Do Reserve Requirements Restrict Bank Behavior?†

Hiroshi Gunji[a*] and Kazuki Miura[b]

[a]Faculty of Economics, Daito Bunka University; [b]Faculty of Policy Studies, Aichi Gakuin University

[*]corresponding author

1-9-1 Takashimadaira, Itabashi, Tokyo 175-8571, Japan.

+81-3-5399-7326 (Tel)

+81-3-5399-7342 (Fax)

hgunji@ic.daito.ac.jp

Abstract

This study aims to examine whether a reserve requirement system constrains bank behavior. In Japan, a system is applied to certain regional banks where required reserve ratios are imposed based on the amount of their deposits. Using a natural experiment, we perform a bunching estimation to examine whether this reserve requirement system decreases bank deposits. To the best of our knowledge, this study is the first to examine the effects of reserve requirement systems through bunching estimation. Our results demonstrate that the reserve deposit system depresses bank deposits, resulting in a decline in total deposits. However, this phenomenon is not observed during periods of unconventional monetary policies. This study highlights an important consideration when discussing changes in the reserve requirement system.

Keywords: Reserve Requirements; Monetary Policy; Central Bank; Bunching; Bank of Japan

JEL classification: E42, E58, G21

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1. Introduction

Monetary policy instruments now include not only short-term interest rate targeting, which is used in conventional monetary policy, but also a variety of unconventional instruments, such as monetary-based balancing and long-term interest rate targeting.[1] Instruments not involving direct operations in financial markets, such as corridor frameworks, also play an important role in guiding interest rates. A corridor framework is a system of central bank lending and interest-bearing reserves. The interbank interest rate hovers between these rates.[2] Modern central banks use these instruments to conduct their operations.

Reserve requirement systems have long been used as a form of central bank operations, but they are rarely used as monetary policy instruments today. In March 2020, the US Federal Reserve Board (FED) set its reserve requirement ratio to zero. This means that banks no longer need to set aside reserves.[3] The reserve requirement system forces financial institutions that engage in transactions with the central bank to hold a certain percentage of their liabilities as non-interest-bearing deposits with the central bank. This system requires banks to hold current accounts with the central bank overnight, which results in transactions in the interbank market during the day. This makes it easier for the central bank to guide the targeted short-term interest rate. Meanwhile, changes in deposit balances constrain banks' behaviors, as they must raise the required reserves.

However, the total amount of funds in the banking sector may remain unchanged because certain banks adjust for increases in their required reserves by borrowing surplus funds from other banks through the interbank market. Furthermore, it is conventional for the central bank to accommodate any changes in its reserves through open market operations, so market interest rates are unaffected. Market interest rates remain constant through such operations, even when private sector deposits increase or decrease. In other words, the central bank's current account will be supplied if the overall demand for reserves increases. Thus, the effect of the reserve deposit system on bank behavior is complex.

However, it remains unclear if the reserve requirement system affects bank behavior.

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[1] See, for example, Bowdler and Radia (2012).
[2] For details, see Kahn (2010).
[3] See https://www.federalreserve.gov/monetarypolicy/reservereq.htm

Central banks supply funds through open market operations to meet banks' demand for funds; therefore, a reserve deposit system would not affect bank fund demand. However, borrowing to meet the reserve requirement of the system would incur funding costs, and there may also be administrative burden costs. In the case of Japan, the average reserve deposits for one month (i.e., from the 16th of one month to the 15th of the following month) must exceed the reserve requirement. Consequently, adjustments would be required to raise funds when the call rate is low and to avoid raising funds when it is high. These costs would be a constraint and could affect bank behavior.

This study examines how a reserve requirement system changes bank behavior. However, identifying the effect on deposits or lending is complex because, in many countries, the statutory reserve ratio does not change frequently, and when it does change, it is often amended simultaneously with other monetary policy instruments. For example, the Bank of Japan (BoJ) has not changed its reserve requirement ratio since 1991—30 years ago.[4] Therefore, we focus on Japan's reserve requirement system. The BoJ operates a system wherein only certain regional financial institutions (known as *Shinkin banks*) are subject to required reserves if they held deposits above a certain amount in the previous year.[5] This system was established in April 1963. The reserve requirement ratio varies across time deposits, certificates of deposits, deposit balances, and other deposits. The reserve requirement was applied to Shinkin banks with deposits of more than 20 billion yen from April 1963 to September 1977, more than 50 billion yen from October 1977 to February 1980, more than 80 billion yen from March 1980 to May 1983, more than 120 billion yen from June 1983 to June 1986, and more than 160 billion yen from July 1986 onwards.[6] In other words, the system is applied differently above and below these thresholds. If the reserve requirement system is restrictive for banks, they must act to avoid exceeding these thresholds. In econometric terms, bunching is expected to occur around the threshold. Bunching is the

[4] See the BoJ's website: https://www.boj.or.jp/en/statistics/boj/other/reservereq/index.htm/
[5] "Shinkin banks are cooperative financial institutions. Their membership comprises local residents and small and medium-sized enterprises. … Shinkin banks limit their lending, in principle, to members. However, their functions are almost the same as those of commercial banks, and they also deal with many people who are not members, accepting deposits, providing exchange services, accepting payments, including those for public utilities, and engaging in over-the-counter sales of public bonds, investment trust funds, and insurance." (See Shinkin Central Bank's website: https://www.shinkin-central-bank.jp/e/financial/.)
[6] See the BoJ's website in footnote 4.

concentrated density around a particular value of a continuous variable that economic agents can choose.[7]

Figure 1 depicts the policy (or call) rate and reserve requirement ratio that Shinkin banks have been charged since 1963. The reserve requirement ratio has changed slightly and has not moved since October 1991. As can be seen, even though it is difficult to analyze a time series, it is possible to analyze a cross-section; thus, we use data from Japanese Shinkin banks to examine whether bunching occurs. It is important to note that Shinkin banks are not subject to the reserve requirement system if their deposits in the previous year are less than a certain amount. Furthermore, if bunching occurs, we estimate the extent to which it affects bank behavior.

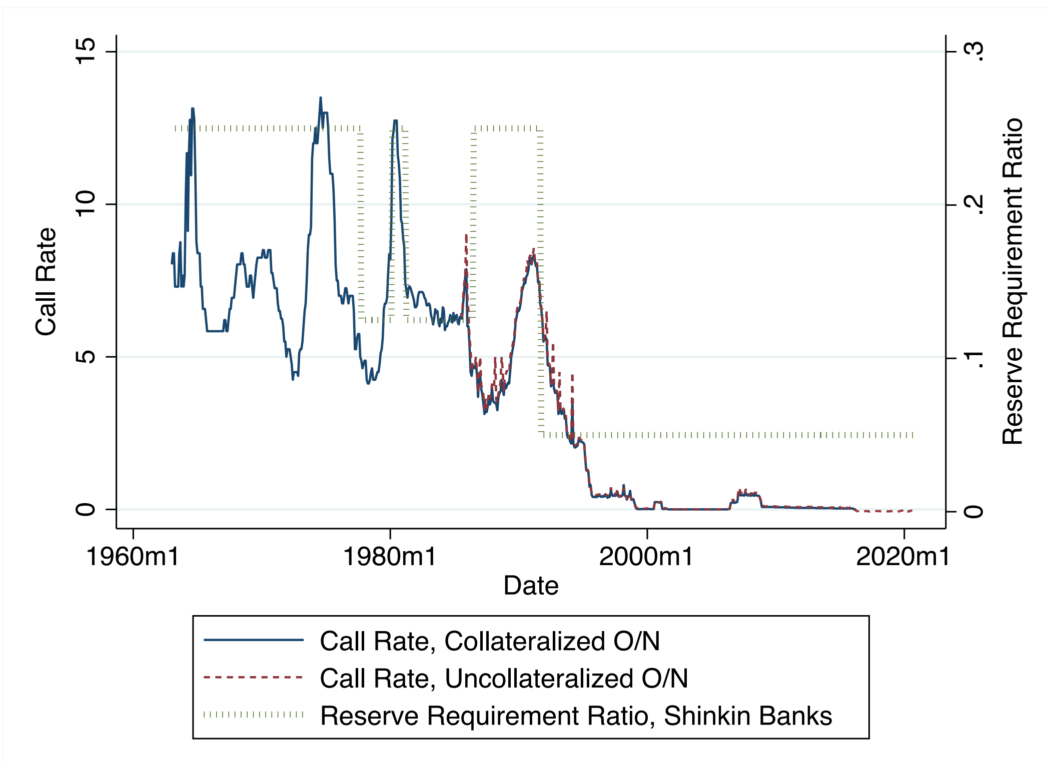

Figure 1: Call Rates and Reserve Requirement Ratios

Notes: Data were obtained from the website of the BoJ. "O/N" denotes the overnight rate. The reserve requirement ratios for Shinkin banks are based on the lowest interest

[7] For a survey of bunching, see Kleven (2016).

rate for time deposits.

While most studies on bunching estimations have examined the effects of taxation, including the pioneering work by Chetty et al. (2011), some have estimated bunching in bank behavior. Because bunching occurs at the highest number of mortgages that Fannie Mae and Freddie Mac are willing to buy in the US, DeFusco and Paciorek (2017) estimated the impact of interest rate changes on mortgage demand. However, they estimated bunching for bank lending, which is not the purpose of our study.

The main estimation results of this study are as follows. First, the reserve requirement system was restrictive for banks during the conventional monetary policy period. The results of the bunching estimation show that approximately 10% of banks tried to avoid reserve deposits. Second, the reserve requirement system reduced deposits by up to 20%. This suggests that the reserve requirement system is restrictive for individual banks and the deposit market as a whole. Third, the reserve requirement system for banks was not constrained during the unconventional monetary policy period. In response to the financial crisis at the end of the 1990s, the BoJ implemented a series of zero-interest-rate and quantitative easing (QE) policies to ensure ample reserves.[8] Under QE, the BoJ purchases government bonds from financial institutions, thereby continuously increasing the amount of money deposited with the central bank. These unconventional monetary policies have existed for over 20 years due to prolonged low inflation. During this period, few banks hesitated to increase their reserves because they could raise reserves in the interbank market at almost no cost while simultaneously holding sufficient excess reserves. These results are important when discussing the existence of the reserve requirement system and should not be ignored by central banks that are considering changes to the system, that is, the abolition of a reserve requirement system like that of the FED.

The remainder of this paper is organized as follows: Section 2 reviews Shinkin banks. Section 3 introduces the related literature. Section 4 presents the theoretical background of the empirical analysis. Section 5 describes the data used and explains our empirical strategy. Section 6 presents the benchmark estimation, followed by estimations of other periods and

[8] See, for instance, Shirakawa (2011).

the results of placebo tests. In Section 7, we provide our discussion and conclusions.

2. Review of Shinkin Banks

Shinkin banks, which are financial institutions created under the 1951 Shinkin Bank Law, differ from regular banks. While banks are for-profit corporations organized as joint-stock companies, Shinkin banks are non-profit cooperative organizations whose members invest in them, and their business areas are limited to certain regions. Members are required to have various qualifications, such as having a domicile or residence in the district. Businesses must have fewer than 300 employees or less than 900 million yen in capital. In addition, while there are no restrictions on deposits, loans are, in principle, only available to members, although there are some exceptions.

Figure 2 shows the time series of deposits held by Shinkin and domestic banks. Deposits of both series are rising; in the 2000s, Shinkin banks had approximately one-fifth of the deposits of domestic banks, but since 2020, domestic banks have been growing in size. Shinkin banks have also grown to some extent in terms of deposits, although their share of deposits has declined in recent years.

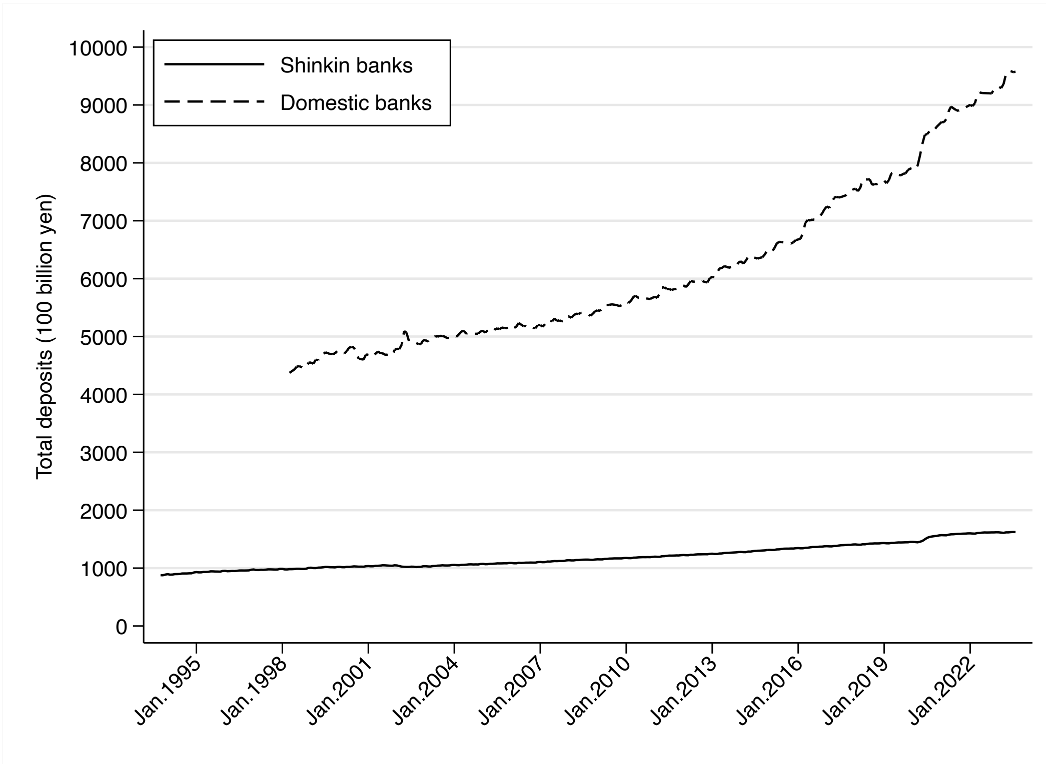

Figure 2: Total Deposits of Shinkin Banks and Domestic Banks

Notes: Data were obtained from the BoJ website.

With respect to Shinkin banks, the minimum deposit amount the reserve deposit system applied to was 20 billion yen in 1963, which was raised to 50 billion yen in 1975 and then to 80 billion yen in 1977, an increase of 30 billion yen each time. Subsequently, the threshold value was raised to 120 billion yen in 1980 and 160 billion yen in 1983, an increase of 40 billion yen. To date, the threshold value has remained at 160 billion yen to date.

Figure 3 shows the number of Shinkin banks whose deposits exceed 160 billion yen, the current threshold value, and the number of Shinkin banks whose deposits are lower. As seen in Figure 3, the total number of Shinkin banks declined gradually in the 1990s and then sharply in the early 2000s. Since then, it has continued to decline slowly. This decline is mainly due to mergers among Shinkin banks. Additionally, the number of Shinkin banks not covered by the reserve deposit system has declined in parallel with the overall decline. In other words, the decline in total Shinkin banks is the result of continued mergers among relatively small Shinkin banks.

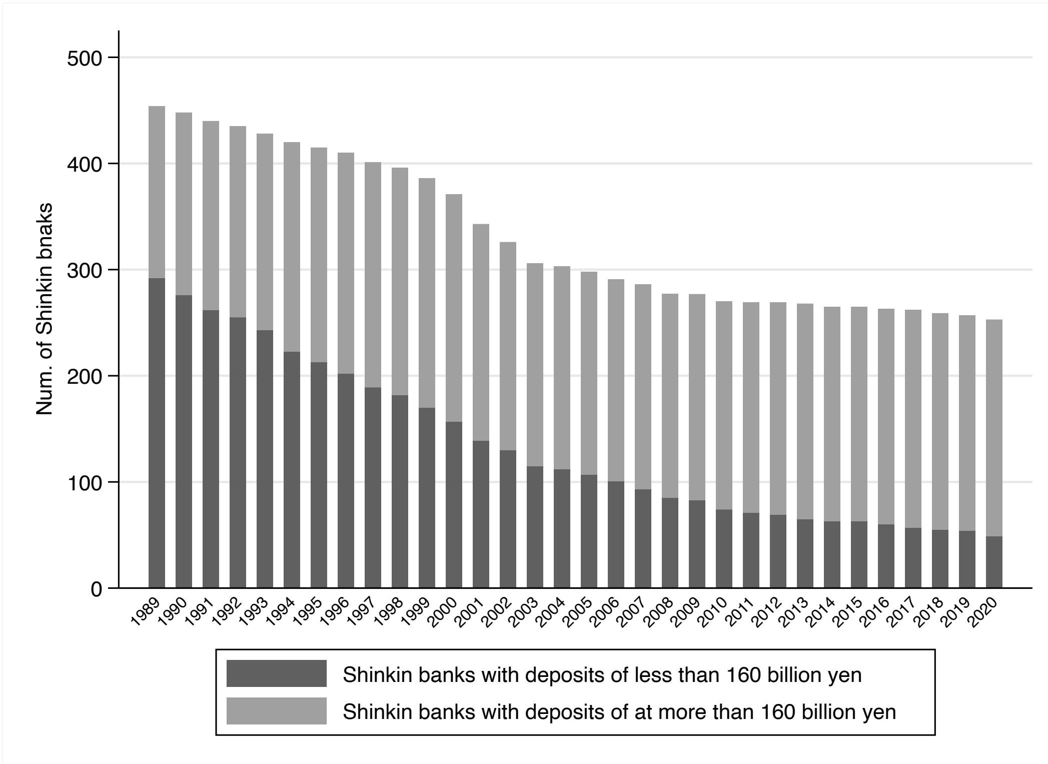

Figure 3: Total Deposits of Shinkin Banks and Domestic Banks

Notes: Data were obtained from the BoJ website.

3. Related Literature

Whether the reserve requirement ratio strongly impacts bank behavior has long been controversial in the literature. Friedman and Schwartz (1963) criticized the increase in the legal reserve ratio by the FED from 1936 to 1937, as it reduced bank loans and caused a contraction in the money supply due to the decline in credit creation. Although many researchers have studied this hypothesis, there are challenges in identifying and estimating causality in the regression analysis—mainly endogeneity. Lown and Wood (2003) studied the determinants of the total reserve ratio and found that the reserve ratio is an inverse function of the market interest rate. Cargill and Mayer (2006) investigated how the cash reserve ratio of FED member and nonmember banks responds to changes in the statutory reserve ratio. They concluded that an increase in the reserve ratio led to a decrease in bank credit provided by member banks. Mora (2014) used the difference-in-differences (DiD) method to estimate whether bank lending differed between the shares of local currency deposits and foreign currency deposits when Lebanon changed its reserve requirement ratio.

Furthermore, Park and Van Horn (2015) used individual bank data to examine whether there was any difference in lending between banks that were members of the FED and those that were not before and after raising the reserve requirement ratio. This is a demonstration of DiD estimation, which is one method of causal inference that uses a quasi-experimental design. In the estimation, they failed to determine whether the reserve requirement ratio change affected bank lending. However, as banks could choose whether to join the FED at the time, their estimates included a selection bias. To the best of our knowledge, no studies have examined the effects of reserve requirement systems through bunching estimation.

4. Theoretical Background

Before conducting the estimation, we theoretically consider the mechanism through which bunching occurs. This allows us to predict the shape of the actual distribution of deposits. Our model is a bank version of the model in Kleven and Waseem (2013), which analyzes elasticities in a tax system using notches.

Consider the scenario of a perfectly competitive market with many banks that collect deposits and make loans. For simplicity, we assume that the banks do not lend.[9] When a deposit is made, the bank pays interest and incurs the costs of maintaining ATMs and other facilities. We assume that maintenance costs are quadratic.[10] Further, bank i maximizes profit as follows:

[9] There are two reasons for making this assumption. First, those who believe that banks collect deposits to lend out can consider the bank's assets as loan claims. Second, those who believe that banks create deposits by lending can regard the checking accounts as being created independently of this bank behavior. For a model in which deposits are created endogenously as in the latter case, see Gunji and Miyazaki (2021).

[10] Whether banks' profit functions have economies of scale is a matter of debate. Regarding Shinkin banks economies of scale, Miyakoshi (1993) demonstrated that they existed for Shinkin banks in 1989 using a trans-log cost function. In contrast, Horie (2010) used data envelopment analysis to show that more than half of Shinkin banks in 2005 had diminishing returns in terms of scale. Although their results are contradictory, we trust the results of Horie (2010), which is a more recent analysis, and for the sake of analytical simplicity, we assume that Shinkin banks are in a state of diminishing returns with respect to size.

$$\pi_i = r_l L_i - r_d D_i - \frac{c_i}{2} D_i^2 \tag{1}$$

subject to the balance sheet:

$$(L_i + \alpha D_i) \cdot \mathbb{I}(D_i > D^*) + L_i \cdot \mathbb{I}(D_i \leq D^*) = D_i, \tag{2}$$

where D^* is the deposit threshold upon which the reserve requirement system is imposed, D_i represents the deposits of bank i, L_i represents the loans held by bank i, and $\mathbb{I}(\cdot)$ is the indicator function. Additionally, r_l is the interest rate on loans, r_d is the interest rate on deposits, c_i is the heterogeneous cost factor, which follows a lognormal distribution $\log c_i \sim N(\mu, \sigma^2)$, and α is the reserve requirement ratio. From the first-order conditions for profit maximization with respect to loans, the optimal deposits of bank i are as follows:

$$D_i = \begin{cases} \frac{(1-\alpha)r_l - r_d}{c_i} & \text{if } c_i < \frac{(1-\alpha)r_l - r_d}{D^*} \\ D^* & \text{if } \frac{(1-\alpha)r_l - r_d}{D^*} \leq c_i < \frac{r_l - r_d}{D^*} \\ \frac{r_l - r_d}{c_i} & \text{if } c_i \geq \frac{r_l - r_d}{D^*} \end{cases} . \tag{3}$$

D_i can be divided into three solutions. First, an efficient bank with a sufficiently small c_i can obtain many deposits because the cost of deposits is low. However, a bank whose deposits exceed a certain amount D^* will be subject to the required reserve ratio. This is the first solution to this problem. Second, a bank with a medium c_i will try to obtain fewer deposits so that the required reserve ratio is not imposed. Banks in this region have a concentration of deposits at threshold D^*. This is the second solution (i.e., bunching). Finally, while an inefficient bank with a large c_i will not be able to attract sufficient deposits, the reserve requirement system will not constrain it. This is the third solution. The inverse of the lognormal distribution also follows the original lognormal distribution; therefore, both the first and third D_i follow the lognormal distribution: $\ln D_i \sim N\big(\ln\big((1-\alpha)r_l - r_d\big) - \mu, \sigma^2\big)$ if $c_i < [(1-\alpha)r_l - r_d]/D^*$ and $\ln D_i \sim N(\ln(r_l - r_d) - \mu, \sigma^2)$ if $c_i \geq (r_l - r_d)/D^*$. The upper panel of Figure 4 depicts the indifference curve for bank i under these conditions. For banks with a high-cost factor c_i, the indifference curve is tangential to the constraint $L_i = D_i$, while for banks with a low c_i, it is tangential to $L_i = (1-\alpha)D_i$. However, banks whose indifference curves are tangential to the constraint on the left of z_+ will also be tangential to the tip of $L_i = D_i$; therefore, deposits are concentrated at D^*, and bunching occurs.

In reality, even above the threshold, the number of banks will not be zero because certain banks will be excluded if they cannot accurately reduce their deposits.[11] This situation is depicted in the lower panel of Figure 4. The dotted line is the distribution that would have been achieved without the reserve requirement system, and the solid line is the actual distribution. The reserve requirement system is expected to push the distribution downward above the threshold.

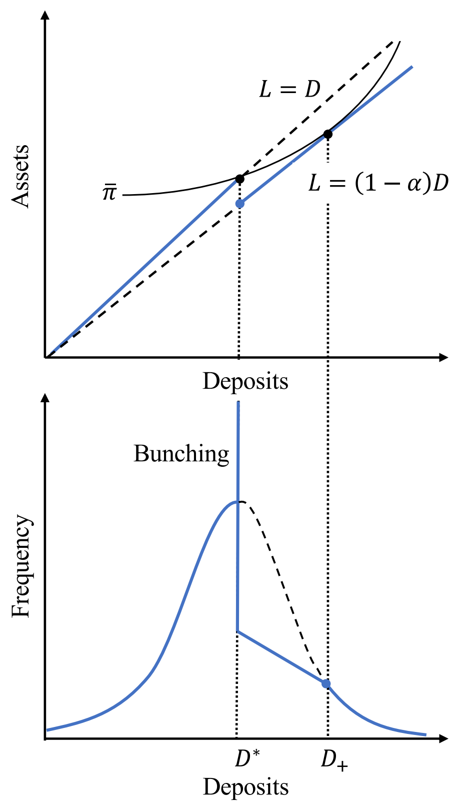

Figure 4: Bunching Analysis

[11] Kleven and Waseem (2013) discussed various scenarios in which a density hole does not occur.

5. Materials and Methods

5.1 Data

Individual data are used for Shinkin banks. The sample is obtained from *Zenkoku Shinyo Kinko Zaimu Shohyo*, published by Kinyu Tosho Consultant Sha. The sample period for the benchmark is from 1992 to 1998. We use 1992 as the starting point because the current reserve requirement ratio was set in October 1991. The final year of the sample period is 1998 because the zero-interest-rate policy (ZIRP) was introduced in 1999, and an unconventional monetary policy was implemented thereafter. Under the ZIRP, the BoJ induces the interbank interest rate to be close to zero, making banks indifferent between investing in the interbank market or holding excess reserves in the BoJ's current account. Therefore, we expect that banks will not be restricted by the reserve requirement system when the ZIRP is in effect. In addition, the QE introduced in 2001, and the quantitative and qualitative easing (QQE) policy introduced in 2013 are aimed at increasing banks' excess reserves by allowing the BoJ to purchase large amounts of government bonds.[12] Therefore, we also expect that the reserve requirement system will not constrain banks when implementing these policies. However, to examine how bunching has changed during the period of unconventional monetary policies relative to the benchmark period, we also derive estimations for the period after 2000 when the respective policies were still in place. Data for the period after 2000 are obtained from Nikkei NEEDS FinancialQUEST.

The variable we examine is the balance of deposits held by Shinkin banks at the end of March each year. In Japan, the fiscal year lasts from April 1 to March 31. While the amount of deposits depends on depositor behavior, it can also change when banks change their deposit rates or engage in lending. Thus, Shinkin banks may adjust their lending to ensure that deposits do not reach 160 billion yen.

Table 1 presents the sample's descriptive statistics. In all years during the benchmark period, the logarithmic mean is slightly below 12 with positive skewness, suggesting that $\ln(160{,}000) \simeq 12$ is a constraint. The standard deviation is approximately 1 for all years. The kurtosis is close to 3, indicating that the distribution is rather sharp. The number of banks

[12] See the BoJ's websites: https://www.boj.or.jp/en/announcements/release_2001/k010319a.htm/ and https://www.boj.or.jp/en/announcements/release_2013/k130404a.pdf

is generally above 400, although it gradually decreases.

Table 1: Summary Statistics

Ln (Deposit)	Average	Std. Dev.	Skewness	Kurtosis	Min	Max	N
Benchmark Periods							
Mar-1992	11.674	1.002	0.264	2.997	8.586	14.750	435
Mar-1993	11.721	1.005	0.263	3.006	8.601	14.760	428
Mar-1994	11.780	1.007	0.232	3.051	8.558	14.857	420
Mar-1995	11.818	1.005	0.205	3.109	8.551	14.926	415
Mar-1996	11.858	0.994	0.207	3.134	8.527	14.866	410
Mar-1997	11.900	0.985	0.188	3.156	8.444	14.714	401
Mar-1998	11.928	0.991	0.184	3.183	8.422	14.737	396
Other Periods							
Mar-1990	11.561	1.018	0.258	3.018	8.622	14.667	448
Mar-2000	12.032	0.980	0.235	3.024	9.373	14.895	371
Mar-2006	12.320	0.977	0.385	2.594	10.420	15.016	292
Mar-2010	12.498	0.946	0.364	2.550	10.513	15.160	272
Mar-2015	12.623	0.955	0.383	2.563	10.627	15.272	267
Mar-2016	12.648	0.961	0.370	2.532	10.639	15.297	265
Mar-2017	12.673	0.964	0.363	2.535	10.646	15.315	264

Note: "Std. Dev." denotes the standard deviation, "Min" and "Max" indicate minimum and maximum, respectively, and "N" denotes the number of observations.

The histograms for 1992–1998 are illustrated in Figure 5. The distribution is approximately symmetrical but slightly skewed to the left of the threshold. The number of banks around the threshold of $\ln(160{,}000) \simeq 12$ is low, and there is a hump below that value. This implies that the reserve requirement system may create a constraint, and banks may control the amount of their deposits.

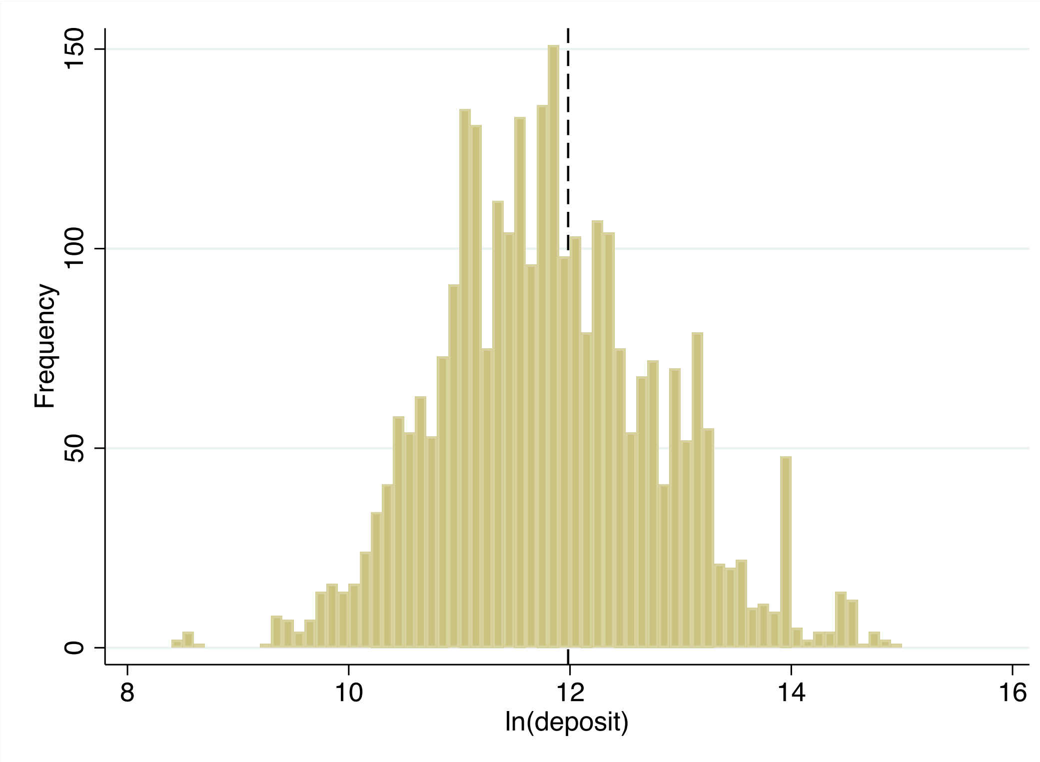

Figure 5: Histogram of Deposits

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits.

As noted in the introduction, the ¥160 billion critical value was established in 1986. In other words, the critical value was set well before our sample period. Therefore, the critical value was not established according to the distribution of deposits in the Shinkin Bank, but rather deposits were allocated based on the critical value.

5.2 Empirical Strategy

We exploit the constraint of Japan's reserve requirement system, which is imposed on Shinkin banks that hold more than 160 billion yen in deposits, to estimate whether bunching occurs around this threshold. Chetty et al. (2011) pioneered the work on bunching estimation, using it in their analysis of the tax system. We modify Chetty et al.'s (2011) model to fit the data in this study and use the following equation for the estimation:

$$n_j = \sum_{i=0}^{p} \beta_i (z_j)^i + \gamma_- \cdot \mathbb{I}(d_- \leq d_j < d^*) + \gamma_+ \cdot \mathbb{I}(d^* \leq d_j \leq d_+) + v_j, \qquad (4)$$

where n_j is the number of banks in bin $j = 1, \dots, J$, d_j is the median deposit amount (natural logarithm) of bin j, $[d_-, d_+]$ is the exclusion range, and v_j is the error term with a mean of zero. In the pooled estimation, the number of bins is set to $J = 71$ from Freedman and Diaconis's (1981) method, and we set the minimum value of d to 8.0 and the width of the bin to 0.1. In the annual estimations, the number of bins is set to $J = 35$, because our sample per year is not large.[13] From these conditions, we set the minimum value of d to 8.0 and the width of the bin to 0.2. The threshold value is $d^* = \ln(160{,}000) \simeq 12$. As banks can change the amount of deposits by changing deposit rates and lending, we assume that bunching occurs from d_- to d^*. In contrast, we assume that bunching occurs upward from d^* to d_+. We define j^* as the bin where deposits contain d^*, j_+ as the upper bound of the estimation, and j_- as the lower bound. The method of setting the degree for polynomial p, the number of bins below the threshold $j^* - j_-$, and the number of bins above the threshold $j_+ - j^* + 1$ is a major concern in the estimation because our sample size is not large, and the precise width of bunching is unknown. We choose polynomials between 3 and 5, -5 to -7 below the threshold, and +8 to +10 above the threshold, such that the Akaike's information criterion for each year is the smallest. The lower threshold uses a narrower range than the upper threshold because a threshold slightly less than the upper threshold is sufficient to avoid a reserve requirement system. In the estimation of bunching, a dummy variable is usually assigned to each possible bin,[14] but our sample size is not large. To conserve parameters and ensure degrees of freedom, one dummy is assigned to each range when there are bins in $[d_-, d^*]$ and $[d^*, d_+]$. This means that γ_- and γ_+ are

[13] Prior studies of bunching estimation often draw on histograms and arbitrarily determine the number of bins. An exception is Bosch et al. (2020), who used Freedman and Diaconis's (1981) method. However, when the same method is applied to our annual data, the bandwidth is too wide to be suitable for estimation. Therefore, we attempt to find the optimal number of bins using (i) Birgé and Rozenholc's (2006) method for 1992, the start of the sample period; we obtain 8 as the optimal number. However, this is an insufficient sample size for estimation. Therefore, (ii) the maximum value of Birgé and Rozenholc's (2006) Matlab code (HistOptimal) and (iii) the default value of the Stata code (histogram) are also obtained. We choose the average of these three methods.

[14] See Chetty et al. (2011) and Kleven (2016).

the averages of the deviations within each range. Note that n_j in Eq. (4) is the number of banks in bin j, not the sample of banks themselves. Thus, there are 2,905 bank*year for 1992–1998, but the sample size of n_j is $J = 71$. This small sample size makes it difficult to assign individual dummies to many bins.

Furthermore, if the number of banks in the absence of bunching is $\hat{n}_j = \sum_{i=0}^{p} \beta_i (x_j)^i$, then excess bunching can be demonstrated as follows:

$$\hat{B} = \sum_{j=j_-}^{j^*-1}(n_j - \hat{n}_j)(j^* - j_-) = \hat{\gamma}_- \cdot (j^* - j_-). \tag{5}$$

Figure 6 illustrates excess bunching. The actual distribution of banks is n, while the hypothetical distribution in the absence of bunching is represented by $\hat{n}$. As the range of excess bunching is $[d_-, d^*]$, the estimator of excess bunching is $\hat{\gamma}_-$.

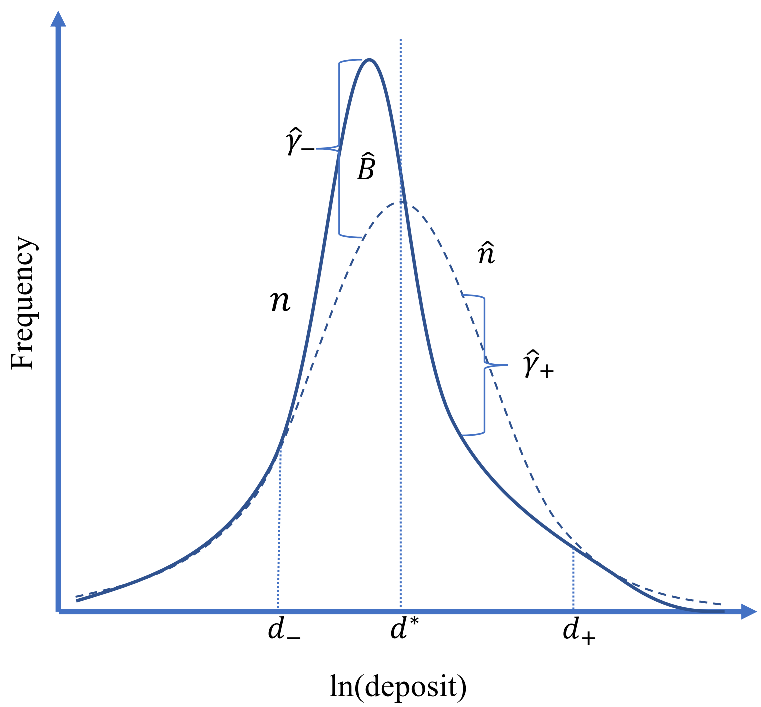

Figure 6: Empirical Bunching

Note: n is the actual distribution of ln(deposit), $\hat{n}$ is the prediction of ln(deposit) without bunching, $\hat{B}$ is the excess bunching, $\hat{\gamma}_-$ is bunching per bin, $\hat{\gamma}_-$ is the decline due to bunching per bin, d^* is the threshold above which the reserve requirement is levied, d_- is the width of the excess bunching, and d_+ is the decline in deposits due to bunching.

We estimate the amount of deposits lost due to the reserve requirement system in the presence of bunching (i.e., when $\gamma_- > 0$ and $\gamma_+ < 0$):

$$\frac{\Delta\widehat{D}}{\widehat{D}} = \frac{\left(\sum_{j=j_-}^{j^*-1}\widehat{\gamma}_-\cdot\exp(d_j)+\sum_{j=j^*}^{j_+}\widehat{\gamma}_+\cdot\exp(d_j)\right)}{\sum_{j=1}^{J}\widehat{n}_j\cdot\exp(d_j)}. \quad (6)$$

6. Results

6.1 Benchmark Estimation

Figures 7 and 8 illustrate the estimation results for the whole sample period and for 1992–1998, respectively. The figures suggest that the actual number of banks (relative to the predicted value of $\hat{n}$) is low above the threshold and high below it. In addition, at both ends of the distribution, the predicted and actual numbers of banks generally overlap, indicating that the estimation is reliable. Thus, it can be inferred that excess bunching occurs annually, and deposits decline.

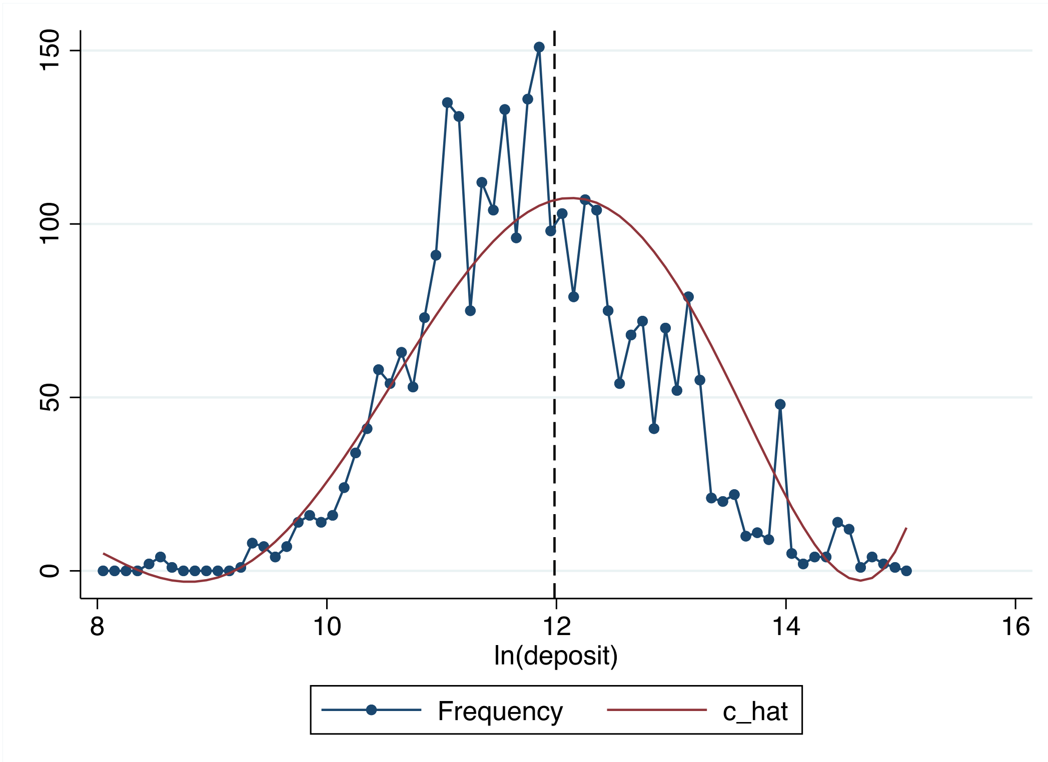

Figure 7: Benchmark Estimation

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

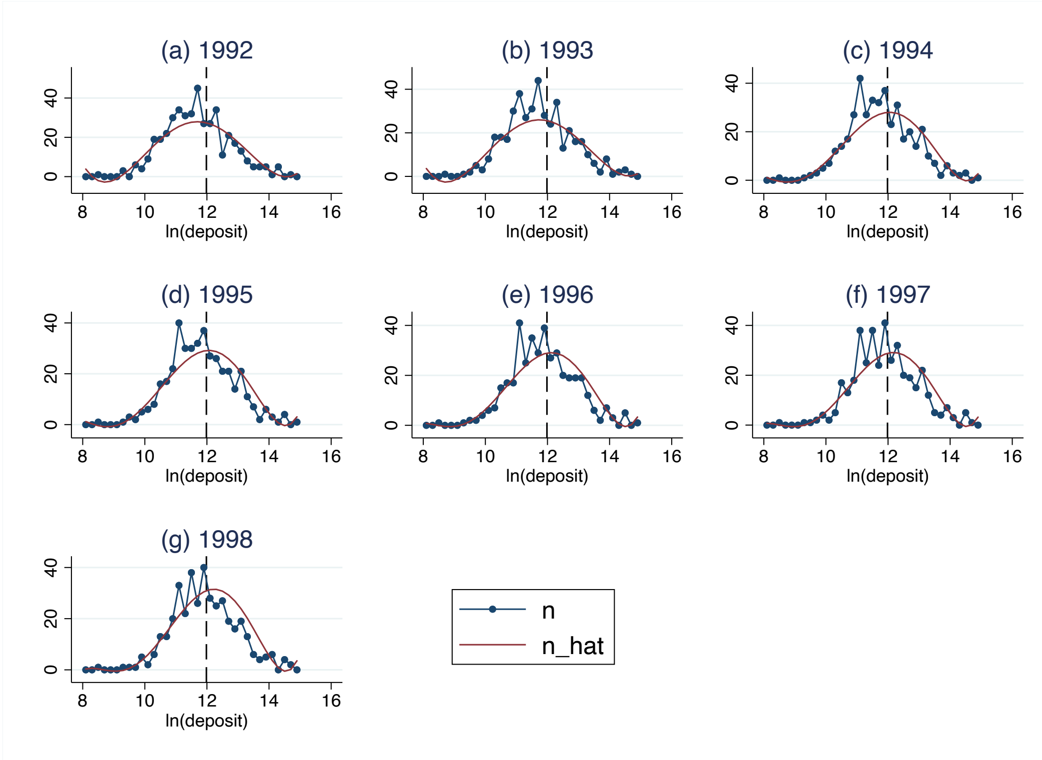

Figure 8: Bunching Estimation in Each Year

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

The estimation results for the whole sample period and 1992–1998 are illustrated in Table 2. The sample is small; therefore, we use the classical standard error, which is an unbiased estimator.[15] The excess bunching per bin that is included in the excess bunching $\hat{\gamma}_{-}$ is positive for all years. This means that excess bunching is observed in all years. The excess bunching $\hat{B}$ ranges from 27 to 50. To determine the density of excess bunching, we divide it by the number of banks to obtain $\hat{B}/N$. The highest density was 12% in 1994, and the lowest was 7% in 1998. This result demonstrates that the range in density is wide and differs significantly depending on the year.

[15] We also computed the bootstrap standard errors, but the results were almost the same as those in Table 2.

Table 2: Bunching Estimation

Fiscal Year	Parameter		S.E.	p-value	#bins	p	$\hat{B}$	N	$\hat{B}/N$	$\Delta\hat{D}/\hat{D}$
1992–1998	$\hat{\gamma}_-$	21.685	8.661	0.015	11	5	238.5	2,905	0.082	-0.238
	$\hat{\gamma}_+$	-25.126	10.728	0.022	19					
Mar-1992	$\hat{\gamma}_-$	6.600	3.634	0.080	6	4	39.6	435	0.091	-0.068
	$\hat{\gamma}_+$	-2.471	3.787	0.519	9					
Mar-1993	$\hat{\gamma}_-$	8.444	3.658	0.029	6	4	50.7	428	0.118	-0.025
	$\hat{\gamma}_+$	-1.737	3.811	0.652	9					
Mar-1994	$\hat{\gamma}_-$	8.631	3.210	0.012	6	5	51.8	421	0.123	-0.133
	$\hat{\gamma}_+$	-4.736	3.913	0.237	9					
Mar-1995	$\hat{\gamma}_-$	7.564	2.880	0.014	5	5	37.8	416	0.091	-0.150
	$\hat{\gamma}_+$	-5.065	3.488	0.158	9					
Mar-1996	$\hat{\gamma}_-$	8.293	3.347	0.020	5	5	41.5	410	0.101	-0.142
	$\hat{\gamma}_+$	-5.000	4.054	0.228	9					
Mar-1997	$\hat{\gamma}_-$	8.211	4.135	0.057	5	5	41.1	401	0.102	-0.147
	$\hat{\gamma}_+$	-5.152	5.008	0.313	9					
Mar-1998	$\hat{\gamma}_-$	5.517	3.345	0.111	5	5	27.6	396	0.070	-0.208
	$\hat{\gamma}_+$	-7.160	4.051	0.088	9					

Note: "$\hat{\gamma}_-$" denotes the number of banks per bin below the threshold that are expected to change, "$\hat{\gamma}_+$" denotes the number of banks per bin above the threshold that are expected to change, "S.E." denotes standard error, "#bins" denotes the number of bins where the distribution is expected to change below/above the threshold, "p" denotes the number of polynomials, "$\hat{B}$" denotes excess bunching, "N" denotes the number of observations, and "$\Delta\hat{D}/\hat{D}$" denotes the rate of change for deposits.

By how much did deposits reduce due to the existence of the reserve requirement system? $\Delta\hat{D}/\hat{D}$ is negative throughout the period of conventional monetary policies: The largest deposit decline of 20% occurred in 1998, while 1993 had the smallest deposit decline of 2.5%. The 1990s were a period of turmoil in Japan's financial markets. Banks were forced to accumulate loan loss reserves, and the cost of such reserves grew each year. This situation is shown in the model in Section 4 as the average μ of the marginal cost c became larger; as μ became larger, the distribution of deposits D shifted to the left, so more banks may have had fewer deposits than the threshold value D^* at which the required reserves were needed.

6.2 Estimation for Other Periods

In the previous subsection, we estimated the model for the periods subject to the same required reserve ratios. As mentioned in the introduction, the BoJ has used the same reserve requirement ratio since 1991. To check for robustness, we estimate whether our results hold for periods with different reserve ratios. The reserve ratio requirement used in the previous section was introduced in October 1991. Therefore, we perform the same estimation for 1990 because the other conditions are close to constant. Panel (a) of Figure 9 illustrates the estimated results for 1990. As with the benchmark period, the actual distribution is less above the threshold and more below it. The estimation results are illustrated in Table 3, where excess bunching is positive, although the excess bunching per period is not statistically significantly different from zero. The rate of decline in deposits is 11.3%, which is not significantly different from the benchmark results.

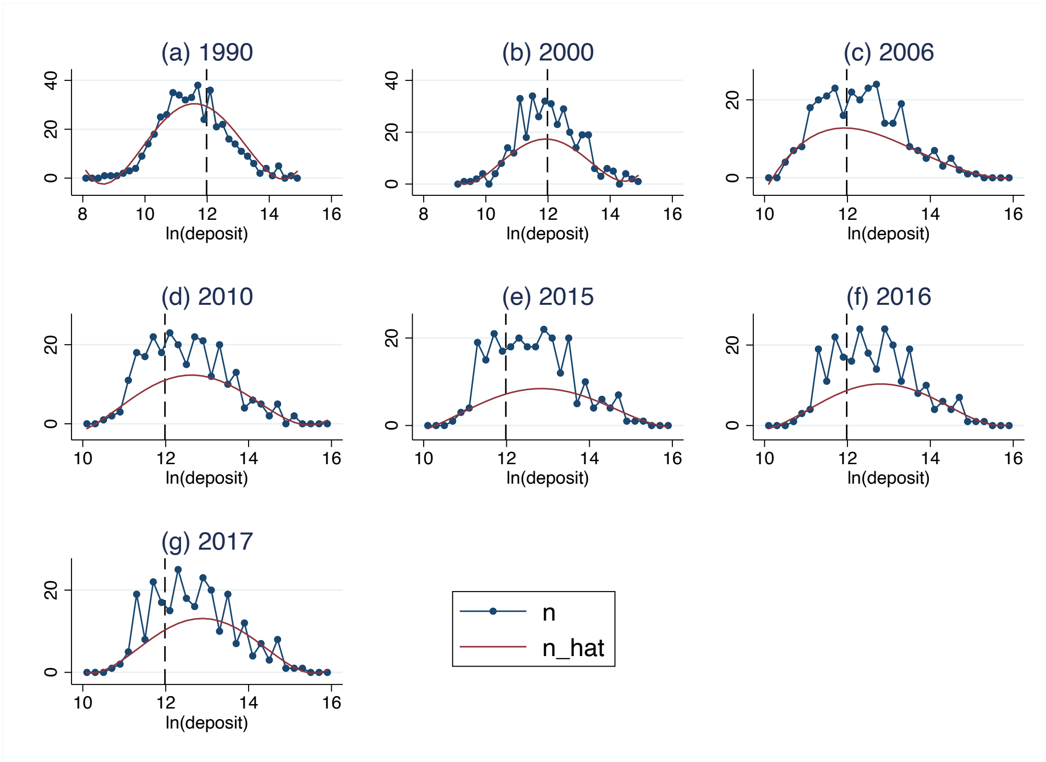

Figure 9: Bunching Estimation During Other Periods

Note: The vertical axis represents frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

Table 3: Bunching Estimation During Other Periods

Fiscal Year	Parameter		S.E.	p-value	#bins	p	$\hat{B}$	N	$\hat{B}/N$	$\Delta\hat{D}/\hat{D}$
Under different rates of reserve requirements										
Mar-1990	$\hat{\gamma}_-$	3.332	3.016	0.279	6	4	20.0	451	0.044	-0.113
	$\hat{\gamma}_+$	-3.024	3.142	0.344	9					
Under the zero-interest rate policy										
Mar-2000	$\hat{\gamma}_-$	12.522	3.851	0.004	5	4	62.6	371	0.169	0.347
	$\hat{\gamma}_+$	8.219	3.788	0.041	7					

Under quantitative easing									
Mar-2006	$\hat{\gamma}_-$	7.749	2.057	0.001	5	5	38.7	292	0.133	0.291
	$\hat{\gamma}_+$	8.398	1.882	0.000	7					
Under the zero-interest rate policy and complementary deposit facility										
Mar-2010	$\hat{\gamma}_-$	8.817	2.506	0.002	5	4	44.1	272	0.162	0.232
	$\hat{\gamma}_+$	7.197	2.364	0.006	7					
Under the zero-interest rate policy, complementary deposit facility, and quantitative and qualitative easing										
Mar-2015	$\hat{\gamma}_-$	12.146	2.004	0.000	4	4	48.6	267	0.182	0.411
	$\hat{\gamma}_+$	10.416	2.069	0.000	8					
Under the negative interest rate policy, complementary deposit facility, and quantitative and qualitative easing										
Mar-2016	$\hat{\gamma}_-$	10.325	2.786	0.001	4	4	41.3	265	0.156	0.307
	$\hat{\gamma}_+$	8.424	2.878	0.008	8					
Under the negative interest rate policy, complementary deposit facility, quantitative and qualitative easing, and Yield Curve Control										
Mar-2017	$\hat{\gamma}_-$	8.785	2.997	0.008	4	4	35.1	264	0.133	0.144
	$\hat{\gamma}_+$	7.095	2.793	0.018	6					

Note: "$\hat{\gamma}_-$" denotes the number of banks per bin below the threshold that are expected to change, "$\hat{\gamma}_+$" denotes the number of banks per bin above the threshold that are expected to change, "S.E." denotes standard error, "#bins" denotes the number of bins where the distribution is expected to change below/above the threshold, "p" denotes the number of polynomials, "$\hat{B}$" denotes excess bunching, "N" denotes the number of observations, and "$\Delta\hat{D}/\hat{D}$" denotes the rate of change in deposits.

In addition, we test whether the effect of the reserve requirement system on bank behavior changes under unconventional monetary policies. Since the distribution of deposits becomes narrower after 2000, we set the number of bins to $J = 30$.[16] Accordingly, we set

[16] If we use the method described in footnote 12 to find the optimal number of bins for the 2000 sample, we

the γ_- range from 3 to 5 and the γ_+ range from 6 to 8. Figure 9 and Table 3 illustrate the results of various unconventional monetary policies. The ZIRP was implemented in 1999–2000. As the ZIRP did not fully set zero as the guiding target for the short-term interest rate but maintained it at a positive level close to zero, the reserve requirement system might be restrictive for banks. Even under the ZIRP, excess bunching is observed ($\hat{B} = 62$), and deposits decline ($\Delta\hat{D}/\hat{D} = 34.7\%$). The reason that the rate of change in deposits is positive is that $\hat{\gamma}_+$ is also positive. Therefore, bunching did not occur in 2000.

Next, we use 2006 as the estimation period when only QE was implemented.[17] This should largely eliminate the need for banks to raise short-term funds within the interbank market and make the reserve requirement system less restrictive. The estimation results confirm excess bunching ($\hat{B} \simeq 38$). However, deposits increase ($\Delta\hat{D}/\hat{D} = 29.1\%$) because $\hat{\gamma}_+$ is also positive.

The complementary deposit facility (CDF), which was introduced in October 2008 and provides interest on excess reserves, is not part of an unconventional monetary policy, but it will have an effect. As there is no year in which the CDF was implemented by itself, it is impossible to disentangle its effect. Thus, we estimate bunching for 2010, the year the CDF was implemented under the ZIRP. At first glance, excess bunching is confirmed ($\hat{B} \simeq 44$), but $\hat{\gamma}_+$ is also positive, and deposits increase ($\Delta\hat{D}/\hat{D} = 23.2\%$) as in QE.

Further, we use 2015 as an estimation year when the ZIRP, CDF, and QQE were implemented simultaneously. QQE is a policy under which assets are purchased more broadly and in larger amounts than in QE. As indicated above, the ZIRP still constrains the reserve requirement system; however, we now observe a larger effect (i.e., than in CDF or QE). The estimation results show that excess bunching is positive ($\hat{B} \simeq 48$). Moreover, as in 2006 and 2010, deposits increased by 41.1%. In other words, this result implies that the reserve requirement system is not constrained under the three policies combined.

In January 2016, the BoJ introduced a negative interest rate policy, which imposed a

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get $J = 32$. However, with this number, some of the bins with high deposit amounts will always be zero. Therefore, we choose $J = 30$ so that the top bin level is zero as infrequently as possible.

[17] When estimating the 2000 period and from 2006 onward, the lower limit is set to 9 and 10, respectively, because the distribution of deposits has risen compared to other periods.

negative interest rate on a portion of excess reserves.[18] Immediately thereafter, using 2016 as a sample year, an increase in deposits similar to QQE is apparent (30.7%). Furthermore, in October 2016, the BoJ introduced yield curve control, which targets the yield on long-term government bonds. The results for March 2017 are similar, with an increase in deposits (14.4%). Therefore, no bunching is estimated for any period after the introduction of unconventional monetary policy, and no deposit decrease has occurred.

6.3 Placebo Test 1: Alternative Threshold

In this subsection, we confirm that the excess bunching and decrease in deposits found above are not observed when an alternative threshold is set. Thus far, we have set the threshold value of the reserve requirement system as $\ln(160{,}000) \simeq 12$, but in this subsection, we use $\ln(22{,}000) \simeq 10$ as the counterfactual threshold value.[19] This threshold is chosen as a value far from $\ln(160{,}000)$ because we must choose an area not affected by bunching, which was confirmed to exist in Section 6.1. If the threshold is smaller than $\ln(22{,}000)$, we cannot take the full width of the bunching, and if the threshold is larger than $\ln(160{,}000)$, we cannot take the full area above the threshold. Therefore, $\ln(22{,}000)$ is better as a placebo for our sample. Since this value has no economic meaning, we should not observe any bunching. Because the lower part of the threshold is closer to the left end of the distribution, we set the range of the bin below the threshold to [-5, -3] and the range of the bin above the threshold to [6, 8].

Figures 10 and 11 illustrate the estimation results for the whole sample period and 1992–1998. The predicted value is fitted on the right side of the distribution, so the actual value is smaller than the predicted value on the left side. No bunching is observed below this threshold.

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[18] For details, see https://www.boj.or.jp/en/announcements/release_2016/k160129b.pdf

[19] There may be a way to take the threshold of the placebo near 160 billion. However, the nature of bunching estimation makes it difficult to identify different thresholds within the bunching window (an area of 11 in the number of bins from the threshold, in our estimation). Indeed, Seim (2017), for example, performs placebo tests with income levels well away from the income level at which the placebo threshold is taxed. This is because the placebo test in bunching estimation is not intended to test the threshold's accuracy of but rather whether it identifies bunching in a smooth region that is not associated with the threshold.

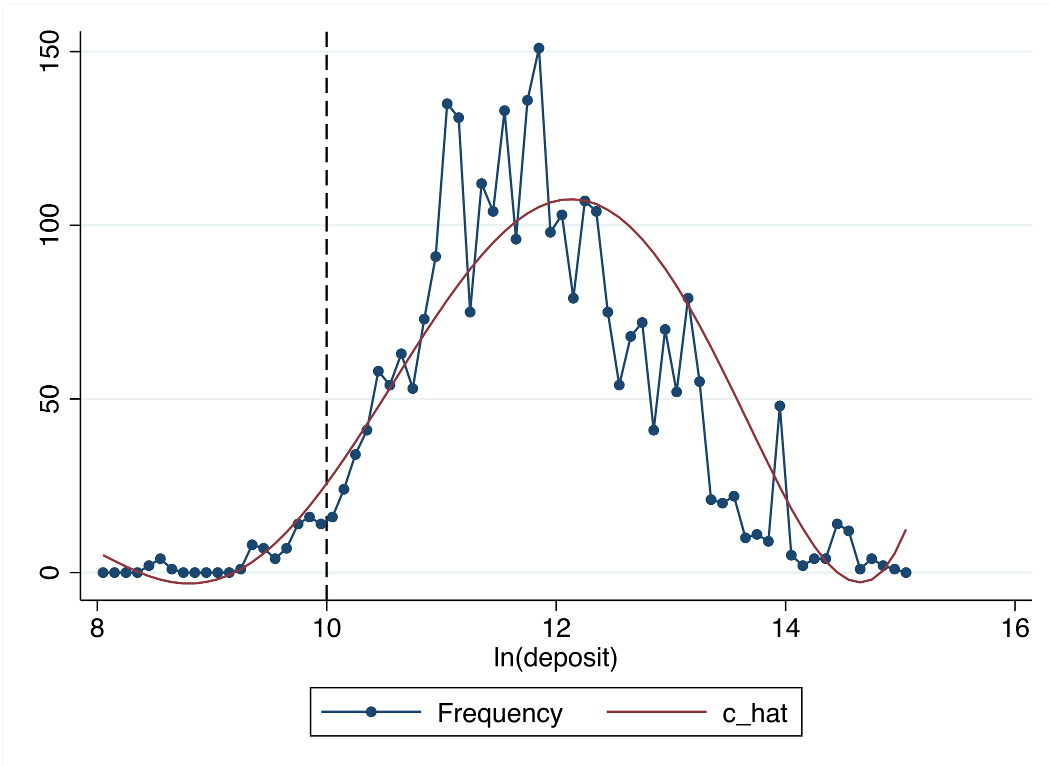

Figure 10: Placebo Threshold

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

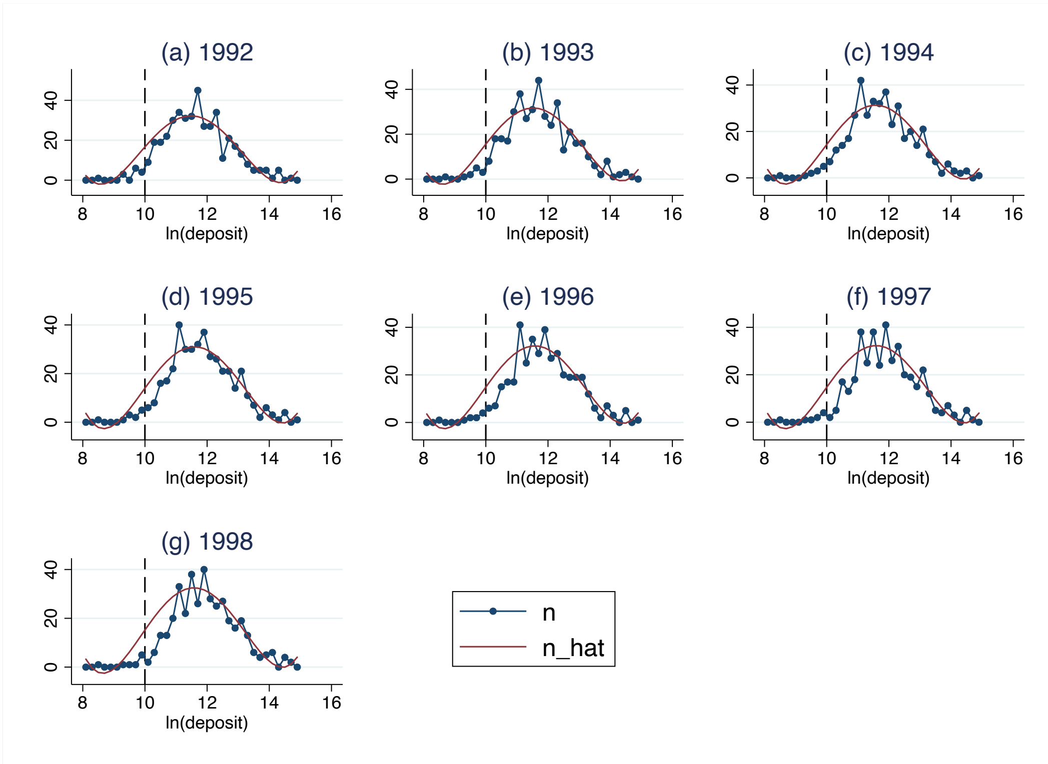

Figure 11: Placebo Threshold in Each Year

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

Table 4 presents the estimation results of the placebo tests. The excess bunching per bin $\hat{\gamma}_-$ is negative in all cases, and the number of banks decreases below the threshold $\ln(22{,}000)$. The number of banks $\hat{\gamma}_+$ decreases above the threshold, such that deposits decrease for all years. Therefore, bunching is not confirmed under the placebo threshold.

Table 4: Placebo Test 1: Alternative Threshold

Fiscal Year	Parameter	S.E.	p-value	#bins	p	$\hat{B}$	N	$\hat{B}/N$	$\Delta\hat{D}/\hat{D}$

1992–1998	$\hat{\gamma}_-$	-24.930	9.797	0.013	5	4	-124.7	2905	-0.043	-0.016
	$\hat{\gamma}_+$	-19.749	7.415	0.010	13					
Mar-1992	$\hat{\gamma}_-$	-7.958	3.851	0.048	3	4	-23.9	435	-0.055	-0.023
	$\hat{\gamma}_+$	-3.340	3.089	0.289	6					
Mar-1993	$\hat{\gamma}_-$	-6.929	4.169	0.108	3	4	-20.8	428	-0.049	-0.024
	$\hat{\gamma}_+$	-3.233	3.343	0.342	7					
Mar-1994	$\hat{\gamma}_-$	-5.707	3.997	0.164	3	4	-17.1	421	-0.041	-0.017
	$\hat{\gamma}_+$	-3.723	3.205	0.255	7					
Mar-1995	$\hat{\gamma}_-$	-5.432	3.559	0.138	3	4	-16.3	416	-0.039	-0.014
	$\hat{\gamma}_+$	-4.974	2.855	0.092	6					
Mar-1996	$\hat{\gamma}_-$	-6.751	3.933	0.097	3	4	-20.3	410	-0.049	-0.026
	$\hat{\gamma}_+$	-6.995	3.154	0.035	7					
Mar-1997	$\hat{\gamma}_-$	-6.912	4.402	0.128	3	4	-20.7	401	-0.052	-0.032
	$\hat{\gamma}_+$	-8.377	3.530	0.025	7					
Mar-1998	$\hat{\gamma}_-$	-7.410	3.501	0.043	3	4	-22.2	396	-0.056	-0.039
	$\hat{\gamma}_+$	-10.033	2.807	0.001	7					

Note: "$\hat{\gamma}_-$" denotes the number of banks per bin below the threshold that are expected to change, "$\hat{\gamma}_+$" denotes the number of banks per bin above the threshold that are expected to change, "S.E." denotes the standard error, "#bins" denotes the number of bins where the distribution is expected to change below/above the threshold, "p" denotes the number of polynomials, "$\hat{B}$" denotes excess bunching, "N" denotes the number of observations, and "$\Delta\hat{D}/\hat{D}$" denotes the rate of change for deposits.

6.4 Placebo Test 2: Alternative Sample

We further perform bunching estimation using a sample of credit unions.[20] Credit unions are smaller deposit-taking institutions than Shinkin banks. Further, credit unions are not covered by the reserve deposit system and so are not required to deposit reserve deposits with the BOJ even if they have over 160 billion yen in deposits. This means that no bunching occurs for credit unions. If bunching were identified at 160 billion yen in the sample of credit unions, this would indicate a problem with the estimation methodology.

The estimation method is the same as that described in Section 5.2. Data are obtained from *Zenkoku Shinyo Kumiai Zaimu Shohyo*, published by Kinyu Tosho Consultant Sha. As the distribution of deposits in credit unions is narrower than that of Shinkin banks, we set the number of bins to $J = 30$. Correspondingly, we set the γ_- range from 3 to 5 and the γ_+ range from 6 to 8.

Figure 12 depicts the estimation results for credit unions, which appear to demonstrate bunching, owing to the concavity around the threshold. However, the actual values for the upper and lower thresholds are lower than the estimated distribution. In other words, the number of credit unions near the threshold is smaller than predicted.

[20] For the placebo test, we also obtain data from Nikkei NEEDS FinancialQUEST on commercial banks other than Shinkin banks, upon which a reserve requirement ratio is always imposed. However, we could not use this data for estimation because the deposit amounts were more than 160 billion yen for all sample periods.

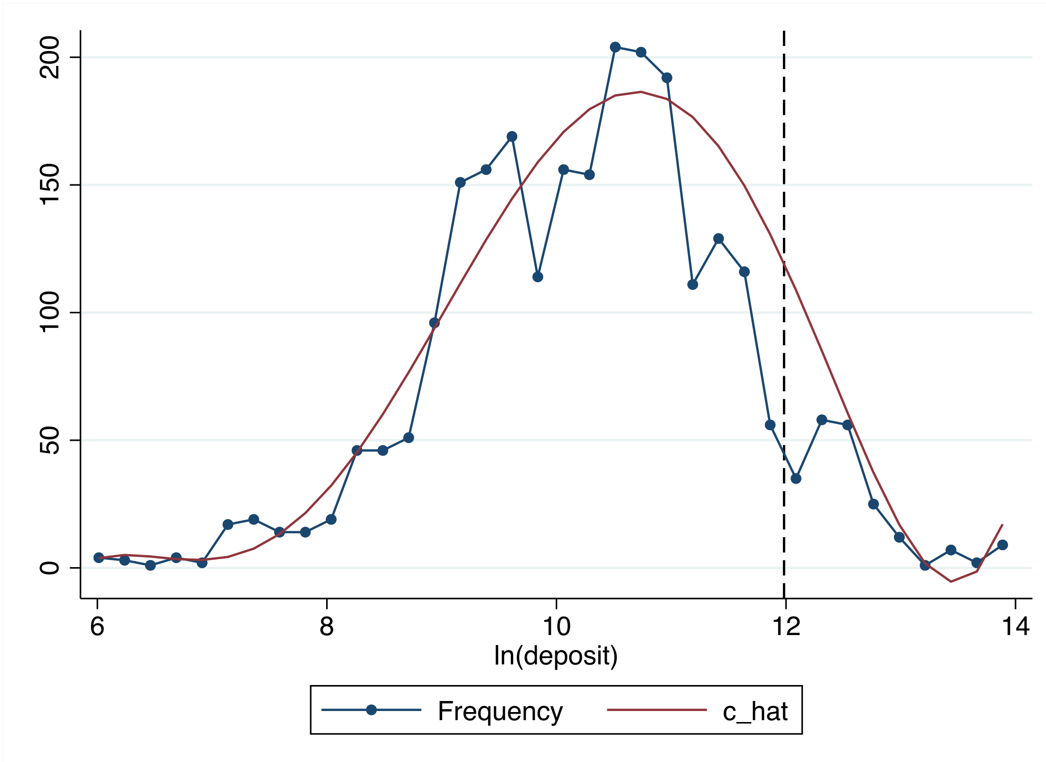

Figure 12: Placebo Sample for Credit Unions

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

Figure 13 illustrates the estimation of the sample of credit unions by year. Due to the small sample size, results vary by year, but generally, no significant bunching is observed around the threshold value.

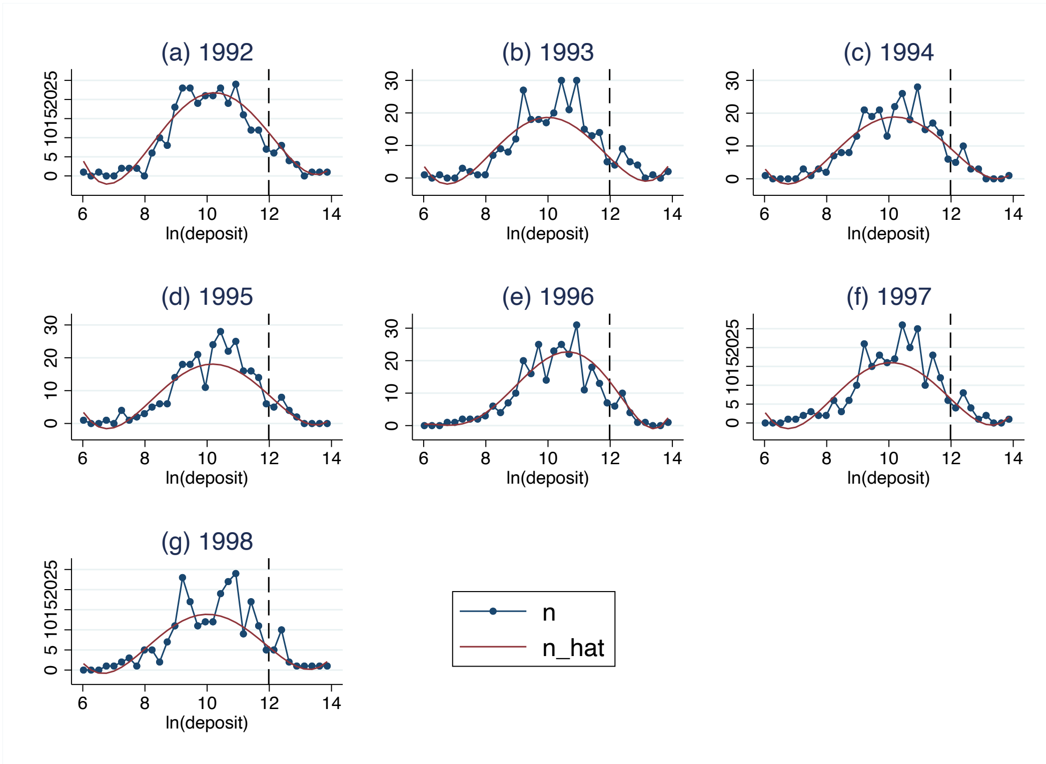

Figure 13: Placebo Sample for Credit Unions in Each Year

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of deposits. The solid line with markers represents the distribution of actual deposits, and the solid line without markers represents the predicted value of deposits.

Table 5 presents the estimation results. There is no bunching except in 1995, which is positive for $\hat{\gamma}_-$ and negative for $\hat{\gamma}_+$, fulfilling the conditions for bunching, but it might be a coincidence that it occurred only in this year due to the small sample size. These results suggest that the threshold of 160 billion yen, to which the reserve deposit system applies, is constraining only for Shinkin banks. There are two possible reasons for this result. First, the estimated model may be misspecified because a dummy variable may have been applied to a region without bunching, and the predicted value may be underestimated. Second, the overall deposits of credit unions may be too low, and there may not be a sufficiently large sample around $\ln(160{,}000)$ to perform a bunching estimation.

Table 5: Placebo Test 2: Credit Unions

Fiscal Year	Parameter		S.E.	p-value	#bins	p	$\hat{B}$	N	$\hat{B}/N$	$\Delta\widehat{D}/\widehat{D}$
1992–1998	$\hat{\gamma}_-$	-52.539	15.438	0.002	4	5	-210.2	2451	-0.086	-0.231
	$\hat{\gamma}_+$	-35.166	16.908	0.047	3					
Mar-1992	$\hat{\gamma}_-$	-1.462	2.124	0.497	5	4	-7.31	294	-0.025	-0.127
	$\hat{\gamma}_+$	-2.260	2.531	0.380	4					
Mar-1993	$\hat{\gamma}_-$	6.392	3.272	0.062	6	4	38.4	298	0.129	0.431
	$\hat{\gamma}_+$	2.434	4.056	0.554	5					
Mar-1994	$\hat{\gamma}_-$	3.788	2.402	0.127	6	4	22.7	288	0.079	0.050
	$\hat{\gamma}_+$	-0.864	2.922	0.770	4					
Mar-1995	$\hat{\gamma}_-$	5.009	2.423	0.049	6	4	30.1	282	0.107	-0.436
	$\hat{\gamma}_+$	-0.543	2.947	0.855	4					
Mar-1996	$\hat{\gamma}_-$	-1.861	3.319	0.580	4	5	-7.4	286	-0.026	-0.164
	$\hat{\gamma}_+$	-3.123	3.420	0.370	4					
Mar-1997	$\hat{\gamma}_-$	5.767	3.108	0.075	6	4	34.6	260	0.133	0.418
	$\hat{\gamma}_+$	1.274	4.016	0.754	6					
Mar-1998	$\hat{\gamma}_-$	6.030	2.767	0.039	6	4	36.2	242	0.150	0.310
	$\hat{\gamma}_+$	1.477	3.366	0.665	3					

Note: "$\hat{\gamma}_-$" denotes the number of banks per bin below the threshold that are expected to change, "$\hat{\gamma}_+$" denotes the number of banks per bin above the threshold that are expected to change, "S.E." denotes standard error, "#bins" denotes the number of bins where the distribution is expected to change below/above the threshold, "p" denotes the number of polynomials, "$\hat{B}$" denotes excess bunching, "N" denotes the number of observations, and "$\Delta\widehat{D}/\widehat{D}$" denotes the rate of change of deposits.

7. Discussion

How do banks control the volume of deposits? One method is to control the supply of deposits by adjusting the deposit rate. However, this method depends on depositor behavior, and it is not easy to precisely control the supply of deposits below a certain threshold. The second method is to increase or decrease lending. Figure 14 illustrates the histograms of lending for 1992–1998. Peaks and valleys are observed around the threshold of 160 billion yen for the reserve requirement system. This seems to provide evidence for lending to control the amount of deposits. Alternatively, since the lending amount is highly variable, the decrease and increase in the number of banks may have been observed only by chance around this threshold. In any case, we expect that the amount of deposits is not determined by depositor behavior alone but is also controlled by bank lending. The lending threshold is unknown because conditions vary across banks, making bunching estimation difficult. Estimating the impact of the reserve requirement system on lending by bunching estimation is a task for future research.

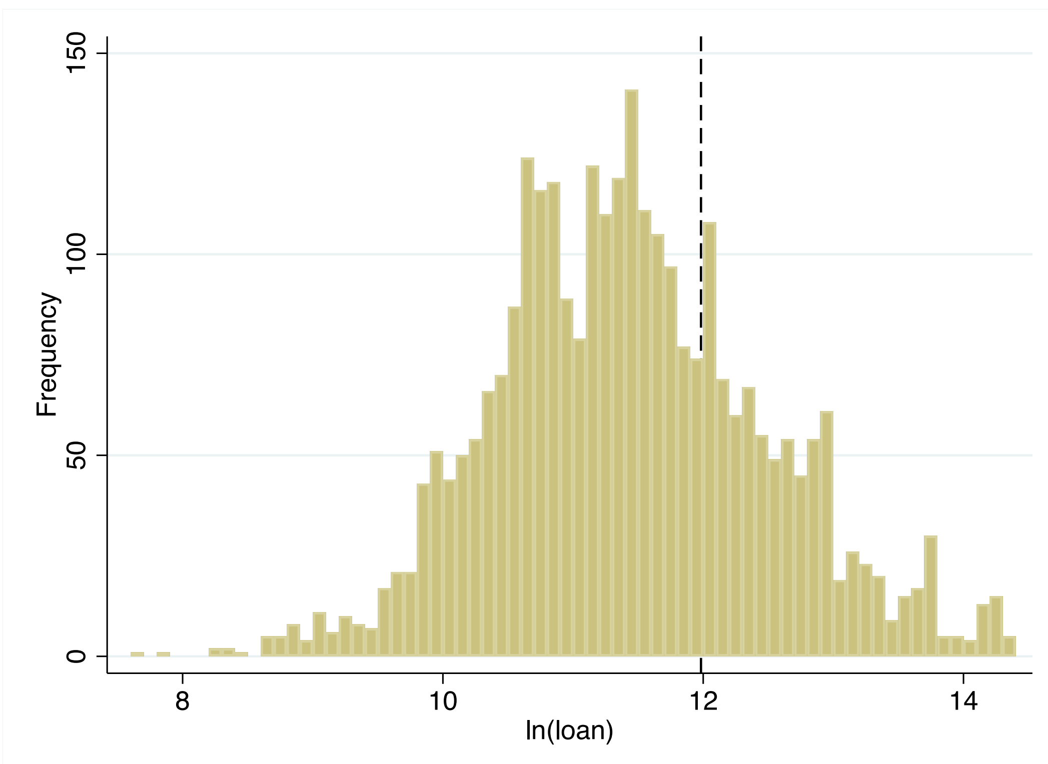

Figure 14: Histograms of Loans

Note: The vertical axis represents the frequency, and the horizontal axis represents the natural logarithm of the loans.

8. Conclusion

In this study, we use bunching estimation to investigate whether the reserve requirement system constrains bank behavior. The estimation results demonstrate statistically significant excess bunching for all years of the conventional monetary policy period. This means that the reserve requirement system constrains banks. The presence of bunching also reveals that total deposits have declined. In contrast, we do not observe excess bunching during the period of unconventional monetary policies. A placebo test confirms that our results do not depend on the threshold for bunching or the specific sample. The fact that the reserve requirement system constrains bank behavior will influence the debate on the nature and existence of this system. Of course, the reserve requirement system allows the central bank to maintain a stable monetary policy. However, the reserve requirement system is not necessarily essential, given the constraints it imposes on banks and the fact that some countries do not use such a system.[21]

The results of our analysis have important implications for the debate on whether the reserve requirement system should be continued. This is because it imposes a heavy burden on the deposit market. As mentioned in the introduction, the FED has abolished the reserve requirement system.

To the best of our knowledge, no study has made rigorous causal inferences about the impact of reserve requirement systems on deposits. However, despite robustness checks and placebo tests, our sample size is not large enough; thus, the magnitude of the estimates needs to be interpreted cautiously. In our future work, we aim to provide a more reliable estimation method.

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[21] Various discussions on the reserve deposit system are summarized in the Frequently-Asked-Question section of the FED's webpage: https://www.frbservices.org/resources/central-bank/faq/reserve-account-admin-app.html

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