrix. Thus, the model was amended to incorporate only three possible transitions given a loan surviving to a given quarter: a claim event; prepayment; or continued survival. To calibrate the conditional transition probabilities, each participating company independently estimated piecewise exponential survival equations for a claim event and prepayment. For consistency with the original FRB analysis, attention was restricted to fixed-rate, conforming-size loans. After completing the calibration process, each of the participating companies independently ran the simulation procedure**.** The numbers in the table reflect the average values, although results based upon the median values are very similar.

declines than the FRB credit model, and, as is discussed below, the MICA results also imply higher asset correlations.

Large Financial Institution (LFI)

A second benchmark consisted of results from the portfolio credit risk model of a large financial institution (LFI) that wishes to remain anonymous. This model combines empirical transition models of mortgage default and prepayment with simulation of risk-factor scenarios based on dynamic equations for interest rate and house price processes. By making certain adjustments, we converted the ten-year, nondiscounted, expected-loss estimates and selected tail-loss estimates provided by the institution into economic capital estimates comparable to those obtained from the calculations using the FRB and MICA models.[25] As can be seen by comparing columns 2 and 3 of table 4, the LFI model generally produces estimates of required economic capital that are on the order of 50 percent higher than the FRB model (column 2).[26]

Model Developed by Fitch Ratings, Inc.

The last benchmarking exercise is based on a model developed by Fitch Ratings, Inc., for use in rating residential-mortgage-backed securities (RMBSs). The credit enhancement or loss coverage needed for a given RMBS to qualify for a given rating grade is determined by this model as a function of the characteristics of the underlying pool of securitized mortgages.[27] Although the model does not define an expected-loss scenario, we interpret the loss coverage associated with a B-rating as representing a reasonable approximation to expected loss. Higher ratings correspond to loss-coverage

[25] The 98th percentile loss rate was obtained by extrapolation and then multiplied by an appropriate fractional quantity to convert nondiscounted into discounted value-at-risk measures. The fractional multiplier was computed using the FRB model with and without discounting and taking the ratio of the results, and generally was equal to 0.60. In the case of subprime loans (low FICO scores) with high LTV ratios, the multiplier was 0.67, reflecting faster accumulation of losses

[26] Although not shown in the table, the LFI model results also support a much larger benefit to national diversification than the FRB model. Whereas the FRB model suggests multiples of 1.5 to 2.5, the LFI model suggests multiples in excess of 3.

[27] These results were derived from Fitch Ratings, Inc., (Fitch) RMBS Model version 4.0. Fitch is currently using version 5.2, which is based on new empirical data. A comparison of the output from the two versions is under way. The preliminary results appear, on average, to be broadly consistent; however, the

thresholds sufficient for conditions of economic stress, in which the higher the rating, the more extreme the associated stress scenario. For a pool of newly originated, thirty-year, fixed-rate mortgages having a specified LTV ratio and FICO score, economic capital is calculated as the difference between the loss coverage required for a BBB-plus rating and the loss coverage for a B rating, multiplied by an appropriate discount factor (table 4, column 4).[28]

The Fitch model and the FRB model produce broadly comparable estimates of economic capital. However, significant differences emerge within specific bands of FICO scores. Economic capital estimates are higher in the 600 FICO score categories using the Fitch model than those implied by the FRB model, but they are lower in the 720 FICO categories.

IV. Solving for the Asset-Correlation Parameter

Here we summarize how the economic capital results described above have been translated into an estimate of the appropriate asset-correlation parameter, ρ, for residential mortgages. The translation is accomplished by solving for the value of ρ that equates the model-generated amount of economic capital to the amount of regulatory capital generated by the Basel II rule for the same PDs and LGDs.

Reverse-engineering of the implied asset correlations from economic capital allocations is accomplished in three steps. First, an annualized PD is derived from the cumulative foreclosure completion rate generated by the model from which the economic capital allocations were obtained. The annual probability of foreclosure completion is defined as the geometric average of the ten-year cumulative foreclosure completion rate. This result is then transformed to be consistent with the proposed definition of default that would apply to U.S. banks under Basel II, which is 180-days delinquent (or less if foreclosure is completed in less than 180 days).[29] Specifically, PD is set equal to the

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completion of this comparison may show some differences in the required enhancement (economic capital estimates) levels generated by the two models for certain combinations of LTV ratios and FICO scores.

[28] Again, a fractional multiplier of 60 percent (or 67 percent in the case of subprime) is applied to serve as a discount factor to convert undiscounted cumulative losses--the focus of the Fitch approach--to a present-value number.

[29] This is the definition provided in "Risk-Based Capital Guidelines: Implementation of New Basel Capital Accord," August 4, 2003, at www.federalreserve.gov/boarddocs/press/bcreg/2003/20030804/default.htm.

probability of foreclosure divided by 0.75, which implies that 25 percent of the loans that are 180-days delinquent ultimately “cure.”[30]

Next, a “historically based” recession LGF is calculated on the basis of evaluation of the FRB’s LGF function for particular interest rate and house price scenarios. The chosen scenarios represent actual, “historical” interest rate and house price outcomes, as described in the appendix. These are then translated into recession LGDs by multiplying the calculated LGF by 0.75, which is based on the previously noted assumption of a 25 percent cure rate from 180-day delinquency.

In the final step of the process, we compute the asset-correlation parameter that best matches the results of the economic capital model to the output of the Basel II rule for regulatory capital, equation (1). Since the Basel II rule incorporates the one-year expected loss rate (PD times LGD) in its definition of capital, the FRB economic capital results are combined with estimates of the one-year expected loss rate. For any given PD and LGD, this combined quantity is substituted for k on the left side of (1), and then the value of the asset correlation that solves this equation is calculated.

No single value of the asset-correlation parameter will produce absolute equality between the capital model and the Basel II rule across the range of mortgage types considered above, as characterized by different LTV ratios and FICO scores. Rather,

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The document is the Advance Notice of Proposed Rulemaking (ANPR) and contains the proposed application of the Basel II accord for the United States and seeks feedback on a number of issues. According to the ANPR, “All residential mortgages ... would be charged off, or charged down to the value of the property, after a maximum of 180 days past due… In addition, the Agencies are proposing to define a retail default to include the occurrence of any one of the three following events if it occurs prior to the respective 120- or 180-day FFIEC policy trigger: (1) a full or partial charge-off resulting from a significant decline in the credit quality of the exposure; (2) a distressed restructuring or workout involving forbearance and loan modification; or (3) a notification that the obligor has sought or been placed in bankruptcy” (p. 40). Reflecting data limitations, the equations used below and in many empirical studies of mortgage behavior use definitions of default that differ from the Basel II definition. Default in these studies is usually defined as foreclosure initiation, a foreclosure alternative or workout, a mortgage insurance claim event, real estate owned (REO), etc. Ultimately, it is necessary to convert the default probabilities and loss severities implied by these models into PD and LGD inputs on the basis of the ANPR definition of default. The FRB model's methodology for making this conversion is described in the text.

[30] A cure rate of 25 percent is based on Larry Cordell and Jericho Trianna, “Who Pays, Who Stays, and Who Strays,” *Secondary Mortgage Market*, Freddie Mac, December 1999, pp. 8-14.

application of this procedure in the case of the FRB credit model generates a range of estimates of the asset-correlation parameter that vary by risk segment (figure 1). The estimates of the asset-correlation parameter center around 15 percent for the particular risk segments considered. The highest estimate is 16.1 percent and the lowest is 12.2 percent. The lowest values are generally associated with LTV ratios of 70 percent. A nonlinear and humpbacked relationship is apparent, although the differences seem likely to fall within the range of uncertainties associated with our statistical and modeling procedures.

The relationship between the FRB results and the value of the asset-correlation parameters implied by the benchmarks is also consistent with the discussion of economic capital in the previous section. Namely, the MICA results imply higher asset correlations--consistently above 20 percent. They also suggest a modest decline with respect to PD. The results based on the Fitch model are, like the economic capital results, generally consistent with the FRB results. However, they do display a modest positive relationship between PD and the asset-correlation parameter. They are also higher than the FRB results for the loans with LTV ratios of 70 percent.

An independent analysis conducted by the Capital Working Group of the Risk Management Association (RMA) provides a different perspective on the size of the asset-correlation parameter.[31] Its recommendations reflect the results of a survey of practices among members of the group. The group recommends an asset-correlation parameter in the range of 6 percent to 10 percent.[32] Furthermore, a positive relationship between PD and the asset-correlation parameter is suggested by its analysis. We have not fully analyzed the reasons for the differences between the RMA results and those of other models.

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[31] See "Retail Credit Economic Capital Estimation – Best Practices," The Risk Management Association, February 2003, at www.rmahq.org/Basel2/RMA_Retail_Credit_Risk_24feb03_FINAL.pdf.

[32] The RMA report also note that their views are also consistent with an independent research project conducted by David Kaskowitz, Alexander Kipkalov, Kyle Lundstedt, and John Mingo, "Best Practices in Mortgage Default Risk Measurement and Economic Capital," February 1, 2002, at www.loanperformance.com.

Summary

The evidence presented above suggests that an asset correlation with a fixed value of 15 percent is reasonably consistent with the available evidence for U.S. residential mortgages. This value is consistent with the FRB credit model and firmly within the range available from other evidence. This conclusion pertains to the characteristics of the products analyzed by the FRB model--high quality, conventional, first lien, newly originated with thirty-year maturities, fixed interest rates, and loan sizes within the Fannie Mae and Freddie Mac size limits. The results based on the Fitch model represent an additional body of evidence broadly consistent with a value of 15 percent for these types of mortgage products.

As with all empirical research, our analysis has limitations relating to data, statistical procedures, and inclusiveness. For instance, adjustable-rate mortgages and home-equity loans are not examined, and subprime mortgages and mortgages with high expected losses are considered only to the extent that they correspond to borrowers with low FICO scores. Also, the analysis adopted certain technical assumptions in developing the PD and LGD inputs. For example, PD in the FRB model is derived from the long-run cumulative default rates assuming a constant maturity. In practice, banks may use other methods of obtaining annualized default rates.

Table 1: Proposed Basel II Capital for Single-Family Residential Mortgages*

Selected examples of simulated PD, LGD, and Basel II capital by risk segments

LTV / FICO Score	Annualized 10-year Default Rate (PD) (percent) (1)	Loss Generated by Default (Recession LGD) (percent) (2)	Risk Weight (percent) (3)	Marginal Tier 1 Capital Requirement (Basis points) (4)
70 / 620	0.27	16	9	34
70 / 660	0.16	16	6	23
70 / 700	0.10	16	4	16
70 / 740	0.07	16	3	12
80 / 620	0.51	25	21	85
80 / 660	0.31	25	15	59
80 / 700	0.20	25	11	42
80 / 740	0.15	25	8	34
90 / 620	1.00	33	46	182
90 / 660	0.62	33	33	131
90 / 700	0.42	34	25	100
90 / 740	0.30	34	19	77
95 / 620	1.38	36	62	248
95 / 660	0.87	37	46	183
95 / 700	0.58	37	35	138
95 / 740	0.43	37	28	111
Jumbo Prime Pool	0.27	25	13	53
Alt-A Pool	0.28	35	19	77
Seasoned & Diversified Portfolio of Prime Loans	0.19	25	10	40

Source: Calculation by FRB staff.

*Corrected version of the table presented in the October 15, 2003, version of this paper, which erroneously showed average values for LGD in column 2; the correction also affects columns 3 and 4. In the text, these changes required the correction of one number on p.5 (the risk weight for the 95/620 LTV/FICO score) and one number on p. 6 (the capital requirement for that score); none of the changes has had a material affect on the paper.

Table 2: Economic Capital Estimates from the FRB Credit Model

Simulated PD, LGD, and economic capital by LTV and credit score for a newly originated loan without PMI

LTV / FICO Score	Annualized 10-year Default Rate (PD) (percent) (1)	Loss Generated by Default (Recession LGD) (percent) (2)	Economic Capital: Nationally Diversified Portfolio (percent) (3)	Economic Capital: Regionally Concentrated Portfolio (percent) (4)
70 / 620	0.27	16.0	0.58	1.03
70 / 660	0.16	16.0	0.37	0.62
70 / 700	0.10	16.0	0.25	0.41
70 / 740	0.07	16.0	0.19	0.30
80 / 620	0.51	25.0	1.57	2.98
80 / 660	0.31	25.0	1.09	1.98
80 / 700	0.20	25.0	0.79	1.38
80 / 740	0.15	25.0	0.61	1.03
90 / 620	1.00	33.0	3.08	6.94
90 / 660	0.62	33.0	2.37	4.92
90 / 700	0.42	34.0	1.90	3.64
90 / 740	0.30	34.0	1.55	2.80
95 / 620	1.38	36.0	3.96	9.56
95 / 660	0.87	37.0	3.20	7.10
95 / 700	0.58	37.0	2.64	5.42
95 / 740	0.43	37.0	2.23	4.25

Source: Calculations by FRB staff.

Table 3: Economic Capital Estimates from the MICA Study

Simulated PD, LGD, and economic capital by LTV and credit score for a newly originated loan without PMI

LTV / FICO Score	Annualized 10-year Default Rate (PD) (percent) (1)	Loss Generated by Default (Recession LGD) (percent) (2)	Economic Capital: Nationally Diversified Portfolio (percent) (3)	Economic Capital: Regionally Concentrated Portfolio (percent) (4)
90 / 620	0.91	33.0	4.57	9.16
90 / 660	0.60	33.0	3.69	6.78
90 / 700	0.39	34.0	3.03	4.97
90 / 740	0.26	34.0	2.37	3.54
95 / 620	1.35	36.0	6.11	12.98
95 / 660	0.90	37.0	4.95	10.19
95 / 700	0.61	37.0	4.10	7.71
95 / 740	0.41	37.0	3.40	5.73

Source: Results produced by a joint effort of MICA and the FRB staff.

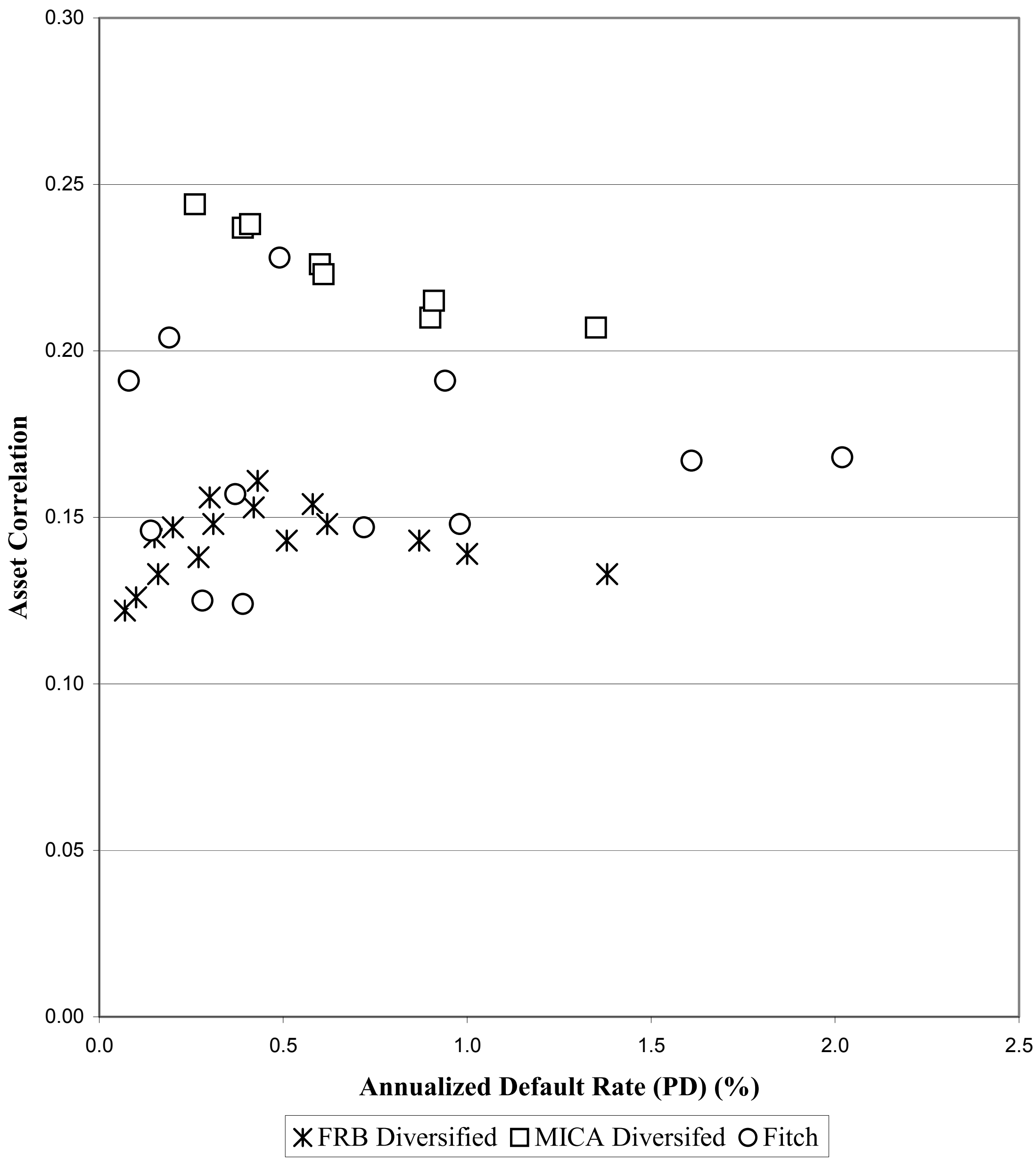
Table 4: Economic Capital Estimates for Nationally Diversified Portfolios

FRB vs. Large Financial Institution vs. Fitch
for a newly originated loan without PMI

LTV / FICO score	FRB Credit Model (percent) (1)	Large Financial Institution Model (percent) (2)	Fitch Model (percent) (3)
70 / 600	0.66	NA	1.00
70 / 660	0.37	NA	0.44
70 / 720	0.20	0.37	0.21
80 / 600	1.78	NA	2.51
80 / 660	1.09	1.68	1.08
80 / 720	0.68	1.00	0.49
90 / 600	3.44	NA	4.75
90 / 660	2.37	NA	2.47
90 / 720	1.72	NA	1.04
95 / 600	4.39	NA	6.13
95 / 660	3.20	NA	3.41
95 / 720	2.41	NA	1.48

Source: Calculations by FRB staff, an anonymous financial institution, and Fitch Ratings, Inc. The Fitch results were derived from Fitch Ratings, Inc. (Fitch) RMBS Model version 4.0. Currently, Fitch is utilizing version 5.2, which is based on new empirical data. A comparison of the modeled output between the two versions is still being completed. The preliminary results appear, on average, to be broadly consistent; however, the completion of this comparison may show some differences in the required enhancement (economic capital estimates) levels generated by the two models at certain LTV / FICO scores.

Figure 1: Implied Asset Correlations
BBB+ Insolvency Standard



Source: Calculations by FRB staff based upon input from MICA and Fitch.

Appendix: Calculation of the Recession LGD

The recession LGD measures in table 2, column 1, correspond to what a regionally diversified institution might calculate as average and stress-period loss severities from historically observed outcomes. These measures are calculated using the state-transition relationships in the FRB model to simulate the performance of historical vintages for an illustrative, geographically diversified portfolio. This is accomplished by suppressing the procedure for randomly generating risk-factor scenarios in the model. That is, loans are assigned regional locations that are held fixed (locations are not reassigned across runs as in the full simulation procedure) while default and loss-rate calculations are conducted for historical vintages defined by origination quarter for origination quarters in 1986 through 1993.

The fourth year after origination is selected to represent the average age of loans that default, and loss-severity measures for loans of this age are then calculated. Expected foreclosure and loss rates in the fourth year subsequent to origination are calculated for each vintage conditional on the historical paths for house prices and interest rates since the origination quarter. The conditional expected loss given foreclosure for each quarterly vintage is then calculated as the conditional expected loss in the fourth year divided by the conditional expected default rate in the fourth year. This value is then multiplied by 0.75 for conversion into a conditional expected LGD, which is averaged over all quarterly vintages to obtain the "historical average LGD." The maximum value over all quarterly vintages of conditional expected LGD is the historically based recession LGD.

The results shown in table 2 indicate that historical stress-period LGDs range from 16 percent to 37 percent for mortgages with an LTV ratio of 70 percent or higher and no PMI. These results, it should be emphasized, depend on the historical house price dynamics in the particular regions to which the loans have been assigned during the period considered, as well as on interest rate levels (which determine the interest carrying charge for a nonpaying mortgage). In particular, the largest loan concentrations (about 50 percent of the regionally diversified portfolio) for these illustrative calculations were assigned to the U.S. Census Bureau's Far West, New England, and Mid-Atlantic divisions, which are areas that experienced housing market weaknesses over much the period from 1988 through 1995.