Alternative Measures of the Cost of Equity Capital for the Federal Reserve Banks' Payments Services:
Technical Supplement to the 2004 PSAF Review

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In this technical supplement, we provide additional information on the methods used to generate alternative measures of the Federal Reserve Banks' cost of equity capital (COE) examined within the context of the 2004 PSAF Review. Specifically, we discuss:

- the construction of a more focused peer group of bank holding companies;
- our ex-ante model selection criteria;
- the various CAPM model specifications we examined and their empirical results; and
- incorporating BHC leverage ratios into the analysis.

I. The refined BHC peer group

For our analysis, we define the sample of comparable firms (or the "peer group") as bank holding companies (BHCs) and thus continue to rely on the so-called "bank holding company model" that has been used historically in the PSAF calculations.[2] Our primary concern was to include in the peer group BHCs actively involved in providing payments services. To that end, the peer group consists of BHCs ranked highly with regard to bank deposits, since deposits can be viewed as a proxy for payment services. We based the peer group on BHCs ranked in the top 50 by total U.S. deposits at year-end 2003 that have been publicly-traded (i.e., their outstanding equity is traded on

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[2] BHCs are identified here using the BHCK9802 variable reported in the quarterly Y-9C supervisory reports. This variable identifies whether a reporting entity is a subsidiary BHC and, if so, whether its BHC parent files a Y-9C report. We are interested only in top-tier BHCs since they are the only entities that typically issue equity and hence provide detailed financial information to the public. In order to select top-tier BHC, firms that report BHCK9802 = "1" or "3" are selected.

an organized stock exchange) for at least five years.[3] As of year-end 2003, 47 of the top 50 BHCs ranked by deposits were publicly traded and were included in our analysis.[4]

This relatively large peer group was further refined by selecting BHCs that are more closely related to the Reserve Banks' payments business with respect to payments activities, capital structure and intended credit rating. This multi-stage application of criteria started with the top 50 BHCs based on deposits and removed those that are not also on the list of top BHCs by due-to balances, which are defined as deposits from other depository institutions and is considered to be a proxy for correspondent banking activities.[5] From that sample, we selected BHCs with a Tier 1 capital ratio within 20 percent of the Reserve Banks' 2003 imputed value of 10.4%.[6] The peer group was further reduced by dropping BHCs without an investment grade rating (i.e., rated below BBB) on their long-term debt. The final peer group contained 20 BHCs, as listed in the appendix.

For our analysis, we used up to five years of data for our regressions.[7] For each peer group BHC, we collected data on:

- their monthly stock returns from CRSP;
- their quarterly payments-related revenues as a share of operating revenues from the Y-9C reports;
- their debt/equity (D/E) ratios, where debt is defined as either total liabilities or total debt, from Compustat and the Y-9C reports; and
- their annual effective tax rates from Compustat.

Note that we adjusted the data to account for BHC mergers when necessary; i.e., if a BHC in our peer group purchased another BHC within our five-year estimation period, we accounted for the merger in all of our calculations. We also collected market data on:

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[3] The definition of deposits used in the exercise is the sum the following four Y-9C variables: BHDM6631 = non-interest bearing deposits in domestic offices, which includes total demand deposits and noninterest-bearing time and savings deposits; BHDM6636 = interest-bearing deposits in domestic offices; BHFN6631= non-interest bearing deposits in foreign offices, Edge and Agreement subsidiaries, and international banking facilities; and BHFN6636= interest bearing deposits in foreign offices, Edge and Agreement subsidiaries, and international banking facilities.

[4] Note that we made exceptions to the filter regarding publicly traded equity for five years to capture three additional BHCs. Specifically, we include HSBC North America, ABN Amro and New York Community Bancorp, even though they started trading in July 1999, August 1999 and November 2000, respectively.

[5] Due-to balances are defined as the sum of total transaction and nontransaction deposits by domestic and foreign depository institutions. The Call Report variables used, as of year-end 2003, were RCONB551, RCONB552, RCON2213, and RCON2236. The individual bank variables were aggregated up to the holding company level.

[6] For BHCs, the Tier 1 capital ratio is the ratio of core capital elements (less goodwill and other intangible assets) to risk-weighted assets with respect to the Basel Capital Accord. The Reserve Banks' ratio of 10.4% in 2003 was determined within the PSAF with respect to their imputed assets and capital.

[7] The choice of five years of data, particularly equity market data is based on our understanding of industry practice; for example, the equity betas calculated by Prof. Aswath Damodoran (http://pages.stern.nyu.edu/~adamodar/) as well as by Standard & Poors (http://www2.standardandpoors.com/spf/xls/index/GICS_500_Scorecard.xls).

- the monthly three-month Treasury bill and 10-year Treasury bond rates from the H.15 schedule provided by the Federal Reserve Board of Governors;[8]
- the monthly market excess return and the one-month risk-free rate provided on Professor Ken French's website;[9] and
- average annual nation-wide interest rates on deposit accounts – specifically, MMDA and NOW accounts – at year-end from the Bank Rate Monitor.

II. Discussion of alternative models and model selection criteria

II. A. Alternative CAPM specifications

For each of the 20 BHCs in our peer group, we calculate their equity betas using the CAPM approach. In our work, we addressed two key model specification questions raised by the Academic Consultants. First, is an additional interest rate factor statistically relevant for our calculations? Second, is the information embedded in the BHCs' payments revenue data statistically relevant for our calculations?

Any asset-pricing model based on the principle of no-arbitrage assumes that the return on the asset is equal to the risk-free rate plus a risk premium to compensate the investor for holding the asset. The benchmark, the single-factor CAPM approach models BHC stock returns as a function of the market risk premium and the asset's sensitivity to this market premium, also known as its beta. The standard single-factor CAPM model for equity returns is typically specified as

$$R_{it} - R_{ft} = \alpha_i + \beta_{Ei}\left(R_{mt} - R_{ft}\right) + \varepsilon_{it},$$

where R_{it} is the BHC monthly stock return; R_{ft} is the risk-free, one-month Treasury bill rate; α_i is a mispricing term; β_{Ei} is the BHC's equity beta that measures the sensitivity of its excess returns to the market equity premium; R_{mt} is the monthly return on the overall market portfolio; and ε_{it} is an error term.

The two-factor CAPM model suggested by the Academic Consultants, which is commonly used for BHCs, includes an interest rate factor. Since banks typically borrow short and lend long, many studies have found that BHC stock returns respond to this additional risk factor. Our two-factor model is specified as:

$$R_{it} - R_{ft} = \alpha_i + \beta_{Ei}\left(R_{mt} - R_{ft}\right) + \beta_{Ri}\left(R_{Lt} - R_{St}\right) + \varepsilon_{it},$$

where R_{Lt} is the constant maturity, ten-year Treasury yield, and R_{St} is the constant maturity, three-month Treasury yield.

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[8] The website is http://www.federalreserve.gov/releases/h15/data.htm.
[9] The website is http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html.

We further extend the benchmark CAPM model to allow for a potential role by BHCs' payments revenues. We specify a four-factor CAPM model that interacts payments related revenue data with the two systemic factors. Note that this larger model nests all the other cases we are interested in, so it is a natural starting point for evaluating the two key specification questions of interest. For each firm, we estimate the regression:

$$R_{it} - R_{ft} = \alpha_i + \left(\beta_{Ei} + \beta_{EPi} PRS_{it}\right)\left(R_{mt} - R_{ft}\right) + \left(\beta_{Ri} + \beta_{RPi} PRS_{it}\right)\left(R_{Lt} - R_{St}\right) + \varepsilon_{it},$$

where PRS_{it} is the BHC's payments revenue share as described below.

If the coefficients on the three additional factors are restricted to be zero, the benchmark CAPM model is recovered. Similarly, if the coefficients related to payments revenue shares are restricted to be zero, the two factor model obtains. However, if the payments revenue share interactions were statistically significant, the sensitivity of the BHC stock returns to the two systematic factors would need to be adjusted.

There are several important empirical issues related to generating the BHC-specific historical time-series of payments-driven revenues for this study. Rice and Stanton (RS, 2003), following on the work of Radecki (1999), present a detailed analysis of BHC payments-driven revenues, which is based on five categories:

- service charges on deposit accounts;
- payments-related credit card revenue;
- ATM fees;
- payments-related trust revenues; and
- foregone interest revenue.

These categories were constructed using variables that generally became available in 2001. To create the five years of historical data necessary for our regressions, we made some strong assumptions, which unfortunately included ignoring ATM fees and payments-related trust revenues due to data limitations

Service charges on deposit accounts and foregone interest revenue can be constructed historically as per the RS study, since all of the required data is available. However, payments-related credit card revenue was proxied for in a different way due to data limitations. Table 1 summarizes some of the relevant information about these different categories, such as their percent of BHC operating revenues, the data availability of their components, and what our course of action was.

For service charges on deposit accounts, we use the Y-9C variable BHCK4483, which is defined as the total amount of service charges on depositor accounts in domestic offices.

With regard to payments-related credit card revenues, we were only able to use the RS definition with regard to on-balance-sheet credit card exposures. For this calculation, the RS study constructs an on-balance-sheet measure of credit card revenues and then assumes that 17% of those revenues are payments-related.[10] This percentage comes from the RS study, which calculates the payments-related fees charged by Master Card and Visa as 17% of issuer revenues in 1999. These fees consist of 14% of revenues due to interchange fees, 2% from annual fees, and 1% from enhancements. This parameter should be stable over time since interchange fees have not changed much over time. For the off-balance-sheet figure, the RS study used data on securitized credit card receivables that are only available starting in 2001.

Table 1. Payments-driven revenue categories from Table 7 of Rice & Stanton (2003)

Payments-driven revenue (PDR) category	**Range of PDR as % of BHC operating revenues**	**Data availability**	**Action**
Service Charges on Deposit Accounts	3.5% - 10.5%	1981 to present	Included in our estimate
Payments-related credit card revenue	<0.1% - 2.7%	On-balance sheet credit card receivables available from 1984 to present; ---------------------------------- Securitized credit card receivables available only from 2001 to present.	Included on-balance sheet credit card receivables in our estimate; -------------------------------------- Not included in our estimate
ATM fees	1.3% - 1.4%	2001 to present	Not included in our estimate
Payments-related trust revenues	<0.1% - 9.2%	2001 to present	Not included in our estimate
Foregone interest revenue	1.6% - 8.5%	1981 to present	Included in our estimate

BHCs receive compensation for their payment services not simply through noninterest income (i.e., explicit fee income). In addition to paying explicit account maintenance and activity fees, depositors compensate BHCs by forgoing interest on their account balances. Customers typically earn little or no interest on deposits in demand, negotiable order of withdrawal (NOW), savings and money market accounts at banks. However, banks benefit by reinvesting these funds in market-rate investments. Radecki (1999) finds this implicit income to be a substantial amount, approximately three times as large as explicit fees collected on these accounts. Following Radecki (1999) and Rice and Stanton (2003), we calculated foregone interest income by assuming that deposits in all accounts earn the bank the federal funds rate. For each type of deposit account, we take the average spread between the federal funds rate and the deposit rate and multiply it by the aggregate balance in each type of deposit account.

[10] The measure of on-balance-sheet credit card revenues we used was on RIAD4054 up to the end of 2000 and RIADB485 from the first quarter of 2001. Both variables consist of all interest, fees, and similar charges levied against or associated with all extensions of credit to individuals for household, family, and other personal expenditures arising from credit cards and related plans in domestic offices, but excluding annual or other periodic fees paid by holders of credit cards issued by the bank.

To measure the foregone interest revenue earned by banks, we calculated the spread between the federal funds rate and average measures of the interest rates paid to depositors. The difference between these rates is the amount of interest that the bank "earns" from depositors' foregone interest. We calculated foregone interest revenue (FIR) as:

$$FIR_{it} = DDA_{it}*f_t + MMDA_{it}*(f_t\text{-}r_{MMDAt}) + NOW_{it}*(f_t - r_{NOWt}),$$

where DDA_{it} denotes a BHC's aggregate balance in demand deposit accounts; f_t is the average federal funds rate in quarter t; $MMDA_{it}$ is a BHC's aggregate deposits in money market accounts; r_{MMDAt} is the national average money market rate for the year; NOW_{it} is a BHC's aggregate deposits in NOW accounts; and r_{NOWt} is the national average NOW money market rate for the year.[11] The deposit rates are national averages for the last week of the year as reported in the Bank Rate Monitor.

The payments-revenue variable used in the RS study was the sum of the various payments revenues divided by operating revenues. For our calculations, quarterly BHC operating revenue is defined as the sum of total noninterest income and total interest income minus total interest expense and provisions for credit losses.[12] Note that foregone interest revenues are not included in the definition of operating revenue, and thus our payments revenue share variable, denoted as PRS_{it}, should be considered a normalized measure of payments revenue and not as a simple percentage.

To estimate our various specifications of the CAPM model, we use both individual BHC regressions and panel data techniques. As noted by Barnes and Hughes (2001), panel data estimation provides more precise parameters by taking account of any information available in cross-sectional data. Individual time-series regressions for each of the 20 peer group BHCs were estimated, and the final conclusions were based on combining the individual results using statistical tools, such as Pearson's p_λ test, or simply by stating that the tests must be rejected in, say, 80% of the cases for there to be an overall rejection of the null hypothesis.[13] Second, a single panel regression with common beta coefficients was estimated so as to take advantage of any cross-equation information that might be present in the system. This would yield CAPM coefficient estimates representative of the BHC peer group, instead of 20 individual betas. We conducted the estimation both ways and compared the outcomes as a robustness test of our final conclusions.

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[11] The variable DDA_{it} is the Y9-C variable BHCB2210. The variable NOW_{it} denotes the balance in "negotiated order of withdraw" accounts as defined by the Y9-C variable BHCB2389. The variable $MMDA_{it}$ is the Y9-C variable BHCB2389.

[12] We use the Y9-C variables BHCK4079, BHCK4107, BHCK4073 and BHCK4230, respectively.

[13] The Pearson p_λ test is used to combine the results of independent tests into an overall rejection (or non-rejection) of the null hypothesis. Suppose there are k cases, and let p_i be the probability in case i of obtaining an estimated coefficient as high as the one obtained if the null hypothesis were true. The p_λ statistic is the sum for all k tests of $-2 \ln(p_i)$, and it has a chi-squared distribution with 2k degrees of freedom.

II.B. Model selection criterion

As in prior PSAF reviews, the 2004 PSAF Review Team set to ex-ante decision criteria for analyzing the empirical questions of interest. Regarding the specification of the CAPM model, there are at least three ways of mounting evidence to answer the above two specification questions within our four-factor CAPM model:

- Model selection criteria, such as the Akaike Information Criteria (AIC) or the Bayes Information Criteria (BIC), can be used since all the models of interest are nested within the four-factor model;
- Hypothesis testing on different combinations of coefficients; and
- Distributional analysis of the fitted values from each of the models.

The first two approaches, which are inter-related, should lead to a conclusion about which model is best from a purely statistical point of view. The third approach would provide a statistical judgment as to whether or not the outcomes from two different models are statistically different from each other; i.e., whether there are any material differences between the outcomes.

The differences in the available criteria suggest that from the onset there is a philosophical choice to make. We either select the best statistical model, regardless of how material its improvement might be, or we select the best statistical model that contributes in a material way relative to a more parsimonious model. In specific terms, the first approach might select, say, the two-factor model if it is the best statistical model, while the third approach might select the one-factor model because the improvement by the two-factor model over the benchmark model is not sufficiently material.

In advance of the following analysis, the 2004 PSAF Review Team agreed that any model selected as best from a statistical point of view must also meet the materiality condition. We required very strong evidence against the benchmark CAPM model to recommend a non-standard alternative. This is consistent with the principle of adhering to industry practice, which currently is to use the single factor CAPM model.

Using just statistical criteria, we would choose the best model using the model selection and hypothesis testing criteria. For the model selection criterion, we estimated the model various times imposing different zero restrictions on the coefficients; see the first column of Table 2. These restrictions correspond to the hypothesis tests described below. For each model of interest, we compute the AIC and BIC statistics, and the best model is the one with the lowest values. In all, seven models were evaluated, including the full four-factor model for which there are no coefficient restrictions.

Table 2 illustrates how the model selection criteria work. If there happens to be a tie between two models, we will let the hypothesis testing approach break the tie. If it is unable to break the tie, we will choose the most parsimonious model. Note that the AIC and BIC statistics effectively embed a comparison of goodness of fit measures, or R^2.

Table 2. Model selection criteria:
Choose the model that optimizes the AIC or BIC statistic.

Model	Statistical Outcome	Action/Conclusion
M1: benchmark CAPM	Calculate AIC_1/BIC_1 associated with this model specification	If AIC_1/BIC_1 is optimal, choose this model, otherwise, do not
M2: $\beta_{EPi} = \beta_{RPi} = 0$	Calculate AIC_2/BIC_2 associated with this model specification	If AIC_2/BIC_2 is optimal, choose this model, otherwise, do not
M3: $\beta_{Ri} = \beta_{RPi} = 0$	Calculate AIC_3/BIC_3 associated with this model specification	If AIC_3/BIC_3 is optimal, choose this model, otherwise, do not
M4: $\beta_{Ri}=0$	Calculate AIC_4/BIC_4 associated with this model specification	If AIC_4/BIC_4 is optimal, choose this model, otherwise, do not
M5: $\beta_{EPi} = 0$	Calculate AIC_5/BIC_5 associated with this model specification	If AIC_5/BIC_5 is optimal, choose this model, otherwise, do not
M6: $\beta_{RPi} = 0$	Calculate AIC_6/BIC_6 associated with this model specification	If AIC_6/BIC_6 is optimal, choose this model, otherwise, do not
M7: Unrestricted, four factor Model	Calculate AIC_7/BIC_7 associated with this model specification	If AIC_7/BIC_7 is optimal, choose this model, otherwise, do not

For the hypothesis testing approach, if the null hypothesis that the coefficient on all factors except the market factor are jointly equal to zero (call this hypothesis H1, which corresponds to M1) can not be rejected, we conclude that the benchmark CAPM model is appropriate. Similarly, if the null hypothesis that the coefficients on the payments-related interaction terms are equal to zero (H2/M2) cannot be rejected, we resort to a model that does not include these terms. If the null hypothesis that the coefficients on the interest rate factors are jointly equal to zero (H3/M3) cannot be rejected, then this information is statistically irrelevant for our purposes. These examples illustrate one way of getting at these issues. We used a 95% confidence interval in our hypothesis testing for each individual BHC. On a peer-group basis, we accept the null hypothesis if, say, 80% of the BHCs' individual tests conclude we should. Table 3 lists the hypothesis tests and what the associated actions and conclusions would be conditional on the test results.

After selecting the best statistical model according to the model selection and hypothesis testing approaches, the output from this candidate model is evaluated for whether its fitted values were materially different to those of the benchmark CAPM model. If the medians or distributions of these fitted values are statistically indistinguishable, the benchmark model is taken to be the best model. This can happen even though the benchmark single factor market model may not be the best model from a standard statistical point of view. Regardless of whether the overarching criterion is to choose the best model or the most parsimonious model that gives the same effective outcome, the above sets of decision criteria should lead to the selection of one model.

Table 3. Hypothesis testing decision criteria

Hypothesis	Test Result	Action/Conclusion
H1: benchmark CAPM	Accept	No further tests/ single factor CAPM appropriate
	Reject	Test H2/ at least one of these additional factors is appropriate
H2: $\beta_{EPi} = \beta_{RPi} = 0$	Accept	Test H4/ payments interaction terms inappropriate
	Reject	Test H3/ at least one of the payments interaction terms is appropriate
H3: $\beta_{Ri} = \beta_{RPi} = 0$	Accept	Test H5/ neither of the interest rate terms is appropriate
	Reject	Test H4, H5 and H6/ at least one of the interest rate or payments factors terms is appropriate
H4: $\beta_{Ri}=0$	Accept	No further tests/ interest rate factor inappropriate
	Reject	No further tests/ interest rate factor appropriate
H5: $\beta_{EPi} = 0$	Accept	No further tests/ interaction between payments revenue and market factor inappropriate
	Reject	No further tests/ interaction between payments revenue and market factor appropriate
H6: $\beta_{RPi} = 0$	Accept	No further tests/ interaction between payments revenue and interest rate factor inappropriate
	Reject	No further tests/ interaction between payments revenue and interest rate factor appropriate

III. Empirical results

III.A. Individual equation results

The results in Table 4 suggest that the model selection criteria applied across the 20 peer group BHCS find the benchmark CAPM model (M1) to be the best fitting model. Frequency distributions of the seven models' rankings across BHCs for both the AIC and the BIC tell a similar, albeit richer, story. The model selected most frequently by the AIC was M3 -- the two factor model with the market factor and the market factor interacted with the PRS data, and the model selected most frequently by the BIC was M2 -- the two-factor model with the market and the interest rate factors. However, M1 remains more appropriate overall since it is chosen within the top two models with the highest frequency and as the worst model with the lowest frequency. To conserve space, we present the frequency distributions only for M1 and M3 in Tables 5 and 6.[14]

Table 4. Model selection criterion

Model	Average AIC	Model ranking according to average AIC	Average BIC	Model ranking according to average BIC
M1: benchmark CAPM	419.60	1	423.79	1
M2: $\beta_{EPi} = \beta_{RPi} = 0$	421.04	7	427.32	2
M3: $\beta_{Ri} = \beta_{RPi} = 0$	420.03	2	428.41	3
M4: $\beta_{Ri} = 0$	420.03	2	428.41	3
M5: $\beta_{EPi} = 0$	420.89	5	429.27	6
M6: $\beta_{RPi} = 0$	420.43	4	428.81	5
M7: Unrestricted, four factor Model	420.99	6	431.46	7
BIC/AIC Model Choice		M1		M1

Table 5.

Panel A. Frequency of M1's rankings across peer group AIC values

Ranking	Frequency	Percent	Cum.
1	7	35	35
2	8	40	75
3	0	0	75
4	1	5	80
5	3	15	95
6	1	5	100
7	0	0	100
Total	20	100	

Panel B: Frequency of M1's ranking across peer group BIC values

Ranking	Frequency	Percent	Cum.
1	17	85	85
2	2	10	95
3	0	0	95
4	0	0	95
5	1	5	100
6	0	0	100
7	0	0	100
Total	20	100	

[14] M3's frequency distributions are provided instead of those for M2 because M3 ranked among the top three models more frequently than M2.

Table 6.
Panel A: Frequency of M3's ranking across peer group AIC values

Ranking	Frequency	Percent	Cum.
1	9	45	45
2	4	20	65
3	3	15	80
4	1	5	85
5	1	5	90
6	2	10	100
7	0	0	100
Total	20	100	

Panel B: Frequency of M3's ranking across peer group BIC values

Ranking	Frequency	Percent	Cum.
1	3	15	15
2	13	65	80
3	4	20	100
4	0	0	100
5	0	0	100
6	0	0	100
7	0	0	100
Total	20	100	

The results of the hypothesis testing using individual likelihood ratio (LR) tests for each of the 20 BHCs overwhelmingly support the null hypothesis that the benchmark model is best. Table 7, Panel A contains these results. Combining all 20 LR tests by forming the Pearson p_λ statistic, the null hypothesis that both PRS-related factors are equal to zero is accepted. Furthermore, since H4 is rejected, the interest rate factor's coefficient can not be restricted to equal zero. This provides some support for M2, as shown in Table 7, Panel B. However, in general, the hypothesis testing approach, which can suffer from the criticism of sequential hypothesis testing bias, does not provide much new information above and beyond that already provided by the model selection criteria in terms of which model should be selected.

Regarding our materiality criteria, distribution analysis suggests that the fitted values from the seven models are not generally statistically different from each other, at least for the models that emerged as statistically superior according to the various model selection criteria. These results are presented in Table 8, Panel A for the medians based on the two-sided sign test and in Panel B for the full distributions based on the Wilcoxon two-sided rank test. M4 and M7 are the only models whose medians are significantly different to that of the benchmark model. However, since these models were not previously strong competitors, their materiality do not change our conclusion in favor of M1.

Comparison of the entire distributions of the predicted values from these models suggests that none of the competing six models are different from the benchmark in a statistically significant way. So, according to our agreed-upon decision criteria, although there is some evidence in support of M2 and M3, the distributional analysis indicates that

Table 7. Hypothesis testing decision criteria
Panel A: Proportion of times that the null hypothesis is accepted or rejected.

Null hypothesis	LR test result: acc./rej. null	Action/Conclusion
H1: benchmark CAPM	**Accept: 95%**	**No further tests/ single factor CAPM appropriate**
	Reject: 5%	Test H2/ at least one of these additional factors is appropriate
H2: $\beta_{EPi} = \beta_{RPi} = 0$	Accept: 90%	Test H4/ payments interaction terms inappropriate
	Reject: 10%	Test H3/ at least one of the payments interaction terms is appropriate
H3: $\beta_{Ri} = \beta_{RPi} = 0$	Accept: 100%	Test H5/ neither of the interest rate terms is appropriate
	Reject: 0%	Test H4, H5 and H6/ at least one of the interest rate or payments factors terms is appropriate
H4: $\beta_{Ri}=0$	Accept: 100%	No further tests/ interest rate factor inappropriate
	Reject: 0%	No further tests/ interest rate factor appropriate
H5: $\beta_{EPi} = 0$	Accept: 85%	No further tests/ interaction between payments revenue and market factor inappropriate
	Reject: 15%	No further tests/ interaction between payments revenue and market factor appropriate
H6: $\beta_{RPi} = 0$	Accept: 95%	No further tests/ interaction between payments revenue and interest rate factor inappropriate
	Reject: 5%	No further tests/ interaction between payments revenue and interest rate factor appropriate

Table 7. Hypothesis testing decision criteria
Panel B: Pearson's p_λ combination of the individual LR tests of the null hypothesis

Null hypothesis	p-values	LR test conclusion	Action/Conclusion
H1: benchmark CAPM	0.017	Accept:	No further tests/ single factor CAPM appropriate
		Reject: x	**Test H2/ at least one of these additional factors is appropriate**
H2: $\beta_{EPi} = \beta_{RPi} = 0$	0.212	Accept: x	**Test H4/ payments interaction terms inappropriate**
		Reject:	Test H3/ at least one of the payments interaction terms is appropriate
H3: $\beta_{Ri} = \beta_{RPi} = 0$	0.000	Accept:	Test H5/ neither of the interest rate terms is appropriate
		Reject: x	**Test H4, H5 and H6/ at least one of the interest rate or payments factors terms is appropriate**
H4: $\beta_{Ri}=0$	0.000	Accept:	Interest rate factor inappropriate
		Reject: x	**Interest rate factor appropriate**
H5: $\beta_{EPi} = 0$	0.014	Accept:	Interaction between payments revenue and market factor inappropriate
		Reject: x	**Interaction between payments revenue and market factor appropriate**
H6: $\beta_{RPi} = 0$	0.001	Accept:	Interaction between payments revenue and interest rate factor inappropriate
		Reject: x	**Interaction between payments revenue and interest rate factor appropriate**

Table 8. Distributional analysis of the model's fitted values
Panel A: Comparison of medians relative to the benchmark model

Hypothesis	p-value of test, reject hypothesis if p-value<=0.05
Median of M1 = median of M2	0.5067
Median of M1 = median of M3	0.4705
Median of M1 = median of M4	0.0193
Median of M1 = median of M5	0.7075
Median of M1 = median of M6	0.2855
Median of M1 = median of M7	0.0141

Panel B: Comparison of distributions relative to the benchmark model

Hypothesis	P-value of test, reject hypothesis if p-value<=0.05
Distribution of M1 = distribution of M2	0.8456
Distribution of M1 = distribution of M3	0.2084
Distribution of M1 = distribution of M4	0.1405
Distribution of M1 = Distribution of M5	0.7205
Distribution of M1 = Distribution of M6	0.3282
Distribution of M1 = Distribution of M7	0.2445

these differences are immaterial, and hence, that we should remain with the benchmark model as the most appropriate choice for our exercise.

III.B. Panel regression results

We use panel regression methods as a robustness check of our conclusion that the benchmark CAPM model is the appropriate choice for our purposes. Since panel methods are not typically used for purposes of calculating COE in industry practice, we are not advocating their usage within the PSAF methodology.

Although we provide model selection results for three different panel regression methods in Table 9, we focus on the results in the middle column that correspond to the random effects (RE) panel regression model. Standard panel regression specification tests indicate that the RE model is the appropriate model for our peer group.[15] Focusing on the results in Panels A and B, the AIC would select M4, and the BIC would choose M3. Using panel methods, M4 would be selected according to the LR hypothesis testing sequence outlined in Panel C. For the RE panel regression model, H1, H2, H3, H5 and H6 were rejected, while H4 was accepted (i.e., the coefficient on the interest rate factor is zero). All of which imply that that all factors, except the interest rate factor, were statistically appropriate, which is consistent with the AIC results.

[15] The other two alternative panel regression models presented in Table 9 are the fixed effects (FE) specification and the random effects with no constant (RENC) specification.

Table 9. Panel regression analysis
Panel A: AIC model selection criterion

Model	AIC for FE	Model Rank	AIC for RE	Model Rank	AIC for RENC	Model Rank
M1: benchmark CAPM	8431.59	7	8437.30	7	8441.65	6
M2: $\beta_{EPi} = \beta_{RPi} = 0$	8430.74	6	8436.46	6	8442.45	7
M3: $\beta_{Ri} = \beta_{RPi} = 0$	8384.49	4	8390.54	4	8390.91	2
M4: $\beta_{Ri} = 0$	8376.78	2	8383.53	1	8392.72	4
M5: $\beta_{EPi} = 0$	8410.80	5	8422.86	5	8435.55	5
M6: $\beta_{RPi} = 0$	8383.82	3	8389.86	3	8392.81	3
M7: Unrestricted, four factor Model	8375.23	1	8383.93	2	8390.72	1
BIC/AIC Decision Criterion Model Choice: Minimize		**M7**		**M4**		**M7**

Panel B: BIC model selection criterion

Model	BIC for FE	Model Rank	BIC for RE	Model Rank	BIC for RENC	Model Rank
M1: benchmark CAPM	8441.77	6	8457.662	6	8456.92	5
M2: $\beta_{EPi} = \beta_{RPi} = 0$	8446.01	7	8461.906	7	8462.81	7
M3: $\beta_{Ri} = \beta_{RPi} = 0$	8399.76	2	8415.987	2	8411.27	1
M4: $\beta_{Ri} = 0$	8397.14	1	8414.071	1	8418.17	2
M5: $\beta_{EPi} = 0$	8431.16	5	8453.397	5	8461.0	6
M6: $\beta_{RPi} = 0$	8404.18	4	8420.404	4	8418.26	3
M7: Unrestricted, four factor Model	8400.68	3	8419.557	3	8421.26	4
BIC/AIC Decision Criterion Model Choice: Minimize		**M4**		**M3**		**M3**

Table 9. Panel regression analysis
Panel C: Hypothesis testing decision criteria

Null hypothesis	Test Result: LR-test P-value FE.	Test Result: LR-test P-value RE	Test Result: LR-test P-value RENC	Action/Conclusion
H1: benchmark CAPM	P-value: 0	P-value: 0	P-value: 0	Accept: No further tests/ single factor CAPM appropriate
Conclusion:	Reject	Reject	Reject	**Reject: Test H2/ at least one of these additional factors is appropriate**
H2: $\beta_{EPi} = \beta_{RPi} = 0$	P-value: 0	P-value: 0	P-value: 0	Accept: Test H4/ payments interaction terms inappropriate
Conclusion:	Reject	Reject	Reject	**Reject: Test H3/ at least one of the payments interaction terms is appropriate**
H3: $\beta_{Ri} = \beta_{RPi} = 0$	P-value: 0.001	P-value: 0.005	P-value: 0.123	Accept: Test H5/ neither of the interest rate terms is appropriate
Conclusion:	Reject	Reject	Accept	**Reject: Test H4, H5 and H6/ at least one of the interest rate or payments factors terms is appropriate**
H4: $\beta_{Ri} = 0$	P-value: 0.059	P-value: 0.205	P-value: 0.045	**Accept: Interest rate factor inappropriate**
Conclusion:	Accept	Accept	Reject	Reject: Interest rate factor appropriate
H5: $\beta_{EPi} = 0$	P-value: 0	P-value: 0	P-value: 0	Accept: Interaction between payments revenue and market factor inappropriate
Conclusion:	Reject	Reject	Reject	**Reject: Interaction between payments revenue and market factor appropriate**
H6: $\beta_{RPi} = 0$	P-value: 0.001	P-value: 0.004	P-value: 0.043	Accept: Interaction between payments revenue and interest rate factor inappropriate
Conclusion:	Reject	Reject	Reject	**Reject: Interaction between payments revenue and interest rate factor appropriate**

Regarding the materiality criteria, the distributional analysis for the panel regressions is illustrated in Table 10. Focusing again on the RE model, the medians of M1 and M3 are insignificantly different from each other, as are their distributions. However, both the medians and the distributions of M1 and M4 are significantly different from each other.

Table 10. Distributional analysis for panel regressions

Panel A: Comparison of medians relative to the benchmark model

Hypothesis	P-value of test, reject hypothesis if p-value<=0.05 FE	P-value of test, reject hypothesis if p-value<=0.05 RE	P-value of test, reject hypothesis if p-value<=0.05 RENC
Median of M1 = median of M2	0.2602	0.2602	
Median of M1 = median of M3	0.2602	0.2602	
Median of M1 = median of M4	0	0	
Median of M1 = median of M5	0.5067	0.4357	
Median of M1 = median of M6	0.002	0.002	
Median of M1 = median of M7	0	0	

Panel B: Comparison of distributions relative to the benchmark model

Hypothesis	P-value of test, reject hypothesis if p-value<=0.05 FE	P-value of test, reject hypothesis if p-value<=0.05 RE	P-value of test, reject hypothesis if p-value<=0.05 RENC
Distribution of M1 = distribution of M2	0.751	0.751	
Distribution of M1 = distribution of M3	0.2429	0.2429	
Distribution of M1 = distribution of M4	0.0356	0.0331	
Distribution of M1 = Distribution of M5	0.3151	0.3145	
Distribution of M1 = Distribution of M6	0.1222	0.122	
Distribution of M1 = Distribution of M7	0.0276	0.0228	

In summary, the individual regression results from all three ex-ante decision criteria favor M1. The panel regression results provide some evidence for M3 and M4. However, we do not change our conclusion that the benchmark model is most appropriate for our analysis. Given that one of the principles of the review is to use standard approaches and that panel methods are not used in industry practice, we conclude that the weight of evidence in support of the alternative models is not sufficient to change our conclusion.

IV. Analyzing the Impact of BHC Leverage on the COE Estimates

IV.A. Analyzing BHC Asset Betas

Based on our analysis so far, we propose to estimate the COE estimate for the Reserve Banks' payments business by estimating 20 separate time-series regressions for the BHCs in our peer group using ordinary least squares estimation.[16] With respect to the benchmark CAPM model, the 20 separate equity betas are aggregated up to a single value using an average; i.e.,

$$\beta_{E,Fed} = \sum_{i=1}^{20} w_i \beta_{Ei}.$$

What weights should be used in our calculations? As discussed by Green et al. (2003), equal weights and weights based on market capitalization (i.e., value weights) are the leading candidates. Those authors argue that value-weighting is more appropriate for CAPM calculations and is more commonly used in practice. Based on discussions with the Review's outside consultants and on the fact that we are proposing to use several criteria in defining the appropriate peer group, the decision was made to proceed with equal weights, but in this technical supplement, we present the results for both weighting schemes.

In addition to suggesting alternative specifications of the CAPM model to examine, the Academic Consultants further suggested an analysis of asset betas. The intuition here is that a firm's capital structure, defined as its reliance on debt relative to equity financing, should have a material impact on the firm's overall riskiness and hence on its beta and COE. In general, increased firm leverage should also raise its equity beta since the shareholder's residual claims in the event of a default have been reduced. As summarized in finance textbooks, firms' equity betas can be adjusted for their balance-sheet leverage as well as tax exposures to generate asset betas as follows:

$$\beta_{Ai} = \beta_{Ei} \left(1 + (1 - \tau_i) \left(\frac{D}{E} \right)_i \right)^{-1},$$

where β_{Ai} is the asset beta for BHC i; β_{Ei} is the equity beta; τ_i is the marginal tax rate; and D_i/E_i is the BHC's book value of the debt to equity ratio. Written as

$$\beta_{Ei} = \beta_{Ai} + \beta_{Ai} (1 - \tau_i) \left(\frac{D}{E} \right)_i,$$

the intuition is clearer in that a BHC's equity beta is its asset beta plus a mark-up for its leverage, adjusted for taxes.

[16] Alternatively, we could create a portfolio of peer group returns and regress this on the excess market return (market risk premium) to obtain a single beta for the entire peer group. This approach was used in Green et al. (2003). We did not pursue the portfolio approach here since we have been working with BHC-specific factors, such as payments revenue share, that preclude this approach.

For our calculations, several empirical questions regarding the D/E ratio need to be addressed. The first question regards the appropriate definition of BHC debt; i.e., should deposits be considered debt? In our analysis, we present results for D/E ratios based on both total liabilities and total debt excluding deposits. The second question regards how the debt and equity are to be valued. We used book values here, since the Reserve Banks do not have direct market values of debt or equity, and we wanted to be consistent in our calculations. However, it might be defensible to use the market value of equity in the individual BHCs' D/E ratios. The third question is what values to use for the Reserve Banks' parameters for these calculations. We decided to use the average of the median annual values for the peer group BHCs over our five year estimation window based on Compustat data. The assumed Reserve Bank D/E ratios were 2.87 when using total debt and 10.64 when using total liabilities, and the assumed Reserve Bank marginal tax rate is 34%.[17]

Since our analysis has recommended using the benchmark CAPM model, we can readily calculate the asset betas as per the above equation. Hence, the Reserve Banks' equity beta based on the peer group's releveraged asset betas is

$$\beta_{RA,FED} = \left(1 + \left(1 - \tau_{FED}\right)\left(\frac{D}{E}\right)_{FED}\right)\sum_{i=1}^{20} w_i \beta_{Ai}.$$

Our discussion of BHC leverage so far has focused on the benchmark, single factor CAPM model. When considering multifactor CAPM models, however, multiple betas must be considered, and conceptual difficulties arise. To our knowledge, the problem of introducing capital structure into such multifactor models has not been resolved in the academic literature or in industry practice. For our analysis of alternative equity betas, we chose to examine just the simple or composite market betas of our alternative model specifications. That is, we ignore the specifications' other beta estimates and analyze just the coefficient on the market factor. These equity betas for the market factor are then deleveraged using the BHC specific parameter values and releveraged using the Reserve Banks' parameter values as per the equation above. While obviously imperfect, the approach permits a comparison across the model specifications, weighting schemes and debt definitions that could be instructive. Table 11 presents the five-year averages for the 42 equity betas of interest; i.e., 7 specifications x 2 weighting schemes x (standard equity beta + two releveraged asset betas based on different definitions of debt) = 42 averages. Table 12 presents the yearly values for the four types of releveraged asset betas for our five-year sample period.

[17] An alternative measure of the Fed's D/E ratio is to use the assumptions in place for other sections of the PSAF calculations. Under those assumptions, the Fed's priced services operations hold 95% debt and 5% equity, which is the minimum amount required to be considered well capitalized under the prompt corrective action guidelines of FDICIA. However, the implied D/E ratio of 19 is in fact in the extreme upper tail of sample distribution. Based upon this discrepancy and discussions with the academic advisors, we settled on the sample's median D/E ratio.

Table 11.
Reserve Bank equity beta comparisons:
Average annual values across CAPM model specifications, weighting schemes, beta types and leverage definitions.

	Equity betas	Equity betas	Releveraged asset betas			
			Total debt		Total liabilities	
Model	**Equally-weighted**	**Value-weighted**	**Equally-weighted**	**Value-weighted**	**Equally-weighted**	**Value-weighted**
M1: benchmark CAPM	0.57	0.82	0.61	0.72	0.60	0.79
M2: $\beta_{EPi} = \beta_{RPi} = 0$	0.58	0.84	0.62	0.73	0.61	0.81
M3: $\beta_{Ri} = \beta_{RPi} = 0$	0.59	0.84	0.63	0.73	0.61	0.79
M4: $\beta_{Ri} = 0$	0.60	0.84	0.64	0.73	0.62	0.80
M5: $\beta_{EPi} = 0$	0.56	0.82	0.60	0.71	0.59	0.79
M6: $\beta_{RPi} = 0$	0.60	0.86	0.64	0.74	0.62	0.81
M7: Unrestricted, four factor model	0.58	0.84	0.62	0.72	0.60	0.79

Note: The value-weighting here is done using the ratio of average BHC market capitalization over the five year sample to the average of all BHC market capitalizations over the sample.

We take as our baseline case the equally-weighted equity beta based on the benchmark CAPM model, which has a value of 0.57. Clearly, moving to value-weighting increases beta, up to 0.82, due to the larger weight placed on the larger, riskier BHCs in our peer group. Looking across the seven model specifications, the baseline case is toward the lower end of the ranges, but the ranges are quite small. For our analysis, the two leverage definitions generated adjusted equity betas that are quite similar. For the equal weighting scheme, the releveraged asset betas are slightly higher than the equity betas across all specifications, while the opposite is true for the value weighting scheme. This result arises due to the fact that the larger BHCs in the peer group have higher D/E ratios than the median value ascribed to the Reserve Banks.

Concerns about variability of the equity beta COE over time were raised by members of the Review. As shown in the panels of Table 12, changes in BHC leverage over time lead to standard deviations that differ across model specifications, weighting schemes and leverage definitions. In general, M1 is among the models with the lowest standard deviations, and M4 tends to be among the models with the highest standard deviations.

Table 12.
Reserve Bank releveraged asset beta comparisons:
Annual values across CAPM model specifications, weighting schemes and leverage definitions.

Panel A. Betas based on equal weights and leverage as total debt

Year	M1	M2	M3	M4	M5	M6	M7
1999	0.66	0.67	0.48	0.52	0.65	0.49	0.51
2000	0.65	0.66	0.32	0.37	0.63	0.33	0.39
2001	0.61	0.62	0.55	0.57	0.59	0.56	0.55
2002	0.58	0.59	0.86	0.84	0.57	0.87	0.79
2003	0.57	0.58	0.93	0.91	0.56	0.94	0.85
Average	0.61	0.62	0.63	0.64	0.60	0.64	0.62
Std. Dev.	0.04	0.04	0.26	0.23	0.04	0.26	0.19

Panel B. Betas based on value weights and leverage as total debt

Year	M1	M2	M3	M4	M5	M6	M7
1999	0.75	0.76	0.63	0.65	0.73	0.64	0.65
2000	0.81	0.82	0.61	0.63	0.80	0.62	0.65
2001	0.75	0.77	0.69	0.71	0.75	0.71	0.70
2002	0.65	0.66	0.84	0.81	0.64	0.84	0.80
2003	0.63	0.64	0.86	0.86	0.62	0.88	0.81
Average	0.72	0.73	0.73	0.73	0.71	0.74	0.72
Std. Dev.	0.07	0.08	0.12	0.10	0.08	0.12	0.08

Panel C. Betas based on equal weights and leverage as total liabilities

Year	M1	M2	M3	M4	M5	M6	M7
1999	0.65	0.67	0.49	0.52	0.64	0.50	0.52
2000	0.69	0.70	0.36	0.41	0.68	0.37	0.43
2001	0.59	0.60	0.53	0.55	0.58	0.54	0.53
2002	0.53	0.54	0.79	0.77	0.53	0.80	0.72
2003	0.54	0.55	0.88	0.86	0.53	0.89	0.80
Average	0.60	0.61	0.61	0.62	0.59	0.62	0.60
Std. Dev.	0.07	0.07	0.22	0.19	0.07	0.22	0.15

Panel D. Betas based on value weights and leverage as total liabilities

Year	M1	M2	M3	M4	M5	M6	M7
1999	0.81	0.82	0.69	0.71	0.80	0.71	0.71
2000	0.98	1.00	0.77	0.79	0.97	0.79	0.81
2001	0.79	0.81	0.73	0.75	0.79	0.75	0.74
2002	0.68	0.69	0.85	0.83	0.68	0.86	0.82
2003	0.68	0.69	0.90	0.90	0.67	0.92	0.85
Average	0.79	0.80	0.79	0.80	0.78	0.80	0.79
Std. Dev.	0.12	0.13	0.09	0.07	0.12	0.08	0.06

IV.B. Analyzing COE Estimates

The analysis in this section so far has been on the equity betas, which are a key input to the final COE estimates, but now we turn our attention to those estimates directly. For the benchmark CAPM model, the COE estimate for a given year is

$$COE_{E,FED} = R_F + \beta_{E,FED} E\left[R_M - R_F\right],$$

where R_F is the one-year risk-free rate and $E\left[R_M - R_F\right]$ is the annualized, expected market risk premium, which is commonly proxied for using a long-term average value. When multifactor CAPM models are considered, the additional factors must be accounted for in the COE estimates; that is,

$$COE_{E,m,FED} = R_F + \sum_{k_m} \beta_{k,FED} f_k,$$

where $COE_{E,m,FED}$ is the Reserve Banks' COE estimate based on the standard CAPM estimation framework for specification m; $\beta_{k,FED}$ is the weighted average estimate of BHC stock return sensitivity to the k^{th} factor in specification m; and f_k is the long-term average value of the k^{th} factor proxying for its expected value.

When considering the impact of firm leverage on COE estimates with respect to multifactor models, the conceptual difficulties mentioned earlier remain. For this component of our analysis, we use a separate method for generating releveraged COE estimates; i.e., we apply the asset beta formula presented earlier to the COE estimates themselves.[18] We generate

$$COE_{RA,m,FED} = \left(1 + \left(1 - \tau_{FED}\right)\left(\frac{D}{E}\right)_{FED}\right)\sum_{i=1}^{20} w_i COE_{RA,m,i},$$

where $COE_{RA,m,i}$ is the leverage-adjusted COE estimate for a given BHC based on CAPM specification m; i.e.,

$$COE_{RA,m,i} = \left(1 + \left(1 - \tau_i\right)\left(\frac{D}{E}\right)_i\right) COE_{mi},$$

where COE_{mi} is the COE estimate for BHC i implied by specification m.

Table 13 provides information on some of the key inputs to many if the alternative COE estimates we examine. The annual market risk premium, denoted as $E[R_M\text{-}R_F]$%, is the average premium from 1927 to the year in question using data available on Professor Ken French's website. The R_F variable is the annual percent return on a one-month Treasury bill, as reported on the French website. Note the sharp drop in this variable that is tied to the Federal Reserve's dramatic interest rate cuts during the period. The variable $E[R_L\text{-}R_S]$ is the average term spread between the 10-year Treasury bond and the 3-month Treasury bill from 1953 through to the year in question.

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[18] This method was suggested to us by one of the Academic Consultants and is supposedly presented in Reilly and Brown (2000).

Finally, the D/E_{FED} variables for debt defined as total debt or total liabilities and tax rate t_{FED}% are the median merger-adjusted values for the defined peer group. Note that for CAPM specifications containing PRS-related factors, we use the individual BHC's PRS values for the year in question; these 100 numbers (20 BHCs X 5 years) are not presented to conserve space. Note that the standard deviation of the market risk premium and the risk-free rate are quite high relative to the standard deviation of the average term spread. This suggests that much of the variability in the COE measures across models will come from those first two factors, especially from the risk-free rate, at least during this sample period that witnessed dramatic declines in short term interest rates.

Table 13. Additional inputs to the COE_{FED} calculation for each sample year

Year	$E[r_m-r_f]$%	R_f %	$E[r_L-r_S]$	D/E_{FED}; D=Debt	D/E_{FED}; D=Liab.	t_{FED}%
1999	9.02%	4.69%	1.19%	3.27	11.68	34.53%
2000	8.66%	5.88%	1.17%	2.86	11.13	34.36%
2001	8.35%	3.86%	1.17%	2.98	10.57	34.35%
2002	7.94%	1.63%	1.21%	2.70	9.86	33.30%
2003	8.25%	1.02%	1.25%	2.56	9.95	32.96%
Average	8.44%	3.42%	1.20%	2.87	10.66	33.90%
Std. Dev.	0.41%	2.05%	0.03%	0.24	0.78	0.72%

Table 14 presents the benchmark model's COE estimates each year of the sample as calculated directly by multiplying the appropriate equity beta by the average market risk premium and adding the risk-free rate per the equation for $COE_{E,FED}$. Again, the equity beta from the benchmark model is not varied across the sample years. We use the same estimated equity beta from our five-year estimation period for all of our comparisons and calculations; hence, we are presenting fitted values, not operational, out-of-sample estimates.

With equal-weighting and without adjustments for capital structure, the average annual $COE_{E,FED}$ is 8.21% with a standard deviation of 2.00%, largely stemming from the rapid decline in short-term interest rates during the period. When value-weighting is used, the average $COE_{E,FED}$ is 10.36%, with a standard deviation of 2.08%. Hence, equal-weighting for this sample, without adjusting for leverage, leads to a lower mean and standard deviation due to larger BHCs generally having larger betas. In fact, regardless of whether we account for differences in leverage in the benchmark model, value-weighting generates higher COE estimates.

The differences that arise in the $COE_{E,FED}$ estimates from using either total debt or total liabilities as the D term depends upon whether we equal- or value-weight. With equal-weighting, the estimates based on total liabilities tend to be smaller on average (8.52% instead of 8.59%) and more volatile (standard deviation of 2.52% compared to 2.31%) than when total debt is used. Note that this pattern does change across the sample years. With value-weighting, however, the estimates based on total liabilities are always higher than when total debt is used; on average, 10.10% instead of 9.49%, with a higher standard deviation of 3.30% instead of 2.90%.

Table 14. COE_{FED} estimates based on the benchmark CAPM model

Model	Equity beta		Releveraged asset beta			
			Total debt definition		Total liabilities definition	
	Equally-weighted	Value-weighted	Equally-weighted	Value-weighted	Equally-weighted	Value-weighted
1999	9.81%	12.11%	10.63%	11.41%	10.59%	11.98%
2000	10.80%	13.01%	11.48%	12.89%	11.87%	14.37%
2001	8.60%	10.73%	8.91%	10.14%	8.76%	10.49%
2002	6.13%	8.16%	6.21%	6.80%	5.87%	7.04%
2003	5.70%	7.81%	5.71%	6.22%	5.49%	6.61%
Average	8.21%	10.36%	8.59%	9.49%	8.52%	10.10%
Std.Dev.	2.23%	2.32%	2.58%	2.90%	2.82%	3.30%

The panels of Table 15 present the 280 Reserve Bank COE estimates that we generated; i.e., (5 sample years) x (7 CAPM model specifications) x (2 weighting schemes) x (2 equity beta types) x (2 leverage definitions). Please note that we present these calculations for the purposes of completeness and comparison. We emphasize that not of these numbers are either statistically or economically meaningful since our various model specification criteria (i.e., model selection criteria, hypothesis testing, and materiality criteria) disqualify many of these numbers from consideration.

Further note that, in contrast to Table 14, here we deleveraged the individual BHCs' COE estimates and then releveraged the aggregate value using the imputed Reserve Bank D/E ratios and tax rates. The COE_{FED} estimates from the benchmark model differ from those in Table 14 because the method for dealing with leverage differs. For the equal-weighted values in Panel A, the COE estimates are the same as in Table 14; however, the value-weighted numbers in Panel B are not the same because here the individual BHCs' COE estimates are value-weighted.

From these panels, we see that the various COE_{FED} estimates vary widely. For the benchmark model, the range is from 5.52% to 15.54%, although much of the variation across years is attributable to the change in the short-term interest rate environment. The COE estimates for CAPM specifications 4, 5, and 7 tend to be either very small or even negative, mainly due to regression coefficients that are large and negative but typically statistically insignificant. This holds true also for Models 2, 3 and 6, although the factors' coefficients in these models are not large and negative enough to pull the COE down as noticeably.

In summary, the COE_{FED} estimates in Table 14 based on the benchmark CAPM model provide us with the evidence needed to address the Academic Consultants' suggestion of analyzing asset betas. Since the COE_{FED} estimates based on the different releveraged asset betas and equal weightings are within a standard deviation of the benchmark value, we conclude that any contributions provided by considering firm leverage are not sufficiently material to change our recommendation away from the standard CAPM approach. With respect to the weighting schemes, the important theoretical differences between them manifest themselves clearly in the empirical results. However, as discussed above, since we are now working with a more focused peer group, the arguments in favor of an equal weighting scheme should be more convincing.

Table 15. COE_{FED} estimates across years, model specifications, weighting schemes, equity beta types and leverage definitions.

Panel A. Equally-weighted using equity betas

Year	M1	M2	M3	M4	M5	M6	M7
1999	9.81	5.21	8.48	-7.28	-23.94	4.22	-18.95
2000	10.80	6.30	8.98	-7.51	-26.24	4.80	-21.04
2001	8.60	4.06	7.28	-8.29	-24.97	3.07	-20.05
2002	6.13	1.46	5.72	-8.69	-22.17	1.36	-17.58
2003	5.70	0.89	5.92	-7.59	-18.63	1.44	-14.37
Average	8.21	3.58	7.28	-7.87	-23.19	2.98	-18.40
Std. Dev.	2.23	2.35	1.47	0.59	2.95	1.57	2.59

Panel B. Value-weighted using equity betas

Year	M1	M2	M3	M4	M5	M6	M7
1999	11.93	5.34	10.99	-1.34	-15.87	4.61	-12.84
2000	13.44	5.09	12.27	-0.60	-13.94	4.12	-11.02
2001	11.01	2.88	10.08	-2.73	-15.21	2.12	-12.69
2002	7.90	0.72	7.59	-4.42	-15.41	0.60	-12.83
2003	7.58	0.39	7.70	-3.63	-12.75	0.69	-10.43
Average	10.37	2.88	9.73	-2.54	-14.64	2.43	-11.96
Std. Dev.	2.56	2.34	2.05	1.58	1.28	1.88	1.15

Panel C. Equally-weighted using releveraged asset betas based on total debt

Year	M1	M2	M3	M4	M5	M6	M7
1999	11.58	5.92	9.99	-10.66	-29.39	4.69	-23.86
2000	12.70	7.42	10.54	-11.13	-33.51	5.64	-28.05
2001	9.44	4.25	7.97	-11.38	-30.14	3.15	-24.77
2002	6.34	1.00	5.90	-11.02	-25.25	0.97	-20.36
2003	5.77	0.32	6.01	-9.84	-20.98	0.93	-16.46
Average	9.17	3.78	8.08	-10.81	-27.85	3.08	-22.70
Std. Dev.	3.08	3.07	2.16	0.60	4.84	2.14	4.43

Panel D. Value-weighted using releveraged asset betas based on total debt

Year	M1	M2	M3	M4	M5	M6	M7
1999	11.51	5.70	10.47	-2.23	-16.64	4.89	-13.48
2000	13.06	5.83	11.71	-1.95	-16.66	4.68	-13.46
2001	10.03	3.23	9.05	-3.38	-16.01	2.46	-13.33
2002	6.66	0.94	6.36	-4.51	-14.90	0.87	-12.34
2003	6.09	0.63	6.23	-3.78	-11.57	0.93	-9.33
Average	9.47	3.27	8.77	-3.17	-15.16	2.76	-12.39
Std. Dev.	3.03	2.49	2.44	1.07	2.13	1.95	1.77

Panel E. Equally-weighted using releveraged asset betas based on total liab.

Year	M1	M2	M3	M4	M5	M6	M7
1999	11.71	6.30	10.18	-10.93	-30.00	5.16	-25.29
2000	13.61	8.26	11.41	-11.37	-34.86	6.42	-29.90
2001	9.24	4.23	7.84	-11.66	-29.75	3.17	-24.91
2002	5.90	0.80	5.51	-11.20	-24.23	0.76	-20.03
2003	5.52	0.12	5.74	-10.41	-21.10	0.70	-17.01
Average	9.20	3.94	8.14	-11.11	-27.99	3.24	-23.43
Std. Dev.	3.54	3.49	2.63	0.47	5.38	2.57	5.01

Panel F. Value-weighted using releveraged asset betas based on total liab.

Year	M1	M2	M3	M4	M5	M6	M7
1999	12.49	6.23	11.42	-1.66	-17.14	5.43	-14.31
2000	15.54	6.82	14.10	-1.00	-17.46	5.58	-14.47
2001	10.49	3.18	9.53	-3.01	-15.64	2.43	-13.20
2002	6.91	0.60	6.63	-4.43	-14.52	0.53	-12.19
2003	6.52	0.31	6.65	-3.89	-12.14	0.63	-9.98
Average	10.39	3.43	9.66	-2.80	-15.38	2.92	-12.83
Std. Dev.	3.81	3.05	3.21	1.45	2.17	2.48	1.84

V. Conclusions and recommendation

The 2004 PSAF Review proposes that the procedure for imputing the Reserve Banks' COE estimate be modified along the following lines:

- refine the BHC peer group to more closely match Reserve Bank operations using additional criteria based on BHC due-to balances, capital ratios, and credit ratings;
- use just the CAPM model to empirically estimate the cost of equity capital;
- use just five years of data in the CAPM model estimation;
- use the benchmark CAPM model; and
- equally weight the individual BHC estimates to generate the aggregate value.

In this technical supplement, we presented much of the empirical work conducted to formulate these conclusions and address the concerns of the Academic Consultants.

Specifically, the Academic Consultants expressed two concerns regarding the specification of the CAPM model to be used. They suggested analyzing whether interest rates and payments revenues impacted BHC stock returns in a sufficiently important way that we should include them in our COE estimation process. Based on our ex-ante decision process that included both statistical and materiality criteria, we concluded that the benchmark CAPM model was the most appropriate for our purposes. Our analysis of alternative estimation techniques (i.e., panel regression techniques) did not provide sufficient evidence to dissuade us of our conclusion.

In addition, the Academic Consultants suggested that BHC leverage might play a sufficiently large role in our COE estimate results that we should modify our estimation procedure. However, analysis of this concern with respect to BHC betas and COE estimates did not indicate numerical differences sufficiently material to warrant a change.

Finally, with respect to the weighting scheme, the important theoretical differences between them manifest themselves clearly in the empirical results. However, as discussed above, since we are now working with a more focused BHC peer group that more closely matches the Reserve Banks' payments services business, the argument in favor of analyzing a representative firm (i.e., the "average" firm) rather than the industry (i.e., a value-weighting of the peer group) appears to be more compelling and closer to actual empirical practice.

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Appendix. Alphabetical List of BHCs in the Peer group

(as per the BHC deposit ranking using 2003.Q4 data)

Name	Ticker	CRSP PERMNO	Entity #
SYNOVUS FINANCIAL CORP	SNV	20053	1078846
COMPASS BANCSHARES INC	CBSS	22032	1078529
COMERICA INC	CMA	25081	1199844
FIFTH THIRD BANCORP	FITB	34746	1070345
FIRST TENNESSEE NATIONAL	FTN	36397	1094640
WACHOVIA CORP	WB	36469	1073551
WELLS FARGO & CO	WFC	38703	1120754
FLEETBOSTON FINANCIAL CORP	FBF	47159	1113514
J P MORGAN CHASE & CO	JPM	47896	1039502
MARSHALL & ILSLEY CORP	MI	51706	1199497
NATIONAL CITY CORP	NCC	56232	1069125
NORTHERN TRUST CORP	NTRS	58246	1199611
MELLON FINANCIAL CORP	MEL	59379	1068762
PNC FINANCIAL SERVICES GRP	PNC	60442	1069778
KEYCORP NEW	KEY	64995	1068025
BANK ONE CORP	ONE	65138	1068294
U S BANCORP	USB	66157	1119794
CITIGROUP INC	C	70519	1951350
BB&T CORP	BBT	71563	1074156
UNION PLANTERS CORP	UPC	78263	1094369