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How Would U.S. Banks Fare in a Negative Interest Rate Environment?*

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Abstract

This paper uses a unique new data set to empirically examine bank-level expectations regarding the impact of negative short-term interest rates on bank profitability through net interest margins. The results show that banks differ significantly in their views regarding how profits might be affected in a negative interest rate environment and that much of this heterogeneity can be explained by cross-bank differences in the provision of liquidity services. We find that those banks that are more active in providing liquidity to borrowers anticipate suffering reduced profitability through declines in interest income on short-duration assets. The opposite is true of banks that are more active in providing liquidity to depositors as these banks expect to benefit form lower short-term funding costs. However, we find that these distributional effects wash out at the aggregate level, as liquidity provision is sufficiently well diversified across all banks.

JEL Classification: E43, E44, G21

Keywords: Banking conditions; net interest margins; unconventional monetary policy

*The views expressed here are solely those of the author and should not interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

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1 Introduction

In the years since the financial crisis a number of central banks, including the European Central Bank, the Danish National Bank, the Swedish Riksbank, the Swiss National Bank, and the Bank of Japan, have all implemented negative interest rate policies with the aim of generating monetary stimulus to affect real economic activity and inflation.[1] In the United States, the possibility of negative interest rates, though not implemented, has been a point of discussion amongst academic economists and in broad policy circles.[2]

In principle, the transmission of monetary policy as implemented through negative interest rates can work through a number of possible transmission channels, but one that has received particular attention operates through the banking sector. The idea is that by charging a fee for holding excess reserves at the central bank, a negative interest rate policy can be used to encourage banks to substitute out of reserves and into other assets. Under a certain set of assumptions, doing so can influence the loan supply schedule such that the resulting increase in bank credit lowers the cost of capital for bank-dependant borrowers. This, in turn, has a stimulative effect on the rest of the macroeconomy. The bank lending channel of monetary policy transmission is articulated in Bernanke and Blinder (1988) and discussed more generally in Bernanke and Gertler (1995). Empirical support is provided by Bernanke and Blinder (1992), Kashyap and Stein, (1995, 2000) and Jimenez, Ongena, Peydro, and Saurina (2012), among others.

However, this transmission channel may be complicated by the effect of negative interest rates on bank profitability.[3] Bank profits are determined, in part, by the net interest margin—the difference between interest income and interest expenses. When the policy rate goes negative, a common concern expressed in policy circles is that banks might not be willing to pass this cost on to their deposit base. In this case, incomplete pass-through to deposit rates leads to compression of the net interest margin which erodes bank profits. In turn, reduced profitability makes it more

[1] Bech and Malkhozov (2016) point to a desire to manage inflation and inflation expectations as a key motivation behind the ECB and the Riksbank implementing negative interest rates, while the the Swiss and Danish National Banks were motivated by a desire to mitigate appreciation pressure on their respective currencies.

[2] From an academic perspective, Goodfriend (2000) is an early contribution on the implementation of negative interest rates and Goodfriend (2015) provides a discussion of the evolustion of the literature since that time. From the policy perspective, a number of prominent economists have commented on implementing negative interest rates in the U.S. including Bernanke (2106), Blinder (2010), Buiter (2009), Kocherlakota (2016), and Mankiw (2009).

[3] Concerns regarding negative interest rates extend beyond bank profitability. Bernanke (2016) points to potential adverse effects on money market funds as well as legal and operational constraints on the implementation by the Federal Reserve. Hannoun (2015) raises additional concerns regarding the potential to influence risk-taking behavior via the search for yield in a low rate environment as well as the adverse impact on non-bank financial institutions which offer long-term liabilities at fixed nominal rates, such as life insurance contracts. See also McAndrews (2015) for additional discussion of the complications associated with negative interest rates.

difficult to raise capital from retained earnings and this can dampen monetary transmission through the bank lending channel. Kishan and Opiela (2000), Gambacorta and Mistrulli (2004), and more recently, Berrospide and Edge (2016) present empirical evidence suggesting that bank's willingness to supply new loans is importantly influenced by bank capital. Even if banks do allow full pass-through to deposit rates, a negative interest rate policy can still pose complications because retail and wholesale depositors might not be willing to pay to hold deposits and may instead substitute into other assets (i.e., cash). This potential for deposit flight undermines financial stability by increasing liquidity risk in the banking sector.

The impact on the strength of monetary transmission as well as on financial stability, more generally, makes it clear that a more complete understanding of how bank profitability might evolve in a negative interest rate environment is important. However, experience with negative interest rate episodes is limited. At best we can look to a short period of recent history for a subset of (mainly European) foreign banks. We are even more limited by lack of historical experience in trying to understand how U.S. banks might be affected.

The main contribution of this paper is to use a unique data set to shed light on how U.S. banks view themselves as being affected by negative interest rates. We use newly available confidential supervisory data from the Comprehensive Capital Analysis and Review (CCAR) stress tests to empirically assess how individual banks view their own profitability—specifically through the lens of net interest margins ($NIMs$)—evolving in a hypothetical negative interest rate environment.[4] The data used in the analysis covers 22 bank holding companies (BHCs) which, taken together, constitute roughly 75 percent of total assets in the U.S. banking system over three consecutive years (2014, 2015, and 2016) of stress test vintages.

Our identification strategy exploits the fact that negative rates were introduced by the Federal Reserve as an explicit scenario design feature in the supervisory severely adverse scenario of the 2016 vintage of CCAR.[5] This design feature allows us to isolate how individual banks view their net interest margins as evolving in a negative rate environment, even after controlling for underlying macroeconomic developments and bank-specific characteristics.

The main results reveal considerable differences across the BHCs in our sample. All banks anticipate reduced profitability in response to the macroeconomic conditions that give rise to the negative rate environment. After controlling for these effects, we find that roughly one-third of the

[4]Negative interest rates can potentially affect bank profitability through a number of different channels beyond net interest margins. For example, negative rates could boost earnings through increased lending volumes or through stronger demand for capital management and investment banking services owing to a low rate environment. Alternatively, negative interest rates may boost profits through asset valuation changes. Our specific focus in this paper on net interest margins owes to data availability, as will be described in greater detail in Section **??** below.

[5]The supervisory severely adverse scenario is a *hypothetical* macroeconomic and financial environment that forms the basis of a forward-looking stress test.

banks view themselves as exposed to lower profits through NIM compression owing to a negative policy rates *per se*. In contrast, an additional one-third have the opposite view; they believe that the incremental effect of negative rates will expand their $NIMs$. The remaining banks in our sample do not believe that negative rates will have a material impact on profitability beyond what can be explained by the underlying macroeconomic environment.

To explain these cross-bank differences we present a simple decomposition of the NIM and use it to highlight some potential nonlinearities that may arise as the policy rate turns negative. The *deposit margin channel* suggests that imperfect pass-through to deposit rates will amplify NIM compression. The *yield curve compression channel* suggests that as the level of the policy rate moves lower and eventually turns negative, the yield curve becomes progressively flatter. This flattening of the yield curve amplifies NIM compression as interest income on long-maturity assets falls more sharply when short rates go below zero. Finally, drawing on Kashyap, Rajan, and Stein (2002), we examine a *liquidity management channel* whereby exposure to negative interest rates is driven by how active a bank is in providing liquidity to borrowers relative to providing liquidity to depositors. In contrast with the deposit margin channel, the liquidity management channel relies on unimpeded pass-through to interest rates on a wide set of short-duration assets and liabilities.

This decomposition allows us to test the empirical relevance of each channel using publicly available balance sheet data. The results do not point to a significant role for either the deposit margin or the yield curve compression channel. However, we do find strong support for the liquidity management channel. The results indicate that BHCs with high exposure to short-maturity assets (interest bearing balances, federal funds sold, and securities purchased under agreement to resell) view themselves as most exposed to amplified NIM compression through depressed interest income on these assets as a result of negative rates. In contrast, BHCs with high exposure to short-term liabilities (deposits, federal funds purchased, and securities sold under agreement to repurchase) anticipate a benefit to $NIMs$ from reducing funding costs.

These findings suggest that, contrary to much of the policy discussion, incomplete pass-through to deposits rates is not what concerns banks the most about a negative interest rate environment. Instead, because pass through through to interest rates on both short-maturity assets as well as short-maturity liabilities is largely expected, those banks with the highest exposure to reduced profitability are the ones most heavily engaged in liquidity provision to borrowers. Those banks that are heavily exposed to liquidity provision to depositors may find it easier to increase lending due to a boost to profitability through lower funding costs.

An additional implication is that the impact of negative rates on the banking system is expected to be largely distributional. Some banks will suffer while others benefit; however, at the aggregate level these distributional effects wash out. Aggregating across all banks, there is sufficient diversity in liquidity provision services for the banks in the sample as a whole such that the reduction in interest income from short-maturity assets is offset by the reduction in funding costs from short-maturity liabilities. From a policy perspective, one interpretation is that policy makers should be less concerned about negative rates undermining the strength of monetary transmission and more focused on the financial stability concerns. In particular, the focus on should be greatest on the soundness of those institutions more heavily engaged in liquidity provision to borrowers through short-maturity lending.

It is worth stating explicitly that these results are not based on *actual data*; instead, they are based on *projections* provided by the BHCs themselves *conditional on hypothetical macroeconomic scenarios*. The CCAR process is designed to ensure that the bank-provided stress test projections are a reasonably accurate representation of how an individual bank views itself as faring in a particular macroeconomic scenario. Indeed, scenario design and internal review plays an important role in the qualitative review for CCAR and the penalties for failing to pass this aspect of the stress test—in the form of restrictions on planned capital actions—can be quite severe.

In terms of related literature, this paper compliments a small, but emerging body of research on negative interest rates. Two recent theoretical contributions are Brunnermeier and Koby (2016) and Rognlie (2016), both of which develop micro-founded models which show that the effective lower bound for monetary policy is not necessarily zero. Brunnermeier and Koby (2016) is more closely due to its focus on how negative interest rates affect profitability through $NIMs$ through the degree of pass-through to short-maturity assets and liabilities. A recent empirical study is Heider, Saidi, and Schapens (2016). Using data from European banks, these authors find that, due to a reluctance to pass negative rates on to depositors, banks that rely more heavily on deposit funding tend to engage in riskier lending. The results presented here offer little role for incomplete pass-through for U.S. (as opposed to European) banks, yet this is not necessarily inconsistent with Heider, Saidi, and Schapens (2016) because this paper does not address bank risk-taking behavior. One important similarity is that both papers conclude that negative rates have a large distributional impact on the banking system. More broadly, this paper relates to a wide body of existing research seeking to understand bank exposure to interest rate risk.[6] Although a few papers have empirically examined the impact of low levels of interest rates on bank profitability, this paper stands out because the focus here is exclusively on negative interest rates.[7]

The remainder of this paper is organized as follows. The next section discusses how scenario

[6]Flannery and James (1984) is an early paper in this literature. More recently see Begeneau, Piazzesi, and Schneider (2012), English, van den Huevel, and Zakrajsek (2012), and Landier, Sraer, and Thesmar (2013)..

[7]Claessens, Coleman, and Donnelly (2016), Borio, Gambacorta, and Hofmann (2015) find evidence of nonlinear effects of low interest rates on net interest margins. In addition, Saunders (2000), Busch and Memmel (2015), and Genay and Podjasek (2014) consider the impact of low interest rates on profitability through net interest margins.

design fits in with the broader objectives of stress testing. Section ?? describes the data and methodology. Section ?? presents the main results and section ?? examines some explanations for the heterogeneity of outcomes in our main results. Finally, section ?? concludes.

2 The Role of Scenario Analysis in Stress Testing

The Federal Reserve conducts stress tests of the largest bank holding companies in two separate, but related, forms: (1.) the Dodd-Frank Act stress tests (DFAST); and (2.) the Comprehensive Capital Analysis and Review (CCAR).[8] In DFAST, the Federal Reserve specifies scenarios (the general macroeconomic background that forms the basis for the stress tests), gathers data from participating bank holding companies, and publishes estimates of their income, losses, and capital ratios in the scenarios. Firms in DFAST are effectively assumed to follow a simple rule in making capital distributions. In contrast, CCAR is a supervisory exercise with both a quantitative component—to evaluate the adequacy of firms capital buffers under a macroeconomic scenario specified by the Federal Reserve—and a qualitative component to evaluate their capital planning processes. Under CCAR, each participating BHC submits a capital plan to the Federal Reserve describing how it measures and manages risk as well as its governance and controls processes. Each participating BHC also submits its planned capital actions over the scenario horizon. The quantitative component of CCAR is similar to DFAST, but instead of assuming that capital distributions follow the simple rule, the capital actions (i.e. share repurchases and dividend payments) in firms own capital plans are used.

These differences aside, DFAST and CCAR are similar in that forward-looking scenarios are a critical component of assessing capital adequacy under both sets of stress tests. A forward-looking scenario consists of a set of variables that, taken together, detail a macroeconomic and/or financial event that forms the basis of the stress test. More specifically, a macroeconomic stress scenario consists of hypothetical paths for different macroeconomic variables (for example: GDP, unemployment, etc.), various interest rates (short- and long-term treasury rates, corporate yields, etc.) and other financial variables (equity prices, the VIX, etc.).[9] Each bank is required to project net income over a nine-quarter forward horizon conditional on the macroeconomic and financial market conditions assumed into the scenario. These net income projections along with assumptions about dividend, share repurchases, and other capital actions, are combined to assess equity capital and regulatory capital adequacy.

[8] A detailed overview of stress testing can be found in Hirtle and Lehnert (2014).

[9] The CCAR stress test also has a market shock as well as a counterpart default component for a subset of the largest participating firms. The set of variables and assumptions that comprise these aspects of the stress test are different from those underlying the macroeconomic scenarios.

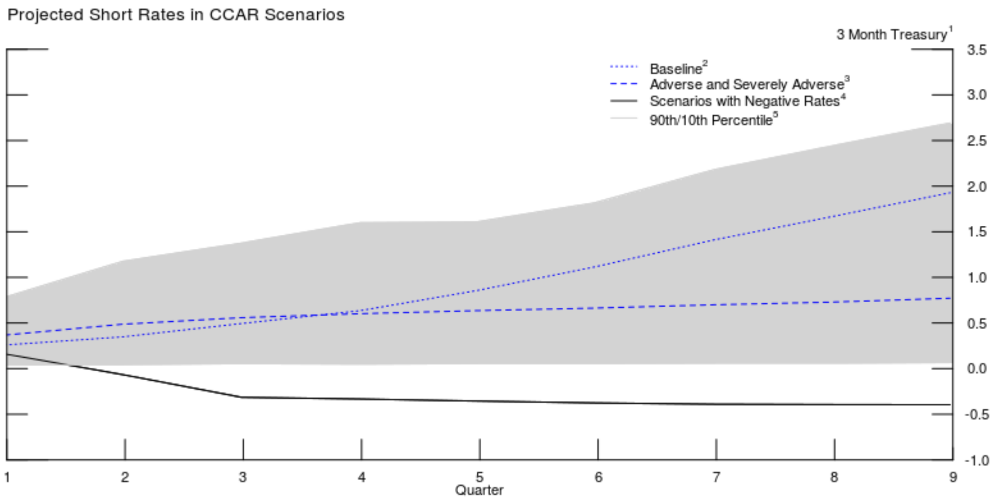
All told, participating BHCs will project their capital ratios under five scenarios. The Dodd-Frank Act calls for the Federal Reserve to evaluate participating firms under three scenarios: a supervisory baseline scenario; a supervisory adverse scenario; and a supervisory severely adverse scenario. All three of these scenarios are provided by the Federal Reserve and typically consists of a set of roughly 28 macroeconomic and financial variables accompanied by a narrative that describes how the variable paths are plausibly tied together by a common underlying macroeconomic and/or financial shock. Supervisory scenarios, as well as the underlying narrative, are made available to the public at the start of the CCAR process. In addition to the supervisory scenarios, each participating BHC is also required to develop two additional scenarios on their own: a BHC baseline and a BHC severely adverse scenario. BHC-provided scenarios are developed internally using models augmented by expert judgment and are designed in such a way as to comprehensively stress the bank given its unique business model and idiosyncratic risk profile.

This paper exploits the fact that the Federal Reserve varies the supervisory stress scenarios in response to changing macroeconomic conditions and risks. Scenarios can stress risks seen as being particularly salient for the health of the banking sector. Alternatively, even if the risk is deemed unlikely to actually materialize, building a particular feature into a scenario can be a useful opportunity to learn about exposures within the regulated banking system.

Design features introduced into scenarios in previous years include, for example, different configurations for the yield curve. In some scenarios, an adverse macroeconomic event is assumed to lead to a lower, flatter yield curve. In others it is assume to lead to a steepening as short rates decline while long rates either stay flat or increase. Stress loss projections under different yield curve configurations reveal information about how different BHCs view their exposure to interest rate risk. Alternatively, in other instances scenarios have featured disproportionate stress playing out in certain markets in order to address potentially worrisome exposures in the banking system. For example, the supervisory severely adverse scenario in 2015 featured a sharp widening of spreads on assets such as high yield corporate debt, leveraged loans, or collateralized debt obligations to assess the exposure of the banking system to risky corporate lending.

In this paper, we focus on a design feature introduced into the 2016 supervisory severely adverse scenario at a time when sovereign bond yields around the world were turning negative. This scenario assumed a severe global recession which resulted in short-term Treasury rates falling to negative 1/2 percent shortly after the onset of the initial shock and staying at that negative level over the remainder of the nine-quarter horizon. The adjustment to negative short-term rates was assumed to proceed without additional financial market disruption.

The grey shaded region in Figure 1 shows the distribution of scenario paths for the three month Treasury rate for all five scenarios across three consecutive years of CCAR (2014 through 2016)



1. We substitute the 3 Month Libor rate for bank scenario submissions which do not report the 3 Month Treasury.
2. Average across all BHC and Supervisory Baseline scenarios for 3 CCAR vintages (2014, 2015, 2016).
3. Average across all BHC and Supervisory Adverse and Severely Adverse scenarios in 3 CCAR vintages (2014, 2015, 2016), excluding scenarios with negative rates.
4. Average across all scenarios with negative rates (2016 Supervisory Severely Adverse and select BHC Severely Adverse scenarios).
5. Range indicates the 90th and 10th percentile of all supervisory and BHC scenarios, excluding those with negative rates.

Figure 1: Projected CCAR short rates across all scenarios, 2014-'16

for all participating BHCs. The black line plots the path of the three month Treasury in the 2016 supervisory severely adverse scenario (which is excluded from the distribution in the grey shaded area). The lower edge of the distribution never goes below zero, suggesting that up until the 2016 supervisory severely adverse scenario, the banks operated under the implicit assumption that the zero lower bound would a binding constraint for interest rates. In this sense, negative interest rates—and the fact that the zero lower bound might not be a binding constraint for policy—appears to have come as a surprise to the banks.

The analysis that follows centers on empirically identifying the degree to which BHCs viewed their profitability as being affected, either favorably or unfavorably, through potential nonlinear effects of negative interest rates on net interest margins.

3 Methodology

In this section, we discuss the data used in the analysis as well as the empirical methodology used to identify how individual banks view the effect of negative interest rates on net interest margins.

3.1 Data

We use data from three consecutive years (henceforth, "vintages") of CCAR stress test exercises. A vintage consists of five different scenarios for every BHC: (1.) the supervisory baseline scenario

(SB); (2.) the supervisory adverse scenario (SA); (3.) the supervisory severely adverse scenario (SSA); (4.) the BHC baseline scenario (BHC-B); and (5.) the BHC severely adverse scenario (BHC-SA). Supervisory scenarios are designed and published by the Federal Reserve.[10] The BHC-B is typically similar to the SB, largely because both are based on the consensus view of economic forecasters. In contrast, banks are given explicit instructions to tailor the BHC-SA to their own risk profiles and unique vulnerabilities.[11] The motivation behind tailoring stems from the recognition of considerable diversity among the CCAR banks. Hence, a generic macroeconomic downturn as captured by the SSA is unlikely to deliver comprehensive stress to all banks participating in the exercise. Tailoring of the macroeconomic scenario helps alleviate this problem. To ensure compliance, the Federal Reserve has increased its scrutiny of the appropriateness of the BHC-SA through the qualitative reviews of the annual CCAR exercise.

For every scenario-vintage, each BHC is required to provide a nine-quarter projection for its NIM conditional on the underlying macroeconomic environment that defines the scenario. In what follows let $i \in [1, 33]$ index bank; let $j \in [SB,\ SA,\ SSA,\ BHC\text{-}B,\ BHC\text{-}SA]$ index scenario; and, let $k \in [2014,\ 2015,\ 2016]$ index CCAR vintage. Finally, let t index time over the nine-quarter projection period for each bank-scenario-vintage.

For each scenario-vintage, bank i submits a nine quarter horizon NIM projection, where each quarterly observation is denoted $\widetilde{NIM}_{i,j,k,t}$. The BHC-provided projection is derived from models—statistical, judgmental, or otherwise—that are internal to the bank. While we do not observe these models, we do observe the underlying macroeconomic data (which are submitted to the Federal Reserve as a requirement of CCAR) upon which the BHC's projection is conditioned. This information is critical because it allows us to construct a model-based projection for bank $i's\ NIM$, denoted $\widehat{NIM}_{i,j,k,t}$, which can be used to purge the BHC-provided projection, $\widetilde{NIM}_{i,j,k,t}$, of its dependance on macroeconomic and bank-specific factors.[12]

We do this in three steps. The first is to estimate individually for every bank in our sample the

[10]The SB is based on surveys of economic forecasters and is chosen to be representative of economic outcomes under normal conditions. The SA is typically a moderate downturn, potentially coupled with some other feature that sets is apart from the SSA. Finally, the SSA is characterized by a severe recession in the United States which propagates globally and is coupled with large declines in asset prices and increases in risk premiums.

[11]The preamble to Capital Plan Rule (See 77 Fed. Reg. 74631, 74636 (December 1, 2011)) states that "the bank holding company-designed stress scenario should reflect an individual company's unique vulnerabilities to factors that affect its firm-wide activities and risk exposures, including macroeconomic, market-wide, and firm-specific events."

[12]In our notation, a $\widehat{hat}$ denotes a model-based projection estimated specifically for bank i, whereas a $\widetilde{tilde}$ denotes a projection taken from a BHC-provided scenario-vintage.

empirical model of Claessens, Coleman, and Donnelly (2016) given by:

$$\begin{aligned} NIM_{i,t} &= \beta_0^i + \beta_1^i NIM_{i,t-1} + \sum_{l=1}^{L} \beta_{2,l}^i 3MT_{t-l} + \sum_{l=1}^{L} \beta_{3,l}^i SPREAD_{t-l} \\ &\quad + \beta_4^i \Delta GDP_t + \beta_5^i \mathbf{X}_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{1}$$

where: $NIM_{i,t}$ is the historic net interest margin data for bank i; $3MT_{t-l}$ is the three month Treasury rate; $SPREAD_{t-l}$ is the spread between the 10-year and 3-month Treasury; ΔGDP_t is quarterly GDP growth; and $\mathbf{X}_{i,t}$ is a vector of bank specific controls. Specifically, $\mathbf{X}_{i,t}$ includes total securities over total assets, deposits over total liabilities, and total equity capital over total assets. The assumed number of lags on the three month treasury and the spread is four quarters, so $L = 4$. The model is estimated using quarterly data over the period 1996Q4 to 2016Q4 to get a set of bank-specific coefficients conditioned on the general macroeconomy (captured by interest rates and output growth, which is obviously common to all banks) as well as bank-specific characteristics and bank $i's$ own historic NIM data. Historic $NIMs$ are obtained from the Call Report data, merger-adjusted and aggregated up to the bank holding company level.

Once we have these bank-specific coefficients, the second step is to use the bank-specific estimated model along with the bank–provided paths for the macro variables in a given scenario vintage ($\widetilde{3MT}_{i,j,k,t}$, $\widetilde{SPREAD}_{i,j,k,t}$, and $\Delta\widetilde{GDP}_{i,j,k,t}$) to project the model-based NIM path, $\widehat{NIM}_{i,j,k,t}$. In generating this conditional model-based projection, we assume that bank's balance sheet stays constant, so that $\mathbf{X}_{i,t}$ is held constant at the last observed value over the entire projection period.

The final step is to construct the difference between the model-based and the BHC-provided projections:

$$\xi_{i,j,k,t} = \widetilde{NIM}_{i,j,k,t} - \widehat{NIM}_{i,j,k,t} \tag{2}$$

The model-based projection, $\widehat{NIM}_{i,j,k,t}$, as well as the BHC-provided projection, $\widetilde{NIM}_{i,j,k,t}$, both internalize the same underlying macroeconomic environment and, at least to some degree, the same broad bank-specific characteristics. Thus, the difference between the two should be purged of these effects. However, this does not necessarily mean that $E[\xi_{i,j,k,t}] = 0$. One reason why $\xi_{i,j,k,t}$ may differ from zero is that bank i might have an understanding of how its particular business model might amplify or dampen the impact of a given macroeconomic environment on its net interest margins in a way that it not easy to quantify through the simple linear empirical model as given by equation **??** above. For example, if $\xi_{i,j,k,t} > 0$ the bank projection is more optimistic with regard to how its $NIMs$ will evolve relative to what the simple linear model would predict. On the other hand, if $\xi_{i,j,k,t} < 0$ the bank projection is pessimistic.

The analysis that follows builds on the fact that negative interest rates have a potentially nonlinear effect on NIMs that will not be captured in our simple linear model-based projection. In contrast, the banks themselves understand very well the nuances of their own particular business model and balance sheet exposures and, as such, the BHC-provide projections should internalize these nonlinear effects. This crucial difference suggests that we can identify the impact of negative interest rates on NIMs by using the qualitative feature of negative interest rates as a scenario design element to explain systematic projection differences for a given bank across different scenario-vintages.

3.2 Empirical Model

The following regression tests the sensitivity of the earnings of bank i to potential nonlinear effects of negative interest rates:[13]

$$\xi_{i,j,k,t} = \alpha_i + \beta_i Z_{i,j,k,t} + \gamma_i D_{k=2016} + \epsilon_{i,j,k,t} \tag{3}$$

where: $Z_{i,j,k,t}$ is an indictor function that takes on the value of one if negative short term interest rates are a qualitative feature of the given bank scenario-vintage in quarter t and zero otherwise.[14] As shown in Figure 1, negative rates are a feature in only the 2016 scenario vintage, so to ensure that $Z_{i,j,k,t}$ is not inadvertently capturing a vintage-specific effect we include $D_{k=2016}$, which is an indictor function that takes on the value of one if the scenario is from the 2016 vintage. The equation also allows for bank-specific fixed effects, α_i, to control for time-invariant differences in the NIM projections for a given bank. Finally, $\epsilon_{i,j,k,t}$ is an error term.

Our main results focus on the parameter of interest, β_i, which gages how bank i views its profitability being influenced through the NIM by negative interest rates. Specifically, we are interested in whether or not the scenario design feature of negative interest rates leads bank i to adjust its internal NIM projection beyond that which can already be explained through our linear model conditional on the general macroeconomic environment and bank-specific characteristics.

If we find that β_i is not statistically different from zero then it suggests bank i does not have a strong view on how negative rates might affect profitability beyond that which can be explained using our linear framework. On the other hand, if we find $\beta_i \neq 0$ this suggests that bank i has some internal view on potential nonlinear effects that are not being picked up by our simple linear model. At this point in the paper, conditional on finding evidence of nonlinearities, we remain agonistic

[13]In principle, we have we have a maximum of 20 vectors of model residuals (each of length nine quarters) for every bank in the sample with five scenarios for each of four CCAR vintages per bank. In practice, we will have less than this because not every bank participated in every CCAR vintage.

[14]Notice that $Z_{i,j,k}$ is not indexed by t, so it effectively ignores time series variation. We are not losing much by making this assumption because, in practice, there is very little time series variation in the sense that once short-term rates go negative in a scenario they tend to stay flat at that negative level over the entire projection period.

on whether the effects are expected to be positive or negative for the profitability of a given bank. We will return to this issue in the next section.

3.3 Estimation

The model is estimated using generalized least squares (GLS) to allow for the possibility that cross-sectional observations may be linked through the error terms. Specifically, we use the following regression specification

$$\xi = \mathbf{X}\beta + \epsilon \tag{4}$$

where: $\xi = [\xi_1\ \xi_2\ \cdots\ \xi_I]'$ and ξ_i is a $(JKT$ x $1)$ stacked vector of projection differences for bank i across each nine quarter scenario vintage; $\mathbf{X}$ is a $(IJKT$ x $3I)$ diagonal matrix whose i^{th} diagonal element is the $(JKT$ x $3)$ matrix $X_i = [1\ Z_i\ D_{k=2016}]$, where the first element is a vector of ones and Z_i and $D_{k=2016}$ are vectors of the dummy variables defined above for each bank i across each nine quarter scenario vintage; $\beta = [\beta_1\ \beta_2\ \cdots\ \beta_I]'$ and $\beta_i = [\alpha_i\ \beta_i\ \gamma_i]'$. Finally, $\epsilon = [\epsilon_1\ \epsilon_2\ \cdots\ \epsilon_I]'$ and ϵ_i is a $(JKT$ x $1)$ vector of errors for bank i. We assume $E\epsilon_i\epsilon_j' \neq 0$. This assumption is motivated by the fact that projection differences may be correlated across banks; for example, different banks may use similar NIMs models.

The data set is a balanced panel that includes 25 banks.[15] The total number of observations is 3,375 (25 banks, 3 vintages, 5 scenarios per bank-vintage; each scenario is 9 quarters long). Negative interest rates feature in 252 of these observations (that is, one nine quarter scenario—the supervisory severely adverse—for the 2016 vintage for each bank plus an additional three banks featured negative rates in the nine quarter BHC severely adverse scenario for that year).

4 Main Results

The main results are presented in Figure 2, which shows the estimated coefficient, $\widehat{\beta}_i$, for each bank along with 90% confidence intervals. The results are presented for a total of 25 banks, increasing in the magnitude of the point estimate going from left to right.[16]

Starting on the left, ten banks have coefficient estimates that are negative and statistically significant. These banks believe that negative interest rates would lead to a compression of their

[15] To be more precise, we have 25 scenarios for 22 banks—three banks included multiple scenarios. As of 2016. a total of 33 BHCs participated in CCAR. We dropped data from 11 banks largely for one of two reasons: (1.) A firm only became a BHC in recent years and, hence, had no record of historic NIMs data with which to derive a model-based estimate for $\widehat{NIM}$; or (2.) A BHC did not participate in three complete vintages of CCAR between 2014 and 2016.

[16] Note that there are only 24 bars because one bank is not shown in the figure as it is a significant outlier. For presentational purposes we simply reference the point estimate and confidence bounds in a note at the bottom.

NIM above and beyond what would otherwise be explained by the underlying macroeconomic environment, even taking into account bank level controls. The point estimates range from -0.06 to -1.03, implying that the NIM is permanently lower over the nine-quarter projection period by between 6 and 103 basis points. On the far right, there are eight banks (including the one in the footnote) that have coefficients that are positive and statistically significant. These banks have a very different view regarding how they will fare in a negative rate environment in the sense that they anticipate improved profitability through an expansion in the NIM by between 6 and 618 basis points. The later estimate comes from a single bank and is six times greater (in absolute value) than the next largest point estimate in the sample. If we exclude it as an outlier, the range of estimates is between 6 and 48 basis points. Finally, the remaining one-third of banks in the middle of the figure all have coefficients that are not statistically different from zero. Our interpretation is that these banks do not have strong views on how negative rates might affect their profitability.

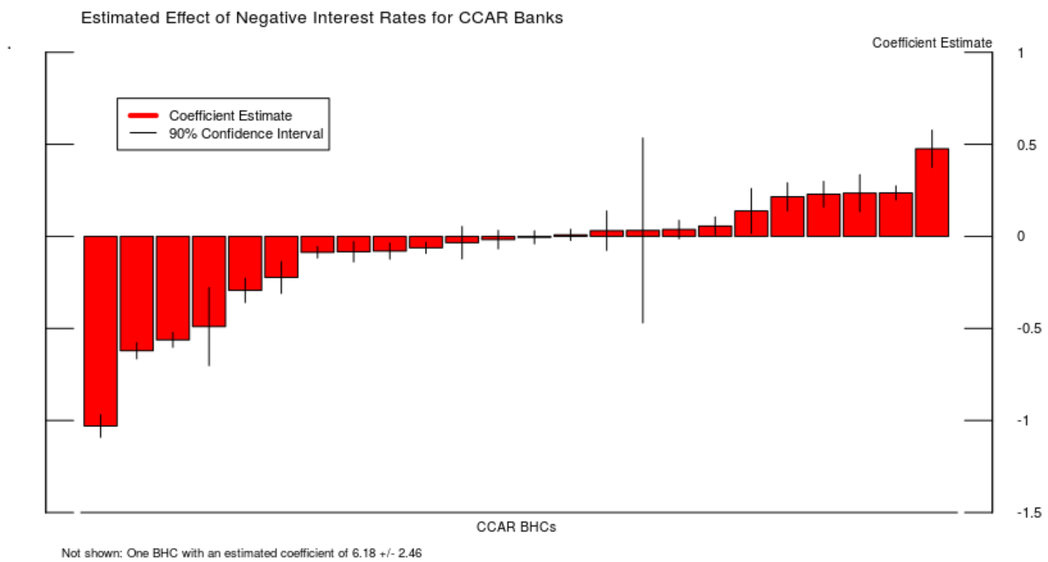


Figure 2: Estimated effect of negative interest rates on NIM projections

To gage the economic significance of these results, we express the estimated coefficient for each bank in the sample as a ratio of the historic volatility of that bank's own historic $NIMs$ data. To preserve the anonymity of the banks in the sample (recall that these estimates are based on confidential supervisory data), the results are reported in Table 1 as averaged across all banks that fall within one of three bins depending on whether negative rates increases, decreases, or has no anticipated impact on $NIMs$.

For the ten banks that anticipate negative rates will lead to NIM compression, the average

	Estimated Coefficient	*Estimated Coefficient Relative to Volatility of Historic $NIMs$*	*Observations*
Anticipated NIM Compression	−0.35	−1.13	10
Anticipated NIM Expansion	0.98	2.45	8
(Excluding Outlier)	0.23	0.55	7
No Anticipated Effect	0.01	0.02	7

Table 1. Average coefficient estimate and economic significance, by anticipated effect of negative interest rates on NIMs.

estimate, shown in the first column, is 35 basis points. When expressed as a ratio of historic NIM volatility, the resulting ratio averages 1.13 across these ten banks. This means that, on average, these banks believe negative rates would introduce a persistent (over all nine quarters of the scenario horizon) shock that is greater than one standard deviation of the distribution of their respective historical $NIMs$ data. Hence, not only are the results statistically significant, but they are quite large in terms of economic impact.

The average coefficient estimate for the eight banks that anticipate an expansion of $NIMs$ is 98 basis points. However, this average estimate is heavily influenced by the outlier. Excluding it gives an average estimate of 23 basis points. In terms of economic significance, a similar calculation as above (and excluding the possible outlier) yields an average ratio of the point estimate to observed volatility in historic $NIMs$ data of 0.55. While this is half as large as the comparable estimate above, it is still economically significant as the one-half standard deviation shocks persists over the entire nine quarter projection.

Comparing banks where profitability is viewed as suffering in a negative rate environment to those where profitability is viewed as improving (excluding the outlier bank), it is interesting to note that the average estimated coefficient across the two cohorts is similar in absolute value. That is, the overall impact on $NIMs$ is similar in magnitude—regardless of whether it is positive or negative. However, based on historic $NIMs$ volatility, a shock of this magnitude is more economically meaningful for banks that anticipate reduced profitability through NIM compression (greater than one standard deviation shock) as compared to banks that anticipate a boost to profits through NIM expansion (roughly a half of a standard deviation shock).

5 What Explains the Cross-bank Differences?

The results presented above reveal considerable heterogeneity in how various banks view their exposure to negative interest rates. We present a simple decomposition of the net interest margin to explain these cross-bank differences. The decomposition allows us to highlight some potential channels through which negative rates can have a nonlinear effects on $NIMs$ not captured by equation **??** above and to test the strength of these channels using balance sheet data.

5.1 Potential Nonlinearities Associated with Negative Rates

The definition of net interest margin is given by

$$NIM = \frac{Interest\ Income - Interest\ Expense}{Interest\ Earning\ Assets}$$

For simplicity, assume that banks hold only two types of assets. Short-duration assets, denoted A^s, deliver a gross return R^s, and long-duration assets, A^l, deliver a return $R^l \geq R^s$. Total interest income can be expressed as $R^s A^s + R^l A^l$. On the liability side of the balance sheet, assume that banks fund themselves through deposits or other short term funding, denoted L^s, and other long-term liabilities, denoted L^l. The deposit rate paid by the bank is given by R^d. In the interest of simplicity, we assume that the cost of funding for long-term liabilities is similar to the return on long-term assets and, hence, is also given by R^l. Total interest expenses can be expressed as $R^d L^s + R^l L^l$. Finally, total interest earning assets are given by $A^s + A^l$, and total interest bearing liabilities are $L^s + L^l$.

Define the share of long duration assets in total interest earning assets, $\chi = \frac{A^l}{A^s+A^l}$, which is a measure of the duration sensitivity of interest earning income. Similarly, define $\eta = \frac{L^l}{L^s+L^l}$ as a measure of the duration sensitivity of interest expenses. Finally, let $\lambda = \frac{L^s+L^l}{A^s+A^l}$ denote total interest bearing liabilities as a share of total interest earning assets.

With these share definitions, we can rewrite the definition of the net interest margin as

$$NIM = R^s - \lambda R^d + \chi(R^l - R^s) - \lambda\eta(R^l - R^d)$$

The net interest margin is a function of three components. The first, $R^s - \lambda R^d$, captures the idea that, all else equal, net interest margins are higher as the short-term lending rate exceeds the short-term cost of funding. The second term, $\chi(R^l - R^s)$, captures the idea that it is profitable for the bank to engage in maturity transformation as the returns on long-term assets exceed those on short-term assets. Finally, the third term, $-\lambda\eta(R^l - R^d)$, highlights the fact that long-term funding of more expensive than short-term funding, so heavy reliance on longer term funding erodes NIMs, making the bank less profitable.

To address potential nonlinearities associated with negative rates we need to make some additional assumptions both about the policy rate itself as well as how the policy rate is passed through to interest rates on assets and liabilities held by the bank. The policy rate, denoted $\hat{R}(\epsilon)$, is assumed to fluctuate around a target level, $\bar{R}$, in response to an underlying shock, ϵ. The realization of the shock induces the central bank to either increase the policy rate above its target, which happens with probability α, or to lower it below target, which happens with probability $1 - \alpha$.

$$\hat{R}(\epsilon) = \begin{cases} \bar{R} + \epsilon \ with \ probability \ \ \alpha \\ \bar{R} - \epsilon \ with \ probability \ \ 1 - \alpha \end{cases}$$

For simplicity, assume that the target rate is sufficiently low so that we just consider the case of $\bar{R} = 0$. In this low interest rate environment, a bank that is forming expectations of the policy response to a shock must take into account not only the realization of the shock, but also whether or not the bank expects the zero lower bound (ZLB) to be a binding constraint for monetary policy. If banks anticipate that the ZLB is a binding constraint then we have $R^*(\epsilon) = max(0, \hat{R}(\epsilon))$. In contrast, if banks believe that central bank is willing to implement negative interest rates then in this case the ZLB no longer binds and the unconstrained policy rate is given by $R^*(\epsilon) = \hat{R}(\epsilon)$. The motivation for including expectations over whether or not the ZLB is anticipated to be a binding constraint for policy when a bank forms its NIM forecast in a given scenario comes from Figure 1. The figure shows that in nearly all of the CCAR scenarios over the past three years, the lower end of the distribution of short term interest rate projections was almost always bounded below by zero. The one exception is the 2016 SSA. The interpretation is that negative interest rates came as a surprise to these banks and therefore the surprise itself may explain the nonlinear results found in Section 4.

The next set of assumptions relate the policy rate to interest rates on short-duration assets and short-duration liabilities held by the bank. The interest rate on short-duration assets is assumed to be a fixed markup, $\mu > 1$, over the policy rate, so that $R^s = \mu R^*(\epsilon)$. The interest rate paid on short-duration liabilities is given by:

$$R^d = \Omega R^*(\epsilon) \text{ where } \Omega = \begin{cases} 1 \ if \ R^*(\epsilon) \geq 0 \\ \omega \ if \ R^*(\epsilon) < 0 \end{cases}$$

In this expression, $\omega \in (0, 1)$ captures differing degrees of imperfect pass-through from the policy rate into the interest rates on short-duration liabilities, including the deposit rate. If $\omega = 1$, as is assumed when interest rates are positive, the policy rate flows through one-for-one into the interest paid on short-term liabilities and pass-through is complete. However, when the policy rate turns negative, values of $\omega < 1$ allow for incomplete pass-through. For example, in the case of deposit rates,a bank might not want to pass on the cost of holding deposits to its customer base out of concern of deposit flight—depositors may look to move their funds elsewhere to avoid paying the fee or they may simply hold cash instead. At the extreme, $\omega = 0$ sets a floor such that $R^d = 0$ when $R^*(\epsilon) < 0$.

Finally, moving up the yield curve, we assume long-term interest rates are proportional to short-term rates, so that $R^l = \phi(R^*(\epsilon))R^*(\epsilon)$, where $\phi(R^*(\epsilon))$ is a sufficiently general function that captures a number of alternative assumptions regarding the response of the yield curve to a decline in short rates. For example, $\phi(R^*) = \bar{\phi} \geq 1$ implies that long-term rates are a fixed proportion of short-term rates, so that the yield curve shifts down in parallel as short-term rates decline. Alternatively, $\phi(R^*)$ could be parameterized to have properties that imply that short-term interest rates are an increasing proportion of long-rates as the level of the policy rate declines (and potentially turns negative). This has the implication that the yield curve becomes progressively flatter as the level of the policy rate declines. Claessens, et al (2016) find evidence that such a relationship is important for describing $NIMs$ in a low interest rate environment.

Substituting these interest rate assumptions into the expression for NIMs and rearranging yields

$$NIM = \left[(1-\chi)\mu - (1-\eta)\lambda\Omega + (\chi - \lambda\eta)\phi(R^*(\epsilon))\right] R^*(\epsilon)$$

This expression allows us to highlight three potential sources of nonlinearities associated with the policy rate as it moves into negative territory. These nonlinearities operate through three distinct channels described in turn below.

5.1.1 The Deposit Margin Channel.

The deposit margin channel allows for changes in bank behavior to introduce nonlinearities to the net interest margin. Specifically, in order to avoid having to pass negative rates through to their deposit base, banks might alter the degree of pass-through as the policy rate turns negative.

We can isolate the deposit margin channel by assuming that $\phi(R^*) = \bar{\phi}$, so that long-term interest rates on assets and liabilities move one-for-one with the policy rate. Under this assumption, the expected change in the NIM with respect to the underlying shock becomes

$$\frac{\partial NIM}{\partial \epsilon} = \left[(1-\chi)\mu - (1-\eta)\lambda\Omega + (\chi - \lambda\eta)\bar{\phi}\right] E[\partial R^*(\epsilon)/\partial\epsilon]$$

As the policy rate moves into negative territory, the shift to incomplete pass-through introduces a nonlinearity as $\Omega = 1$ changes to $\Omega = \omega < 1$. With incomplete pass-through to deposit rates, the decline in the policy rate does not fully translate into lower funding costs on short-term liabilities. All else equal this should compress NIMs relative to the alternative of complete pass through.

This channel is summarized with the following hypothesis:

Hypothesis 1 *If banks are hesitant to let negative interest rates flow through to their deposit base, imperfect pass-through implies additional NIM compression as the policy rate moves below zero.*

In order to test this hypothesis, we can proxy for the strength of the deposit margin channel using balance sheet data to measure the share of deposits in total interest-bearing liabilities, $(1-\eta)\lambda$. A bank that greater dependance on deposit funding likely values its deposit base more relative to a bank that can easily substitute into other funding sources. As a result, these should be more reluctant to pass negative rates through to deposit rates and, hence, more likely to suffer NIM compression in a negative rate environment.

5.1.2 The Liquidity Management Channel.

The liquidity management channel—in contrast to the deposit margin channel—assumes pass through to interest rates on short-duration assets and liabilities is not impeded and, as a result, generates potential gains and losses depending on a banks' liquidity management practices. An important aspect of the identification of this channel stems from the fact that the violation of the zero lower bound comes as a surprise. As discussed previously, the evidence from Figure 1 suggests this is indeed the case for the CCAR scenarios.

To understand the importance of the ZLB in identifying this channel consider that when the policy rate is positive, $R^*(\epsilon) \geq 0$, our assumptions on pass-through imply $\Omega = 1$. As long as the bank believes that the ZLB is a binding constraint for policy, we have $E[R^*(\epsilon)|ZLB] = \alpha$. These expectations reflect the fact that the policy rate is assumed to respond only asymmetrically to shocks. This asymmetry carries over to the expected evolution of the NIM as the ZLB effectively dampens anticipated losses (gains) on interest income (expenses) from short duration assets (liabilities) in the event of an adverse shock. However, if the monetary authority pushes the policy rate into negative territory, this insulating effect no longer applies. In this case, we have $E[R^*(\epsilon)|No\ ZLB] = 2\alpha - 1$ and because $E[R^*(\epsilon)|No\ ZLB] \leq E[R^*(\epsilon)|ZLB]$ this means that a bank with a large share of short-duration assets will suffer NIM compression through amplified losses on interest income. In contrast, a bank with a large share of short-duration liabilities will experience an expansion of its NIM through a reduction in funding costs. Hence, it is the liquidity management practises of the bank that determine the response of $NIMs$ when the movement of the policy rate into negative territory comes as a surprise to the banks..

This leads to the following testable hypothesis:

Hypothesis 2 *When the policy rate moves into negative territory, relaxing the zero lower bound amplifies the exposure of $NIMs$ via pass-through to short-term interest rates.*

We can proxy for the strength of the liquidity management channel using balance sheet data to measure the share of short-duration assets in total interest-earning assets, $(1 - \chi)\mu$, and the share of short-duration interest-bearing liabilities in total interest-bearing liabilities, $(1 - \eta)\lambda$. Banks that have a large exposure to short-duration assets because they are more heavily engaged in liquidity provision to borrowers will suffer amplified NIM compression as the policy rate turns negative. The opposite it true of banks that have a large exposure to short-duration liabilities because they are more heavily engaged in liquidity provision to depositors.

5.1.3 The Yield Curve Compression Channel.

A number of authors have offered empirical evidence showing that the yield curve becomes progressively flatter as the level of short-term interest rates decline. The yield curve compression channel captures the resulting implications for $NIMs$.

It can be highlighted by assuming full pass through into deposit rates, $\Omega = 1$. Additionally, rather than assuming $\phi(R^*) = \bar{\phi}$ as above, assume the yield curve flattens (nonlinearly) as the level of the policy rate moves lower and eventually turns negative. To capture this we assume $\phi(R^*)$ is convex, so $\partial\phi(R^*)/\partial R^* \geq 0$ and $\partial^2\phi(R^*)/\partial R^{*2} > 0$. We also allow for an effective lower bound to the (gross) policy rate, $\underline{R}^*$ (which is less than one to accommodate a negative net policy rate) and further assume $\lim_{R^* \to \underline{R}^*} \phi(R^*) = 1$ and $\lim_{R^* \to \underline{R}^*} \partial\phi(R^*)/\partial R^* = 0$.

With these assumptions in mind, consider the change in $NIMs$ with respect to the policy rate

$$\frac{\partial NIM}{\partial R^*} = (1-\chi)\mu - (1-\eta)\lambda + (\chi - \lambda\eta)\left(\phi(R^*) + \frac{\partial\phi(R^*)}{\partial R^*}R^*\right)$$

The first two terms capture the deposit margin and liquidity management channels discussed above; absent shocks to the economy these two channels are linear in the policy rate. In contrast, the third term captures a potential nonlinearity that occurs through a flattening of the yield curve that gets more pronounced as the level of the policy rate declines and eventually turns negative. For most banks, the share of long-term assets in total interest interest earning assets exceeds that of long-term liabilities, so that $\chi > \lambda\eta$, implying that the flattening of the yield curve will increasingly depress $NIMs$ as the level of the policy rate declines.

This leads to the following testable hypothesis:

Hypothesis 3 *As the level of interest rates moves into negative territory a flattening of the yield curve leads to amplified NIM compression.*

The strength of the yield curve compression channel is measured using balance sheet data on the share of long-duration assets in total interest-earning assets, χ, and the share of long-duration liabilities in total interest-bearing liabilities, $\eta\lambda$. As the level of short-term interest rates decline banks that have a higher share of long-duration assets should experience a larger decline in $NIMs$.

5.2 Empirical Model

We test our three hypothesized non-linearities using the following regression framework:

$$y_i = \alpha + \beta X_i + \lambda D_i + \theta Size_i + \varepsilon_i \tag{5}$$

where: y_i is a measure of bank-specific sensitivity to negative interest rates, which we proxy with the estimated coefficient from equation **??** weighted by its standard error. To explain this bank-specific sensitivity, we include a set of two dummy variables, denoted D_i. The first dummy variable takes on the value of one if the BHC is a custodial bank. Custodial banks are unique in that they do not follow a traditional banking business model, but instead take on custodial functions in transactions between third parties. These banks tend to hold a large share of assets in cash and securities compared to other banks in our sample. We also include a dummy variable for banks whose t-statistic is an outlier (outside of two standard errors of the mean statistic across all banks) in the analysis in the previous section. Finally, we include bank size, $Size_i$, measured as the log of total assets (in billions of dollars). This variable is included because banks size generates differences in economies of both scale and scope that might help a bank deal with the nonlinear effects of negative interest rates. For example, large banks are more likely to have the expertise and personnel to more effectively hedge interest rate risk using derivatives.

The focus of the analysis is to uncover a systematic link between the sensitivity to negative rates and bank balance sheet characteristics, denoted generically in the regression as X_i. The exact measurement of X_i is tailored to each hypothesis. Regardless, all measurement is done using Call Report data collected by the Federal Reserve as of the fourth quarter of 2015, the last possible observation available prior to the conduct of the 2016 CCAR stress test. This gives us the most accurate description of the asset and liability structure of the bank at the time the negative interest rate scenario came into play. Details of the data construction are given in Appendix A.

To test the *deposit margin channel* we measure $1-\eta$ using data on the share of deposits in total interest bearing liabilities. Combining this with data on the share of interest bearing liabilities in total interest earning assets, our measure of λ, we construct $X_{L_d} = (1-\eta)\lambda$ and include it in the regression above to proxy for the degree to which the bank is reliant on short-term deposit funding.

Allowing $\hat{\beta}_{L_d}$ to denote the estimated coefficient on X_{L_d}, the following null hypothesis tests the empirical validity of the deposit margin channel:

$$H1_0 : \hat{\beta}_{L_d} < 0$$

If this hypothesized transmission channel is important we would expect banks that rely more heavily on deposit funding should be less likely to want to pass the costs associated with negative interest rates through to their depositor base. Hence, these banks would be expected to suffer the most in terms of NIM compression as a result of negative interest rates.

To test the *liquidity management channel* we use data on the share of short-term interest earning assets in total interest earning assets to measure $1-\xi$. Specifically, we take the sum of interest-bearing liabilities in U.S. and foreign offices (deposits); federal funds sold in domestic offices; and securities purchased under agreement to resell (repo). Letting $X_{A_s} = 1-\xi$, this measure enters into the regression framework above to proxy for the exposure of $NIMs$ to short-term interest rates through the asset side of the balance sheet. On the liability side, we use data on the share of short-term interest bearing liabilities—that is, the sum of deposit liabilities, federal funds purchased, repo sold, and other borrowed money—in total interest bearing liabilities to measure $1 - \eta$. Combining this with the measure of λ described above, we let $X_{L_s} = (1-\eta)\lambda$ proxy for the exposure of $NIMs$ to interest rates through short-term liabilities.

Allowing $\hat{\beta}_{A_s}$ and $\hat{\beta}_{L_s}$ to denote the estimated coefficients on X_{A_s} and X_{L_s}, respectively, we can test the following null hypothesis to assess the empirical validity of this transmission channel:

$$H2_0 : \hat{\beta}_{A_s} < 0; \hat{\beta}_{L_s} > 0$$

If negative interest rates leads to an amplified impact on $NIMs$ via unimpeded pass-through, banks with a larger share of short-term interest earning assets would be expected to suffer a larger decline in $NIMs$ through reduced interest income. By the same token, banks with higher dependance on short-term funding would expect an expansion in $NIMs$ through lower funding costs as the negative policy rate passes through to interest rates on short-term liabilities.

Finally, to test the *yield curve compression channel* we measure ξ as the share of loans in total interest earning assets and construct $X_{A_L} = \xi$. On the liability side, we measure η using data on the share of subordinated notes and debentures in total interest bearing liabilities and combine it with data on the share of interest bearing liabilities in total interest earning assets to construct $X_{L_L} = \eta\lambda$.

Allowing $\hat{\beta}_{A_L}$ and $\hat{\beta}_{L_L}$ to denote the estimated coefficients on X_{A_L} and X_{L_L}, respectively, we can test the following null hypothesis to assess the empirical validity of this transmission channel:

$$H3_0 : \hat{\beta}_{A_L} < 0; \hat{\beta}_{L_L} > 0$$

If the yield curve flattens disproportionately as the level of interest rates declines, we would expect banks with the highest exposure to a reduction in long-term interest rates to suffer the most through lost interest income on long-term assets. By the same token, banks that have a larger share of long-term liabilities should suffer the least as a reduction on interest expenses through long-term liabilities should boost $NIMs$.

5.3 Results

Results are presented in Table 2. Column one shows results for an empirical test of Hypothesis 1. If banks were hesitant to pass negative rates through to their depositor base, we would expect the estimated coefficient on the deposit share, X_{L_D}, to be negative and statistically significant. As can be seen from the first column of the table, the estimated coefficient is the wrong sign although it is not statistically significant. We conclude that there is little empirical support for the deposit margin channel as it operates through imperfect pass-through to deposit rates. This result is surprising because concerns over the impact of sticky deposit rates on bank profitability play prominently in much of the policy discussion on negative rates. One possible explanation for why we find no evidence to justify these concerns is that the empirical measure of deposits used in this analysis is not granular enough to capture sticky rates in narrowly defined deposit categories (for example, retail deposits only).

The next two columns report results for Hypothesis 2. In contrast to the sticky deposit rate hypothesis, if the negative policy rate is expected to pass through to interest rates on short-duration assets and liabilities more broadly then we would expect this pass through to affect profitability through reduced interest income (expenses) on these assets (liabilities). In this case, we would expect the estimated coefficient on the share of short-duration assets, X_{A_S}, to be negative and statistically significant and the estimated coefficient on the share of short-duration liabilities, X_{L_S}, to be positive and statistically significant.

The results presented in column two show strong evidence in favor of this hypothesis. Banks with a larger share of short-term interest earning assets suffer more pronounced declines in revenue through $NIMs$ in a negative interest rate environment. The estimated decline, roughly 36 basis points for every additional percentage point increase in the share of short-term assets, is highly statistically significant. In contrast, banks with a larger share of short-term funding benefit from reduced interest expenditure. For every additional percentage point increase in the share of short-term funding, the NIM is boosted by roughly 29 basis points.

By estimating separate coefficients for X_{A_S} and X_{L_S} the regression presented in column two, in principle, allows for asymmetric pass-through to interest rates on short-term assets and liabilities. A Wald test of the hypothesis that $\hat{\beta}_{A_S} + \hat{\beta}_{L_S} = 0$, however, cannot reject symmetric pass-through (F statistic of 0.06 with associated p-value of 0.81). In light of this, column three present results that include the quantity $X_{A_S} - X_{L_S}$ in the regression and estimate a single coefficient, $\hat{\beta}_S$, which explicitly imposes the assumption of symmetric pass-through. The resulting coefficient estimate is negative, as expected, and highly significant. An increase in the share of short-term assets (liabilities) by one percent amplifies (dampens) the exposure of losses through $NIMs$ as a result of negative interest rates by 33 basis points.

Given the symmetric nature of pass through, whether or not a bank anticipates suffering reduced profitability as a result of negative interest rates is largely determined by the relative holdings of short-duration assets and liabilities. For banks that are more actively engaged in liquidity provision to lenders, the overall decline in $NIMs$ resulting from the deterioration in macroeconomic conditions that gives rise to the negative rate environment is amplified through a decline in interest income on a relatively large share of short-duration assets. In contrast, the delcine in $NIMs$ is damped for banks that are more actively engaged in liquidity provision to depositors. Finally, banks that are sufficiently well diversified in the provision of liquidity services expect the reduction in interest income on short-duration assets to be offset by a decline in short-term funding costs.

	$H1_0 : \hat{\beta}_{L_d} < 0$	$H2_0 : \hat{\beta}_{A_s} < 0; \hat{\beta}_{L_s} > 0$		$H3_0 : \hat{\beta}_{A_L} < 0; \hat{\beta}_{A_L} > 0$	
	Imperfect Pass-through to Deposit Rates	*Direct Exposure via Short-term Assets & Liabilities*		*Yield Curve Compression*	
	1.	2.	3.	4.	5.
Constant	−23.4	−15.9	−13.8	−77.1.***	−76.7***
	(0.30)	(0.37)	(0.51)	(0.00)	(0.00)
X_{L_D}	43.1				
	(0.17)				
X_{A_S}		−35.6***			
		(0.00)			
X_{L_S}		29.3*			
		(0.08)			
$X_{A_S} - X_{L_S}$			−33.0***		
			(0.00)		
X_{A_L}				44.3***	
				(0.00)	
X_{L_L}				−55.8	
				(0.68)	
$X_{A_L} - X_{L_L}$					43.9***
					(0.00)
Size	−0.33	−0.32	−0.58	1.71	1.70
	(0.73)	(0.75)	(0.59)	(0.16)	(0.16)
Processing Bank	3.8	14.8***	13.9***	19.4***	19.3***
Dummy	(0.33)	(0.00)	(0.00)	(0.00)	(0.00)
Outlier Dummy	−28.3***	−12.3***	−24.7***	−24.4***	−24.4***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
R^2	***0.52***	***0.65***	***0.65***	***0.60***	***0.60***
Obs.	***25***	***25***	***25***	***25***	***25***

Table 2. Tests of Hypothesized Nonlinearities Associated with Negative Interest Rates.

	$\hat{\beta}_{As}$	$\hat{\beta}_{Ls}$	H_0 : $\hat{\beta}_{As} + \hat{\beta}_{Ls} = 0$
Short-term Assets and Liabilities	−35.6	29.3	0.06
	(0.00)	(0.08)	(0.81)
Disaggregated, by category...			
Deposits with domestic offices	−76.1	44.3	4.2
	(0.04)	(0.17)	(0.05)
Deposits with foreign offices	167.5	−31.4	9.0
	(0.02)	(0.50)	(0.01)
Federal funds bought (sold) in domestic offices	−411.3	−369.3	*xxx*
	(0.30)	(0.01)	(*x.xx*)
Securities purchased (sold) under agreement	−55.5	216.9	4.0
to resell (repurchase)	(0.00)	(0.02)	(0.06)

Table 3. Symmetry of Pass-through to Short-term Assets and Liabilities, by Category.

The last two columns of Table 2 present results for Hypothesis 3. If the primary transmission comes through a progressive flattening of the yield curve as the policy rate turns negative, we would expect banks to suffer compressed $NIMs$ as the policy rate turns negative. In this case, we would expect the estimated coefficient on the share of long-duration assets, X_{A_L}, to be negative and statistically significant and the estimated coefficient on the share of long-duration liabilities, X_{L_L}, to be positive and statistically significant. As can be seen from the fourth and fifth columns of the table, which allow for asymmetric and symmetric pass-through, respectively, to long term interest rates, the estimated coefficients are of the opposite sign. From this we conclude that the impact on $NIMs$ that occurs through short-duration assets (liabilities) dominates the effect of longer duration assets (liabilities). One conjecture about why this is the case is that, in absense of incomplete pass-through, short-duration assets (liabilities) reprice more frequently than long-duration assets (liabilities) simply because they roll over faster.

Table 3 digs deeper into the results that support Hypothesis 2 by examining whether the symmetric pass-through result extends to disaggregated data on short-duration assets and liabilities. The table presents coefficient estimates and p-values for disaggregated short-term assets (first column) and liabilities (second column) as well as the F-statistic for a Wald test that the coefficients are equal in absolute value. For reference, the first row of the table shows restates the results based on aggregate data as presented in column two of Table 1 above. The remaining rows show results estimated separately on deposits held in US and foreign offices, federal funds bought (sold) in domestic offices, and securities purchased (sold) under agreement to resell (repurchase).

The aggregate results mask some important differences in the degree of exposure across different categories of short-term asset and liabilities. First, in contrast with the aggregate data, the hypothesis of symmetric pass-through is rejected for every subcategory. For domestic deposits pass-through is stronger on the asset-side of the balance sheet with the adverse effect of reduced interest income more than offsetting the gain from lower interest expenses on deposit liabilities.[17] The results on foreign deposits show the opposite result likely reflecting expectations of gains on deposits held abroad owing to a depreciation of the U.S. dollar that may be exacerbated by the implementation of negative interest rates.[18] This is a noteworthy finding because it suggests U.S. banks anticipate significant international spill overs from a negative interest rate policy. The results on exposure to federal funds are surprising as well. Regardless of whether it is on the asset or the liability side of the balance sheet, any exposure to federal funds is anticipated to negatively affect NIMs in a negative interest rate environment. The coefficient estimates on both the asset- and the liability-side are negative and quantitatively large, but is only statistically significant on the liability side of the balance sheet. Finally, for repurchase agreements statistically significant effects operate through both interest income (deteriorating $NIMs$ as interest rates turn negative) and interest expenses (boosting $NIMs$). However, the magnitude of the coefficient estimate on the liability side is much greater in absolute value than the estimate on the asset side suggesting that banks that rely on repurchase agreements as a source of short-term funding anticipate much larger gains as a result of negative interest rates relative to losses expected by banks that extend short term credit through repurchase agreements.

6 Conclusion

There is no historical experience from which to draw upon to understand how U.S. banks would fare in a negative interest rate environment. In light of this, the contribution of this paper is to exploit a unique new data source to empirically examine expectations of the banks themselves believe they would fare in a negative rate environment.

Our results reveal a significant degree of heterogeneity in how various banks expect that negative rates would affect their profitability through net interest margins. Roughly speaking, one-third of the banks in our sample view negative rates as having a significant adverse effect through compressed net interest margins. An additional one-third of the banks in the sample expect to negative rates to boost earnings through expanded net interest margins. The remainder do not view negative interest

[17] Note that the estimate for $\hat{\beta}_{Ls}$ reported for deposits with domestic offices is comparable to the estimate in column one of Table 2, although they are not identical because the regression used in Table 2 includes only deposit liability shares where as the estimate in Table 3 includes both deposit asset and liability shares.

[18] As pointed out in Beck and Malkhozov (2016), one motivation for implementing negative interest rates in some European countries has been to stimulate growth through the external sector.

rates as having a significant impact on earning through NIMs. These cross-bank differences can largely be explained by differences in liquidity provision practices. Banks that are actively engaged in liquidity provision to borrowers expect to by hurt by negative rates owing to reduced interest income on short-duration assets. In contrast, banks that are actively engaged in liquidity provision to depositors expect to gain through a reduction in short-term funding costs. These distributional effects—some banks loose while others gain in a negative rate environment—largely wash out at the aggregate level, however, as the banks in the sample as a whole are sufficiently well diversified across liquidity provision services.

These results have important policy implications. The fact that negative interests are anticipated to have largely distributional effect suggests that concerns about reduced profitability for the banking system as a whole (and hence muted monetary policy transmission) are likely overstated. In contrast, policymakers would be better suited by focusing attention on the safety and soundness of those specific institutions which are most exposed to losses in a negative interest rate environment. Stepping into financial stability concerns more broadly, our results show that these institutions are highly exposed because they are heavily engaged in liquidity provision to borrowers through short-term lending. One conceivable side effect of a negative interest rate policy could be that depressed profits cause these banks to roll back their supply of short-term lending. Because these banks are the ones most engaged in this activity, such a response could manifest as a funding shock to those dependant on bank lending as a source of short-term funding.

A future iteration of this paper we will investigate whether the liquidity coverage ratio—a new regulation designed force banks to hold a larger share of high quality liquid assets in order to be able to withstand cash outflows during a period of significant stress—increases the exposure of of the banking system to higher potential losses in a negative interest rate environment.

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