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Did BOJ's Negative Interest Rate Policy Increase Bank Lending?

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Abstract

We investigate the effects of the negative interest rate policy (NIRP) in Japan on bank lending using regression discontinuity design (RDD). On January 29, 2016, the Bank of Japan announced the beginning of the NIRP from February 16, 2016. Since the financial market did not anticipate this policy, we use the event as a natural experiment. For a few months, starting from February 2016, a negative interest rate was levied on banks that held reserves exceeding the average monthly reserves of 2015. This allows us to employ RDD. The results suggest the average treatment effect on the banks to which a negative interest was levied was approximately -1.5% to -3.5%. In other words, the loan rates of banks to which negative interest rates were levied declined compared to those of the banks that were not subject to NIRP.

Keywords: negative interest rate policy, regression discontinuity design, Bank of Japan, bank lending

JEL classification: E52, E51, G21

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1 Introduction

Since the 2000s, central banks in Japan, the United States, the UK, and Europe have been searching for policies other than a conventional monetary policy. By reaching a zero limit on interest rates, they could not use ordinary monetary easing to lower the policy interest rate. Therefore, Japan's central bank adopted a quantitative easing policy (QE), under which it purchases government and other bonds and supplies a sufficient monetary base.

In addition, after Denmark's National bank temporarily imposed a negative interest rate on central bank deposits in 2012, the European Central Bank (ECB) and Swiss National Bank adopted similar policies in 2014, the National Bank of Sweden in 2015, and the Bank of Japan (BOJ) in 2016. However, each central bank's negative interest rate policy (NIRP) is somewhat different. Although they all impose a negative interest rate on central bank deposits, they have different purposes, such as increasing bank lending, lowering loan and deposit interest rates, and depreciating the exchange rate.

On the other hand, many researchers consider the effect of NIRP theoretically. For instance, Gunji and Miyazaki (2016) show that NIRP for central bank deposits has a negative impact on bank lending and deposits using a theoretical model that applies the Cournot model to the banking industry and obtained the following results. A negative interest rate on central bank deposits is a cost for commercial banks. Banks that increase loans increase deposit accounts for borrowers and need to increase central bank deposits in preparation for an increase in withdrawals from borrowers' deposits. If a central bank's deposit becomes a cost, banks will hesitate to increase loans and their accompanying deposits. However, this is contrary to the expectations of the central banks in countries that hitherto introduced a NIRP. Similarly, Honda and Inoue (2018) use the general equilibrium model of Tobin (1969) with money, bonds, stocks, and foreign assets to demonstrate that lowering interest rates on reserves will result in lower bond yields, higher stock price returns, and currency depreciation. Additionally, Eggertsson et al.

(2017) use a new Keynesian dynamic stochastic general equilibrium (NK-DSGE) model with banks to indicate the NIRP has a negative impact on the economy by deteriorating the bank's interest. These theoretical investigations suggest that empirical analysis would result in the NIRP having a negative impact on bank lending.

However, attempting to analyze NIRP empirically poses two difficulties. First, to capture the influence of NIRP post-implementation using aggregate data, it is not easy to identify the effects of other macroeconomic factors and the negative interest rates. In other words, if multiple policy changes and macroeconomic shocks occur at the same time, it is difficult to identify these effects from the econometric viewpoint. Furthermore, even if researchers attempt to capture these effects using individual data, NIRP influences all economic entities simultaneously, making the effects difficult to identify.

To overcome such difficulties, several previous studies have used difference-in-differences (DiD) estimations. For example, Heider et al. (forthcoming) estimate the impact of ECB's NIRP on bank loans by DiD and find a negative impact on bank loans. Similarly, Molyneux et al. (2017) use bank level data from 33 OECD countries, and the DiD results show that bank loans decreased after adopting the NIRP.[1] Although the results of these studies suggest NIRP has a negative impact on bank loans, some strong assumptions are needed to obtain consistent DiD estimates. One is that there is no other exogenous shock at the time the treatment is taken. Regarding this point, the empirical strategy is reliable because no other major shocks were seen at the introduction of ECB's NIRP and the policy was not anticipated. The second is that there is a parallel trend between the treatment and control groups. To demonstrate that the outcome variables of these groups would have fluctuated in parallel, similar to the previous period, even if no treatment was taken, at least a parallel trend must be observed before the treatment. However, neither study has presented persuasive results on this point.

Therefore, this study examines whether BOJ's NIRP adoption in 2016 affected bank

[1] From another viewpoint, Nucera et al. (2017) create an indicator showing to what extent banks can tolerate the global stock price decline in the euro area using bank data from 111 banks from 2012 to 2014, and show that small banks that adopt traditional management had taken risks further after implementing NIRP.

lending using a regression discontinuity design (RDD) with bank level data. The BOJ announced an amendment to the "Condition of Complementary Deposit Facility as a Temporary Measure to Facilitate Supplying of Fund" at the Monetary Policy Meeting on January 29, 2016, and implemented NIRP from February 16, 2016. Prior to the January 2016 Monetary Policy meeting, the markets did not expect the introduction of NIRP. In fact, Haruhiko Kuroda, the President of the BOJ, denied that the bank would adopt NIRP until just before the meeting, and almost everyone believed him. Therefore, BOJ's introduction of NIRP can be treated as a natural experiment to verify its effect. Moreover, since negative interest rates do not apply to all banks, but only to those that satisfy certain conditions, it is possible to verify the policy's effects by comparison.

There is limited empirical analysis on BOJ's NIRP. For instance, Fukuda (2018) uses a GARCH model to estimate the impact of long-term interest rates on stock prices in Korea, Singapore, Taiwan, China, and Thailand during Japan's NIRP period. His estimation suggests a statistically significant negative impact. Since the interest rates for long-term bonds in this period were negative, Japan's long-term interest rate had actually the effect of boosting stock prices in these countries. Further, Hattori (2017) shows that interest rates were divided for each market under Japan's NIRP. However, to the best of our knowledge, there is no empirical study that analyzes the direct effects of negative interest on the Japanese banking industry.

From the empirical results, NIRP reduced the lending of banks with NIRP by -1.5% to -3.5% relative to the banks without it. This result does not change when using either linear or quadratic functions and a subsample consisting of regional banks. Nonparametric and donut-RD estimations also do not affect the results. In addition, since the results change with different cutoffs, it is suggested that NIRP had an impact on bank lending. On the other hand, we conducted the same estimate with data on Shinkin banks, which are smaller local financial intermediaries but obtained ambiguous results. This is believed to be because Shinkin owns a lot of deposits to non-BOJs and does not necessarily aim for profit maximization but runs for welfare of members. From these results, the result that bank loans with NIRP applied were less than for banks not applying it are robust.

The structure of this paper is as follows. Section 2 explains how we can apply RDD to verify NIRP and introduces the data. In Section 3, we use the nonparametric density function to determine whether the running variable is appropriate and show the benchmark estimation using a parametric model. For the outcome variable, we analyze not only the loan growth rate, but also the growth rates of deposits and securities. In Section 4, we verify the robustness of the results in the previous section by nonparametric estimation, donut-RD estimation, different cutoff points, and Shinkin bank sample. The final section concludes the paper.

2 Method

2.1 Empirical Strategy

BOJ's NIRP can be described as follows.[2] We denote the reserves as R_i for bank i and the rate of required reserves as α. The bank imposes an interest rate of 0.1% on the amount obtained by subtracting the required reserves αR_i from the *Basic Balances*, $\bar{R}_{i,2015}$, which is the average balance of BOJ's current account from January to December 2015. The balances to which a positive interest rate is applied R^+ are current account balances minus required reserves, and the upper bound is the Basic Balance minus the required reserves, that is,

$$R_i^+ = \min\{\underbrace{R_i - \alpha R_i}_{\text{Actual amount}}, \underbrace{\bar{R}_{i,2015} - \alpha R_i}_{\text{Upper bound}}\}. \tag{1}$$

The Bank imposes a 0% interest rate on αR_i minus R_i^+, and the upper bound is the sum of required reserves and the *Macro Add-on Balances* R_i^M, which is $\bar{R}_{i,2015}$ multiplied by a certain rate. That is,

$$R_i^0 = \min\{\underbrace{R_i - R_i^+}_{\text{Actual amount}}, \underbrace{\alpha R_i + R_i^M}_{\text{Upper bound}}\}. \tag{2}$$

[2]See also http://www.boj.or.jp/en/statistics/outline/notice_2016/not160216a.pdf.

NIRP imposes a -0.1% interest on the *Policy-Rate Balances* R_i^-, which are current account balances minus the balances to which positive and zero interest rates are applied, that is,

$$R_i^- = R_i - R_i^+ - R_i^0. \tag{3}$$

Substituting Eqs. (1) and (2) into Eq. (3) and solving it, we have

$$R_i^- = R_i - \min\{R_i, \bar{R}_{i,2015}\} - \min\{R_i^M, R_i - \min\{R_i, \bar{R}_{i,2015}\}\}. \tag{4}$$

Furthermore, noting that $\min\{a, b\} = -\max\{-a, -b\}$, we obtain

$$R_i^- = \max\{R_i - \bar{R}_{i,2015} - R_i^M, 0\}. \tag{5}$$

The proof is shown in the Appendix. In the calculation of R_i^M, the rate imposed on $\bar{R}_{i,2015}$ was 0% when the BOJ introduced the NIRP. Since the other part of R_i^M is not much higher, we can ignore the Macro Add-on Balance. As $R_i^M \simeq 0$ for all i, we obtain $R_i^- \simeq \max\{R_i - \bar{R}_{i,2015}, 0\}$. Therefore, BOJ applies negative interest rates to banks whose current accounts increased more than the average of 2015 and to those whose current accounts declined to benefit from the positive interest rates. In other words, interest on the current account was determined based on whether the current account increased more than the average of 2015.

Figure 1 shows the interest rates imposed in February 2016 for each balance. There was no interest rate on required reserves, but a positive interest rate was added to the balances above that and a negative interest rate imposed on the remaining balances. The above calculation result represents this situation.

[Insert Figure 1 here]

Now, we define the rate of change in the current account of bank i, R_i, from the Basic Balance, $\bar{R}_{i,2015}$, as

$$RR_i \equiv \frac{R_i - \bar{R}_{i,2015}}{\bar{R}_{i,2015}}. \tag{6}$$

Therefore, a negative interest rate is applied to banks with $RR_i > 0$. More importantly, banks whose RR_i at the time of the announcement (January 29, 2016) exceeded 0 should have tried to avoid negative interest rates by February 16, when the policy was implemented. Therefore, we estimate the effects of NIRP by identifying the banks where RR_i was around 0 as of December 2015 or immediately before this period.

We employ parametric and nonparametric estimations of RDD. First, we use the following parametric model:

$$\Delta \ln L_i = \beta_0 + \beta_1 \mathbb{1}(RR_i > 0) + \beta_2 RR_i + \beta_3 RR_i \times \mathbb{1}(RR_i > 0) + \varepsilon_i, \tag{7}$$

where $\Delta \ln L_i$ is the growth rate of the loans of bank i from March 2015 to March 2016, that is, $L_{2016/03,i}/L_{2015/03,i} - 1$. $\mathbb{1}(\cdot)$ is a function equal to 1 if the condition holds, and 0 otherwise, and ε_t an error term with mean zero. β_1 is an estimation of the average treatment effect around $RR_i = 0$. To handle nonlinearity, we also use a quadratic equation:

$$\begin{aligned} \Delta \ln L_i = \beta_0 + \beta_1 \mathbb{1}(RR_i > 0) + \beta_2 RR_i + \beta_3 RR_i \times \mathbb{1}(RR_i > 0) \\ + \beta_4 RR_i^2 + \beta_5 RR_i^2 \times \mathbb{1}(RR_i > 0) + \varepsilon_i. \end{aligned} \tag{8}$$

Since our sample size is relatively moderate, we cannot take a higher-order polynomial. Further, Gelman and Imbens (forthcoming) recommend linear or quadratic polynomials for RDD. Therefore, we set the upper order as 2.

We do not use the demand-side or macroeconomic variables in our estimation method because such factors are also randomly determined between banks around $RR_i = 0$. Similarly, other individual factors of each bank are randomly determined, so it is not necessary to consider them.

2.2 Data

We use data on individual banks (city, regional, second regional, and trust banks) from the Nikkei NEEDS Financial QUEST database. $\Delta \ln L_i$ is the rate of change in loans from the fiscal year ending March 31, 2015 to the one ending March 31, 2016.[3]

For variable R_i, representing the individual bank's deposits to BOJ just prior to the introduction of the NIRP, we use cash and cash due or cash and cash equivalents at the end of the period, that is, December 31, 2005. Although the former includes deposits to other institutions, we use these data because we cannot separate BOJ's current account. The latter also has limitations because it includes cash, but we use these data because few banks disclose cash on the balance sheet. However, since the amounts of deposits to other banks and cash are not so large, the influence of term definitions is considered small.

For the average BOJ deposit in 2015 $\bar{R}_{i,2015}$, we use the average of the available data periods among the balances at the end of March, June, September, and December 2015. Many observations are available when using cash and cash due as R_i for the data on the four quarters, while there is usually only data released for September and December when using cash and cash equivalents at the end of the period. In addition, although the Basic Balance of the actual NIRP is based on the reserve maintenance period from the 16th day of a month to the 15th of the next month, measurement errors may occur because we use the balance at the end of the term.

Therefore, we confirm robustness with two indicators: the reserve ratio calculated with cash and cash due, RR1, and the reserve ratio calculated with the term-end balance for cash and cash equivalents, RR2. Cash due consist of deposits to the BOJ and the other financial institutions, including the Japan Post Bank. Although there are no data on the accurate classification of deposits, almost all deposits are considered to be deposits to BOJ, as a complementary deposit facility provided a positive interest rate for excess reserves during this period. Cash and cash equivalents equal cash and cash due minus

[3] L_i includes loans overseas, but it is negligibly small compared to domestic lending.

deposits to non-BOJ institutions. Therefore, it is desirable to obtain RR2. However, since the number of observations in RR2 is small, we also use RR1. To remove outliers, we exclude observations with loan growth rates over 40%.[4]

Figure 2 shows for what type of timing these data are obtained. R_i is the last period value of $R_{i,2015}$. Since BOJ announced NIRP after R_i, banks were unable to manipulate R_i in response to the policy. $\Delta \ln L_i$ is the rate of change of L_i before and after BOJ's announcement. Therefore, the data after the announcement are only the L_i for March 2016.

[Insert Figure 2 here]

In addition to loans, we also verify deposits D_i and securities B_i as dependent variables. For each variable, we use the rate of change from the fiscal year ending March 31, 2015 to the fiscal year ending March 31, 2016.

Table 1 shows the summary statistics. The top panel presents the statistics of all samples. Comparably, the statistics for the cases where RR_i is positive or negative are shown in the four panels below it. For RR1 < 0, the average of $\Delta \ln L$ is slightly higher, whereas it is lower for RR1> 0. This trend can also be seen in RR2. In other words, for the aggregate data, the rate of increase in lending was small for banks with a large reserve prior to BOJ's announcement.

[Insert Table 1 here]

3 Results

3.1 Density Function of the Reserve Ratio

Before estimating discontinuity, we confirm that no bank controlled the reserve ratio by predicting the introduction of the NIRP before its announcement. Figure 3 shows the

[4] Consequently, we exclude only the Seven Bank, which uses most cash and deposits for ATMs and others. Additionally, most of the ordinary income comes from ATM fees, while loans are around 2% of total assets.

estimated density functions for RR1 and RR2. Although there are small humps, they are almost symmetrical. However, the nonparametric density function of RR2 in Figure 2 has a vertex at a position somewhat higher than zero. However, the shape and spread of the distribution are similar to RR1.

[Insert Figure 3 here]

It is important to note the distributions of the two reserve ratios around 0. If a bank predicted NIRP and controlled its reserve ratio to ensure that it did not exceed 0, the distribution should be skewed to the left. In this case, we expect a big hump at the point where the reserve ratio is slightly below 0 and a dent at the point slightly above 0. However, the density functions of RR1 and RR2 are both smoothly distributed. This suggests that BOJ's NIRP was not anticipated and banks did not control the reserve ratio by including it.

To check for robustness, we conducted Cattaneo et al. (2017)'s density discontinuity test. Using the robust bias-corrected method in the constrained test, we did not reject the null hypothesis of no disruption for RR1, whereas we obtained a p-value of 8% for RR2. Although we should not place significant emphasis on the p-value only, we compare the estimation results of both RR1 and RR2 for a more detailed analysis.

3.2 Eyeball Test

As is common in RDD, we identify if a bank's behavior changed around the cutoff point using a scatter plot. Figure 4 depicts the scatter plot using the value obtained by dividing reserve ratio RR1 by bins and taking the average loan growth rate within the bins, which allows us to identify a certain trend in the scatter plot. Figure 4 has a linear approximation line on the left and right sides of the reserve ratio of 0. For RR1, the intercepts of the two approximated lines are shifted. The intercept of the sample whose reserve ratio is above 0 is located below the sample with a smaller reserve ratio. The sample of banks with a reserve ratio near 0 have almost the same conditions, meaning the loans from banks levied negative interest rates are relatively fewer than otherwise.

[Insert Figure 4 here]

From the shape of the distribution, it may not be possible to approximate it using a linear model. Therefore, Figure 5 draws an approximate curve using a quadratic function. In this case, the intercept is relatively low for observations where RR1 exceeds 0. Therefore, even if we assume a quadratic function, NIRP seems to have reduced bank lending.

[Insert Figure 5 here]

However, since RR1 has large variations in the distribution, we must be careful in interpreting the results. Therefore, for RR2, we draw the approximate curves for the linear and quadratic functions in Figures 6 and 7, respectively, since the definition of RR2 is better than that of RR1. In Figure 6, the linear approximation for RR2 jumps at 0 and the distribution around 0 is not scattered as much. This result is consistent with RR1. In Figure 7, we apply the quadratic approximation for RR2. Although the curvature in Figure 7 is not similar to that in Figure 5, we find discontinuity in both figures. In sum, there is a difference in the rate of change for loans around 0. That is, banks with a negative interest rate reduced their loans.

[Insert Figure 6 here]

[Insert Figure 7 here]

3.3 Benchmark Estimation

Next, we verify whether the negative interest rates had a negative effect on bank lending in more detail by conducting statistical testing. Table 2 reports the results of the parametric estimation. For RR1, the average treatment effect is -1.6 % in the linear model and is statistically significant at the 10% level. Although this is not significant using a quadratic function, it is similar to the −1.5% result in the linear case. For RR2, the results are −2% and −3% for the linear and quadratic functions, respectively, being slightly larger than those for RR1 and statistically significant. These results are consistent with the trends in the previous section's graph and, thus, NIRP did have a negative effect on the lending growth rate.

[Insert Table 2 here]

Many of the observations are regional and second regional banks, but the sample also includes some city and trust banks, which may affect the results. Therefore, Table 2 shows the estimation using regional banks only. For both estimation results, the average treatment effect is slightly more negative than for the full sample estimation. For the quadratic functions of RR2 with the highest estimate, the average treatment effect is −3.4%. Therefore, even if we limit the sample to regional banks, the negative NIRP effect does not change.

The questions is why the above results were obtained. The reason is that NIRP plays the role of a tax to the bank. When lending out, the bank only makes a transfer to the deposit account. However, if cash is brought in at the time of repayment, the deposit reserve may increase, which is a risk factor. Therefore, it is considered that loans decreased.

We also examine the effects on other variables. Table 3 reports the estimates of the average treatment effect with respect to the change rate in deposits. Although the results for RR1 are not statistically significant, for RR2, we obtain a positive effect of around 2%. Table 3 also shows the average treatment effect for the change rate in securities. Similar to deposits, we find a statistically significant effect of around 2%. However, in the nonparametric estimation described below, there was no NIRP effect on deposits and securities. Since the sample size in this paper is relatively small, attention is required when interpreting results that depend on the setting.

[Insert Table 3 here]

4 Robustness

4.1 Nonparametric Estimation

In the parametric estimation, we also use samples that are farther from the cutoff point for estimations with the same weight, so it is possible that they influence the estimates around the cutoff point, that is, the estimated values of intercepts. Thus, we conduct a nonparametric estimation.

Although a parametric estimation uses the same weights on all observations, RDD focuses on a discontinuity, making the estimation with different weights more effective. Using a nonparametric kernel as weight, the estimator is

$$\widehat{\boldsymbol{\beta}}_{+,p}(h_n) = \arg\min_{\boldsymbol{\beta}} \sum_{i=1}^{N} 1(RR_i > 0)\{\Delta \ln L_i - \mathbf{r}_p(RR_i)'\boldsymbol{\beta}\}^2 K_{h_n}(RR_i),$$
$$\widehat{\boldsymbol{\beta}}_{-,p}(h_n) = \arg\min_{\boldsymbol{\beta}} \sum_{i=1}^{N} 1(RR_i \leq 0)\{\Delta \ln L_i - \mathbf{r}_p(RR_i)'\boldsymbol{\beta}\}^2 K_{h_n}(RR_i),$$

where $\mathbf{r}_p(x) = (1, x, \ldots, x^p)'$ for $p = 1, 2$, $K_h(u) = K(u/h)/h$, $K(\cdot)$ is a kernel, and h_n is a bandwidth. We define the intersections of $\widehat{\boldsymbol{\beta}}_{+,p}(h_n)$ and $\widehat{\boldsymbol{\beta}}_{-,p}(h_n)$ as

$$\widehat{\mu}_{+,p}(h_n) = (1, 0, \ldots, 0)\widehat{\boldsymbol{\beta}}_{+,p}(h_n),$$
$$\widehat{\mu}_{-,p}(h_n) = (1, 0, \ldots, 0)\widehat{\boldsymbol{\beta}}_{-,p}(h_n).$$

Then, we obtain the average treatment effect with a nonparametric estimation:

$$\widehat{\tau}_p(h_n) = \widehat{\mu}_{+,p}(h_n) - \widehat{\mu}_{-,p}(h_n).$$

We use a triangular kernel as $K(\cdot)$ and employ the robust bias correction approach for bandwidth h and the standard error following Calonico et al. (2014).

Table 4 reports the results of nonparametric estimation for the loan change rate. The estimation using the entire sample is shown in the upper panel. The estimated average treatment effect is around 1% higher than that of the parametric estimation, from −3.2% to −4.2%. However, since RR2 is not statistically significant, NIRP had a negative effect of approximately 3% on the lending growth rate. The results are similar for the lower panel of Table 4, which presents only the estimation for regional banks. Although there are statistically insignificant estimates, all estimates are negative. This is consistent with the results in the previous section.

[Insert Table 4 here]

4.2 Donut-RD estimation

In the estimation in the previous section, we estimated discontinuity in the vicinity of $RR_i = 0$, which is the cutoff for the negative interest rate applied to reserves. This was based on the assumption that the Macro Add-on Balance is 0, $R_i^M = 0$. However, this case is different from the actual data for several reasons. First, as mentioned in Section 2.2, the Basic Balance is calculated from the 16th of a month to the 15th of the next month, but it cannot be determined from the bank's settlement of accounts. Second, even when NIRP was implemented, if banks used the system of Loan Support Program and Funds-Supplying Operation to Support Financial Institutions in Disaster Areas affected by the Great East Japan Earthquake and received a loan from BOJ, the balance was added to R_i^M. Consequently, there were banks for which their R_i^M were not 0 from the beginning. Third, accurate data representing RR_i are not available. The data we use include not only the central bank deposits of each bank, but also cash and deposits to other financial institutions. Therefore, the cutoff point for the negative interest rate application to each bank may not necessarily be $RR_i = 0$.

To solve this problem, we perform a Donut-RD estimation, excluding observations before and after the cutoff.[5] If the observations around the cutoff point are ambiguous, we

[5]For another application of donut-RD estimation, see Barreca et al. (2011).

can estimate the discontinuity around the cutoff point from an overall trend by removing these observations. Of course, even if the data can be accurately obtained in the excluded section, the condition that the shape of the distribution over the interval can be estimated from other observations is necessary. Additionally, since our sample is small, the donut hole must be relatively narrowly restricted.

The first column in Table 5 sets the donut-hole to $(-0.005, 0.005)$. The ATEs are around -4% in both the linear and quadratic functions, which is similar to the results of the nonparametric estimation. Columns 2 and 3 extend the donut holes to $(-0.01, 0.01)$ and $(-0.015, 0.015)$, respectively. In this case, the ATEs are slightly larger, from -5% to -7%, and the p-values are also relatively small. This is probably because the observations with an ambiguous distribution are excluded and efficient estimation is possible. Consequently, the findings in the previous section did not result from the fact that RR_i cannot be accurately measured.

[Insert Table 5 here]

4.3 Different cutoff points

We conjectured that banks change their behavior around $RR_i = 0$ due to NIRP, but that change may be indirectly caused by some other factors. For example, a relatively large bank is likely to sell government bonds to the BOJ, so the cutoff point may be somewhat higher. Alternatively, relatively small banks may be trying to obtain revenue by lending to other financial institutions on the call market, as it is difficult to find a better investment opportunity on financial markets. In this case, reserves will decrease and there is the possibility that actions different from other banks' may be seen when RR_i is low.

To confirm such possibilities, we use -0.20, -0.10, 0.10, and 0.20 as cutoff points. Table 6 shows the results. Unlike before, the ATEs are positive for any cutoff points, while standard errors are relatively large. Estimations with small p-value do not exist for either the linear estimation or quadratic estimation. In other words, discontinuity cannot be identified for these cutoff points. Therefore, the findings in the previous section were not a result of the cutoff arising due to other influences apart from NIRP.

[Insert Table 6 here]

4.4 Shinkin Banks

Most of the observations in the previous section were on regional and second regional banks. In Japan, there are also many Shinkin banks, which are smaller regional financial institutions. Nevertheless, since Shinkin bank data can only be obtained once a year, we could not analyze it simultaneously with the sample in the previous section. Here, considering the data constraints, we investigate whether the same results as in the previous section can be obtained for Shinkin banks. Data are obtained from Nikkei NEEDS Financial QUEST, as in the previous section.

There are two caveats when analyzing the impact of negative interest rates on Shinkin banks. First, since Shinkin banks' accounts are only available at the end of March, we assume the timing of reserves R_i is March 2016. Note that this assumption is strong, as R_i was for December 2015, before the announcement of the NIRP by the BOJ in the previous section. Second, Shinkin banks' required reserve is only charged if the deposit balance in the previous year exceeds JPY 150 billion. Therefore, we only analyze the Shinkin banks that satisfy this condition. Third, deposits as assets include deposits to the BOJ, as well as deposits to the Shinkin Central Bank, the parent organization. In other words, let R_i^c be the deposit to the Shinkin Central Bank for Shinkin i; then, Shinkin i's total deposits are $R_i^* = R_i + R_i^c$ and its Basic Balance is $\bar{R}_{i,2015}^* = \bar{R}_{i,2015} + \bar{R}_{i,2015}^c$. We assume that deposits to the Shinkin Central Bank will not change during 2015, that is, $R_i^c = \bar{R}_{i,2015}^c$. Then, the cutoff point becomes $RR_i^* = 0$, which allows us to conduct the same analysis as in the previous section.

The results are shown in Table 7. In the linear estimation results in the first and third columns, negative estimates are obtained for both RR1 and RR2. However, both quadratic estimates for the second and fourth columns are positive and smaller. Additionally, standard errors are large on any row for the ATEs. In other words, since ATE is positive or negative depending on the estimation method, it is difficult to determine whether loans by Shinkin banks were affected by NIRP. Indeed, there exists the possibility that some of the ambiguous assumptions above resulted in ambiguous results. However, the purpose of Shinkin banks is different from that of commercial banks: it is not the achievement of profit, but the mutual aid of members. Although commercial banks do not hesitate to reduce loans to pursue profit, Shinkin banks might not have reduced loans due to their consideration for members. Therefore, this result does not necessarily deny those of the previous section.

[Insert Table 7 here]

5 Conclusions

In this study, we examined the effects of BOJ's NIRP on bank lending using RDD. From the parametric estimation, NIRP had a negative effect from 1.5% to 3.5% on the loans of banks with negative interest rate. This trend is the same for the nonparametric estimation, but the effect was -3.2% to -4.2% larger than that of the parametric estimate. In donut RD, ATEs increased further. These results not only support the predictions of the theoretical studies reviewed in the Introduction, but also strengthen the extant results of the empirical analyses using DiD. In other words, NIRP may have a negative impact on loans of banks with negative interest rate.

However, the results of this paper focus on NIRP's impact on individual banks, not on the economy as a whole. If loan demand increases by lowering the interest rate level of the economy, loans will increase at the macroeconomic level. On the other hand, since the negative effects on loans are added to the individual banks to which NIRP applies, a negative effect may be observed on the applied banks. We would like to consider this comprehensive analysis in future studies.

Appendix: Proof of the Policy-Rate Balance Equation

Substituting R^+ and R^0 into the definition of R^-, we calculate

$$\begin{aligned}
R_i^- &= R_i - R_i^+ - R_i^0 \\
&= R_i - \min\{R_i - \alpha R_i, \bar{R}_{i,2015} - \alpha R_i\} - \min\{\alpha R_i + R_i^M, R_i - R_i^+\} \\
&= R_i - \min\{R_i, \bar{R}_{i,2015}\} + \alpha R_i - \min\{\alpha R_i + R_i^M, R_i - \min\{R_i - \alpha R_i, \bar{R}_{i,2015} - \alpha R_i\}\} \\
&= R_i - \min\{R_i, \bar{R}_{i,2015}\} + \alpha R_i - \min\{\alpha R_i + R_i^M, R_i - \min\{R_i, \bar{R}_{i,2015}\} + \alpha R_i\} \\
&= R_i - \min\{R_i, \bar{R}_{i,2015}\} + \alpha R_i - \alpha R_i - \min\{R_i^M, R_i - \min\{R_i, \bar{R}_{i,2015}\}\} \\
&= R_i - \min\{R_i, \bar{R}_{i,2015}\} - \min\{R_i^M, R_i - \min\{R_i, \bar{R}_{i,2015}\}\} \\
&= -\min\{0, \bar{R}_{i,2015} - R_i\} - \min\{R_i^M, -\min\{0, \bar{R}_{i,2015} - R_i\}\}.
\end{aligned}$$

Since $\min\{a, b\} = -\max\{-a, -b\}$, we obtain

$$\begin{aligned}
R_i^- &= \max\{0, R_i - \bar{R}_{i,2015}\} - \min\{R_i^M, \max\{0, R_i - \bar{R}_{i,2015}\}\} \\
&= \max\{0, R_i - \bar{R}_{i,2015}\} + \max\{-R_i^M, -\max\{0, R_i - \bar{R}_{i,2015}\}\} \\
&= \max\{\max\{0, R_i - \bar{R}_{i,2015}\} - R_i^M, 0\}\} \\
&= \max\{\max\{-R_i^M, R_i - \bar{R}_{i,2015} - R_i^M\}, 0\} \\
&= \max\{R_i - \bar{R}_{i,2015} - R_i^M, 0\}.
\end{aligned}$$

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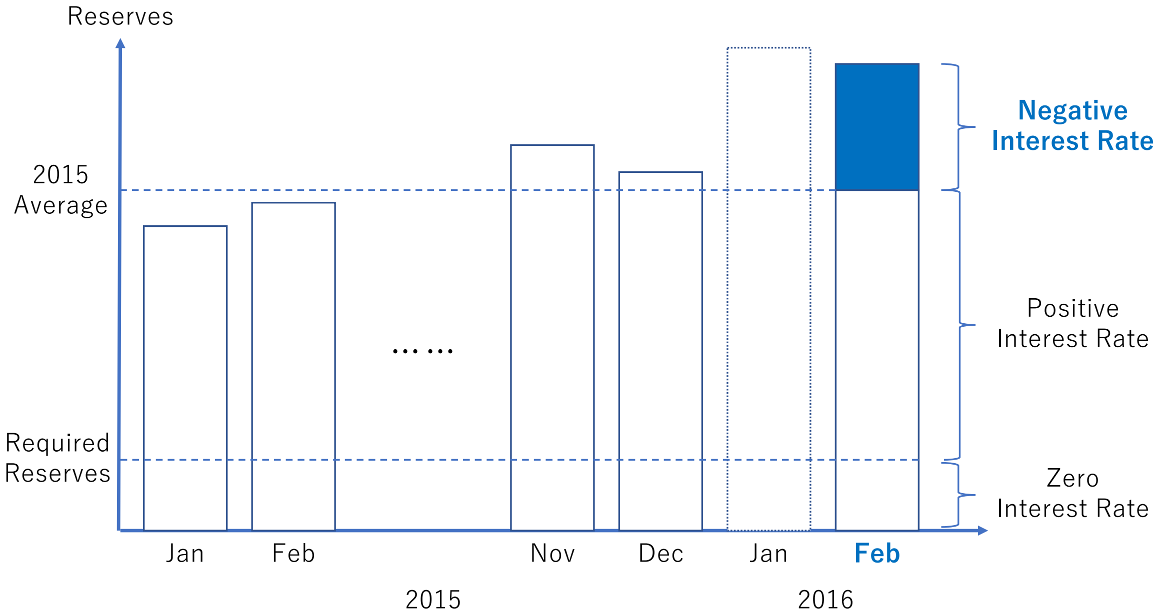

Figure 1: Summary of BOJ's NIRP

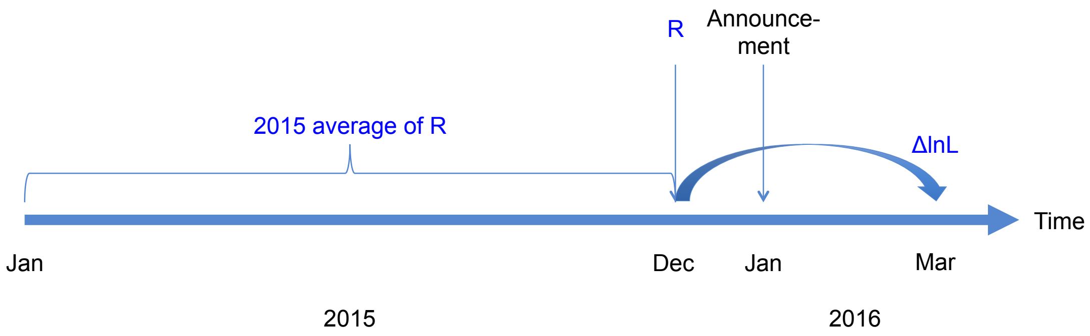

Figure 2: Empirical timeline

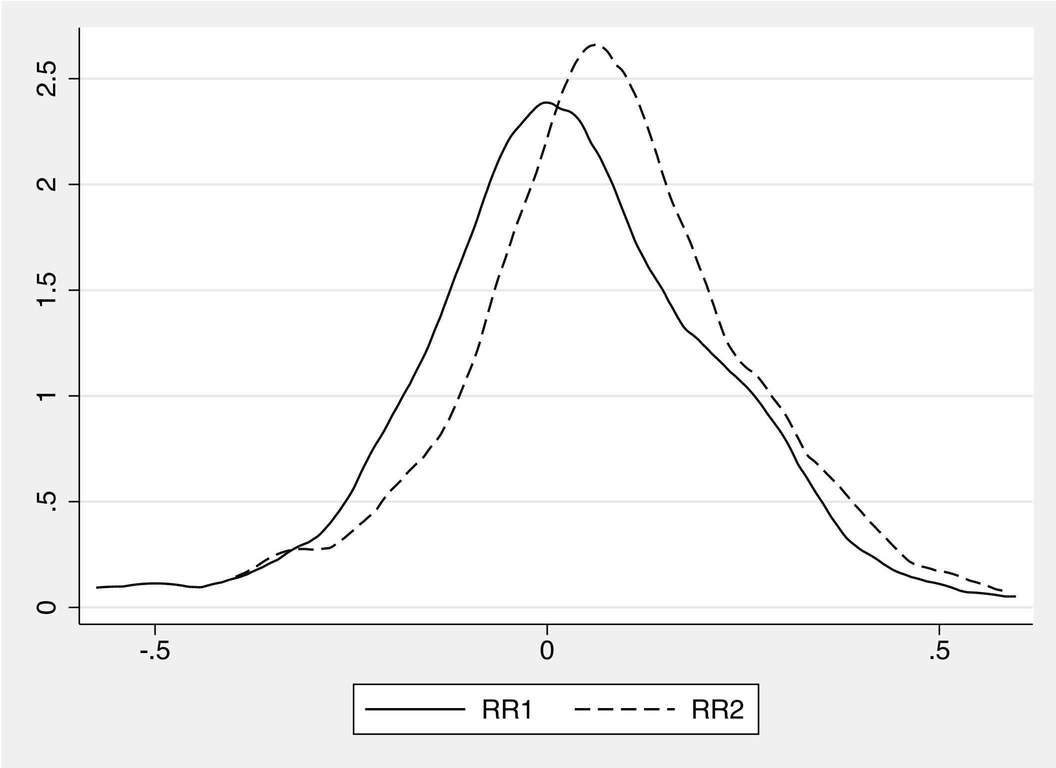

Figure 3: Nonparametric density function of RR

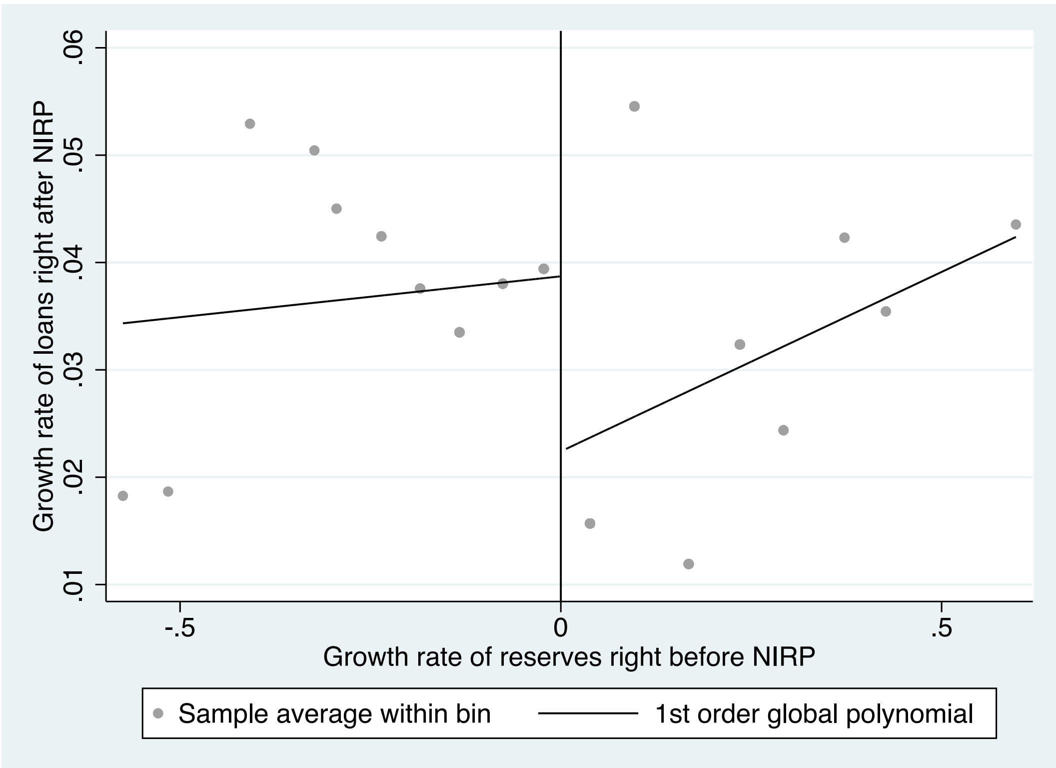

Figure 4: Rate of change in loans and RR1: Linear approximation

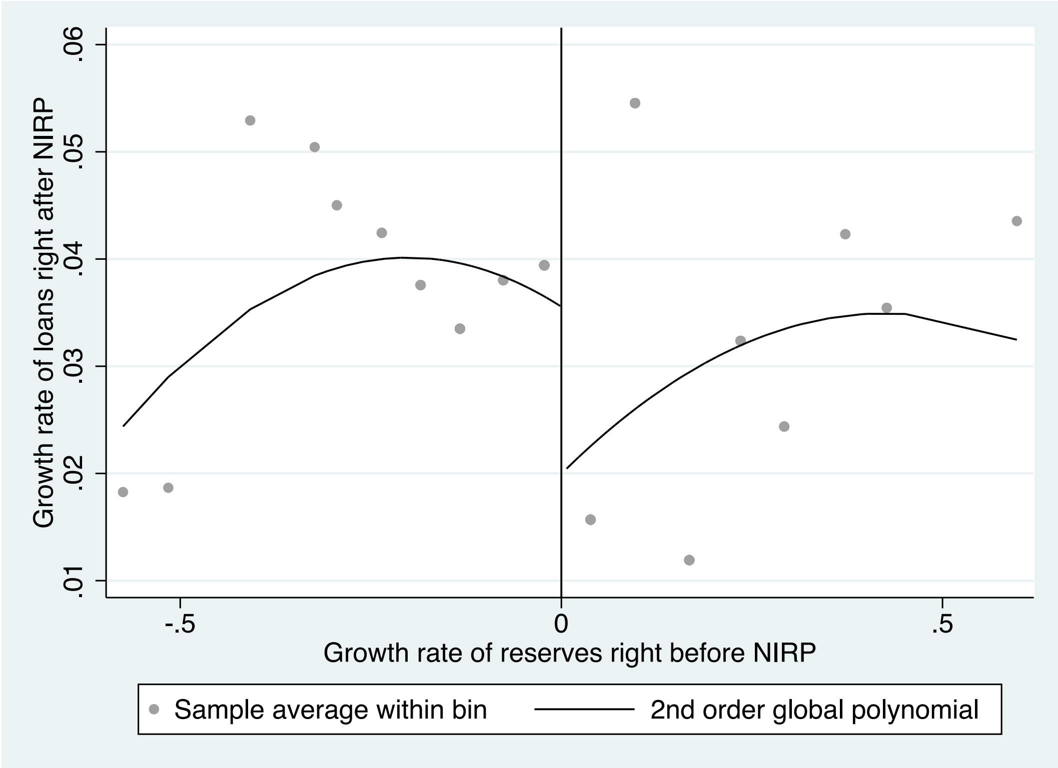

Figure 5: Rate of change in loans and RR1: Quadratic approximation

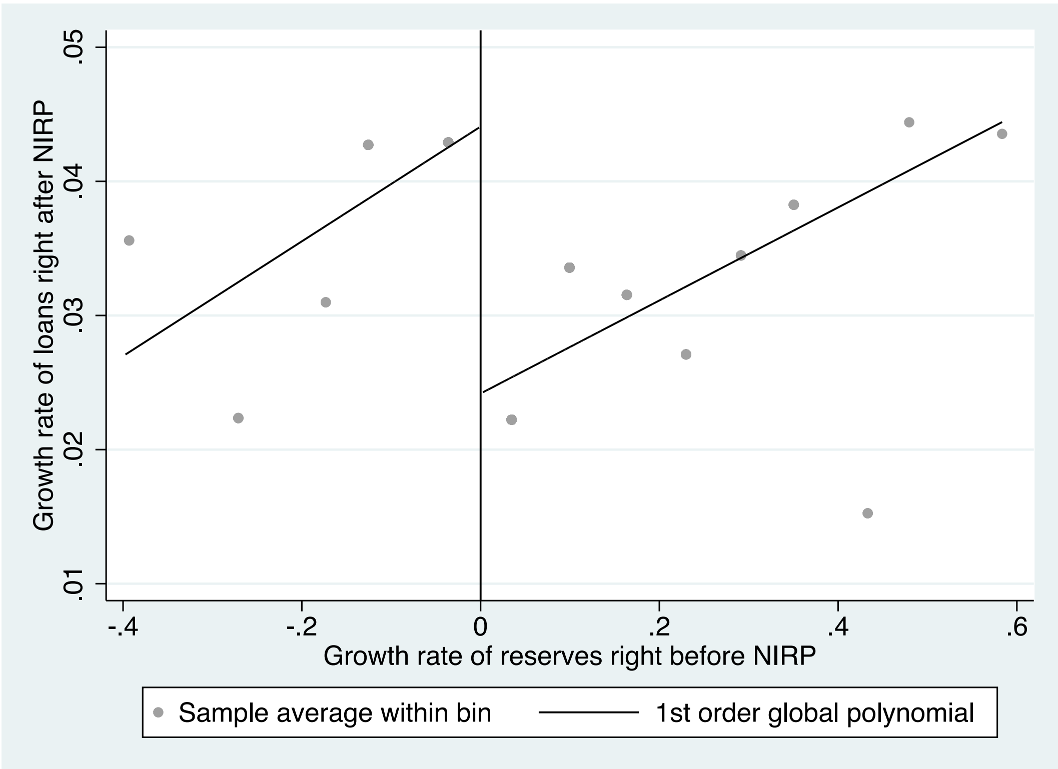

Figure 6: Rate of change in loans and RR2: Linear approximation

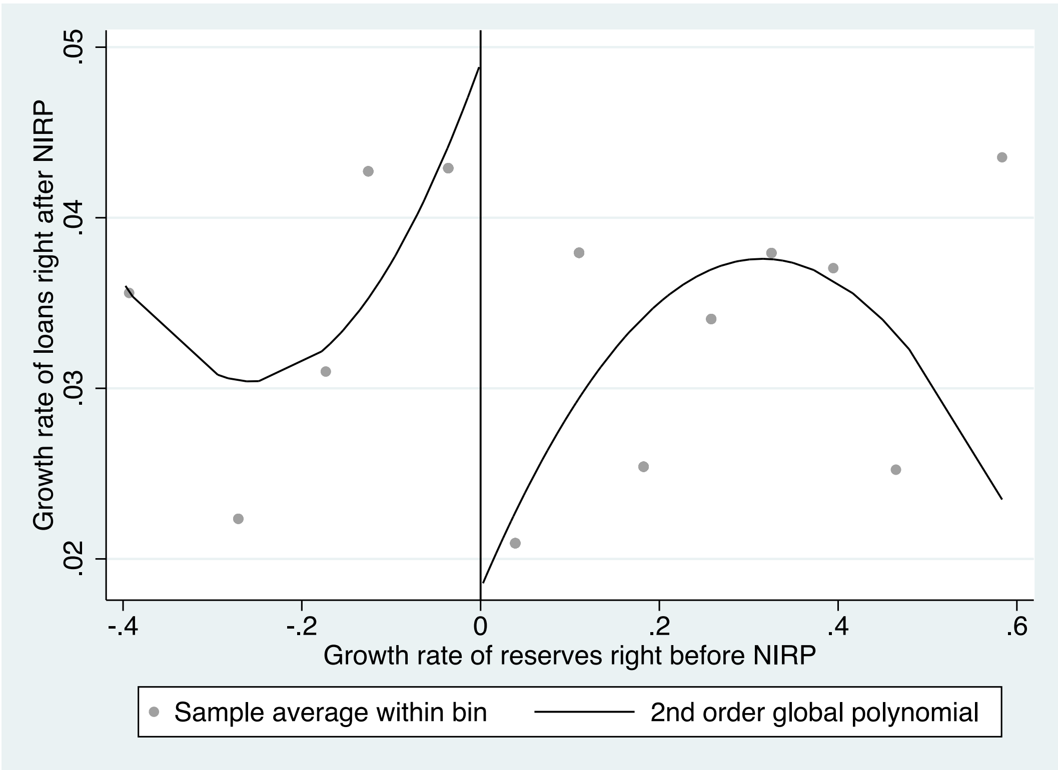

Figure 7: Rate of change in loans and RR2: Quadratic approximation

Table 1: Summary statistics

Variable	Obs.	Mean	Std. dev.	Min	Max
dlnL	111	0.033	0.034	-0.095	0.142
RR1	109	0.027	0.190	-0.575	0.598
RR2	102	0.076	0.177	-0.397	0.583
dlnD	107	0.020	0.027	-0.070	0.150
dlnB	109	-0.047	0.088	-0.344	0.108
RR1< 0					
dlnL	49	0.038	0.030	-0.026	0.142
RR1	49	-0.129	0.128	-0.575	-0.001
RR2	46	0.002	0.169	-0.397	0.328
dlnD	49	0.014	0.020	-0.036	0.090
dlnB	49	-0.034	0.079	-0.344	0.105
RR1> 0					
dlnL	62	0.028	0.036	-0.095	0.140
RR1	60	0.155	0.127	0.007	0.598
RR2	56	0.137	0.161	-0.248	0.583
dlnD	58	0.025	0.030	-0.070	0.150
dlnB	60	-0.058	0.095	-0.344	0.108
RR2< 0					
dlnL	29	0.039	0.035	-0.062	0.142
RR1	29	-0.072	0.232	-0.575	0.451
RR2	29	-0.126	0.112	-0.397	-0.002
dlnD	28	0.009	0.020	-0.036	0.048
dlnB	29	-0.050	0.081	-0.344	0.080
RR2> 0					
dlnL	82	0.030	0.033	-0.095	0.140
RR1	80	0.063	0.159	-0.324	0.598
RR2	73	0.157	0.127	0.003	0.583
dlnD	79	0.024	0.028	-0.070	0.150
dlnB	80	-0.046	0.092	-0.344	0.108

Table 2: Benchmark estimation of the average treatment effect

	(1)	(2)	(3)	(4)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR2	RR2
Sample: All				
ATE	-0.0163	-0.0156	-0.0199	-0.0308
Std. Err.	0.010	0.013	0.011	0.015
p-value	0.096*	0.227	0.084*	0.049**
Order Loc. Poly. (p)	1	2	1	2
Observations	109	109	102	102
	(5)	(6)	(7)	(8)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR2	RR2
Sample: Regional banks				
ATE	-0.0206	-0.0187	-0.0234	-0.0346
Std. Err.	0.010	0.013	0.011	0.016
p-value	0.035**	0.140	0.043**	0.031**
Order Loc. Poly. (p)	1	2	1	2
Observations	103	103	96	96

Table 3: Estimation of the average treatment effect: Deposits and securities

	(9)	(10)	(11)	(12)
Outcome	dlnD	dlnD	dlnD	dlnD
Running Variable	RR1	RR1	RR2	RR2
ATE	0.0131	0.0199	0.0221	0.0220
Std. Err.	0.007	0.010	0.009	0.012
p-value	0.078*	0.042**	0.016**	0.080*
Order Loc. Poly. (p)	1	2	1	2
Observations	106	106	100	100
	(13)	(14)	(15)	(16)
Outcome	dlnB	dlnB	dlnB	dlnB
Running Variable	RR1	RR1	RR2	RR2
ATE	0.0006	-0.0180	0.0360	0.0093
Std. Err.	0.025	0.032	0.030	0.040
p-value	0.980	0.577	0.228	0.818
Order Loc. Poly. (p)	1	2	1	2
Observations	109	109	102	102

Table 4: Nonparametric estimation of the average treatment effect

	(1)	(2)	(3)	(4)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR2	RR2
Sample: All				
ATE	-0.0350	-0.0327	-0.0352	-0.0424
Conventional Std. Err.	0.015	0.015	0.021	0.034
Robust p-value	0.010**	0.039**	0.146	0.256
Order Loc. Poly. (p)	1	2	1	2
BW Loc. Poly. (h)	0.131	0.176	0.118	0.132
Observations	109	109	102	102
	(5)	(6)	(7)	(8)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR2	RR2
Regional banks				
ATE	-0.0354	-0.0338	-0.0376	-0.0461
Conventional Std. Err.	0.015	0.015	0.022	0.036
Robust p-value	0.008***	0.032**	0.130	0.256
Order Loc. Poly. (p)	1	2	1	2
BW Loc. Poly. (h)	0.127	0.174	0.121	0.131
Observations	106	106	99	99

Table 5: Donut-RD estimation

	(1)	(2)	(3)
Outcome	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR1
Donut-hole	(-0.005,0.005)	(-0.01,0.01)	(-0.015,0.015)
Linear			
ATE	-0.04071	-0.05066	-0.05498
Std. Err.	0.023	0.025	0.027
Robust p-value	0.067*	0.029**	0.026**
Observations	104	102	101
Quadratic			
ATE	-0.0471	-0.06528	-0.07471
Std. Err.	0.027	0.031	0.034
Robust p-value	0.092*	0.038**	0.031**
Observations	104	102	101

Table 6: Estimation with different cutoff points

	(1)	(2)	(3)	(4)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR1	RR1
Cutoff	-0.20	-0.10	0.10	0.20
Linear				
ATE	0.248	0.019	0.021	0.032
Std. Err.	0.020	0.014	0.027	0.036
Robust p-value	0.232	0.152	0.534	0.359
Observations	109	109	109	109
Quadratic				
ATE	0.032	0.019	0.021	0.028
Std. Err.	0.027	0.020	0.030	0.051
Robust p-value	0.290	0.538	0.542	0.794
Observations	109	109	109	109

Table 7: Shinkin banks

	(1)	(2)	(3)	(4)
Outcome	dlnL	dlnL	dlnL	dlnL
Running Variable	RR1	RR1	RR2	RR2
ATE	-0.0099	0.0026	-0.0106	0.0056
Std. Err.	0.0080	0.0109	0.0079	0.0101
p-value	0.217	0.808	0.179	0.578
Order Poly. (p)	1	2	1	2
Observations	189	189	189	189