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The Impact of the Bank of Japan's Low-Interest Rate Policy on the Japanese Banking Sector[1]

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Abstract

This paper presents an analysis of the impact of the Bank of Japan's low-interest rate policy on the banking sector in the wake of the 1998 Japanese financial crisis. We show how the low-cost liquidity provision as a means to stabilize banks has created a growing gap between deposits and loans in the financial system and how the low-interest rate policy has compressed interest margins as the traditional source of banks' income. Efficiency scores are compiled to estimate the effect of the Bank of Japan's monetary policy on banks' technical efficiency. The estimation results provide evidence that the Japanese monetary policy has contributed to declining efficiency in the banking sector, despite – or possibly because of – the increasing concentration within this sector.

Keywords: Japan, Monetary Policy, Crisis Management, Banking Sector, City Banks, Regional Banks, Shinkin Banks, Concentration

JEL Classification: E52, E58, F42, E63

I. Introduction

During the second half of the 1980s, the Bank of Japan introduced a low-interest rate policy to mitigate the appreciation pressure on the Japanese yen.[2] This policy contributed to the emergence of a 'bubble' in the Japanese stock and real estate markets, which ended in the early 1990s (*Bayoumi/Collyns* 2000). During most of the 1990s, the destabilizing effect of the resulting balance-sheet recession (*Koo* 2003) was contained by the Bank of Japan by gradually cutting the interest rate to almost zero. This enabled Japanese banks to cover their loss-

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[2] The Bank of Japan cut short-term interest rates from roughly 8 percent in 1985 to 3.5 percent in 1987.

es, incurred from declining asset prices, by providing credit to Japanese enterprises operating in Southeast Asia (*Hoffmann/Schnabl* 2008). The 1997/98 Asian crisis, however, finally triggered strong adjustment pressure on the Japanese banking sector (*Schnabl* 2015) leading to a consolidation process among Japanese banks and financial institutions (*Hosono* et al. 2009; *Murai/Schnabl* 2021).

The continuation of the zero-interest rate policy after 1999, and the advent of unconventional monetary policy measures, have been widely understood as stabilizing measures for the Japanese banking sector (*Posen* 2000; *Koo* 2003). The ample low-cost liquidity provision of the Bank of Japan stabilized asset prices while also stabilizing the banks' balance sheets by reducing the number of potential bad loans. However, the liquidity provisions of the Bank of Japan arguably prevented *Schumpeter's* (1942) process of 'creative destruction' and thereby prevented sustained recovery among Japanese banks (*Sekine* et al. 2003; *Peek/Rosengren* 2005; *Caballero* et al. 2008). Furthermore, previous studies have shown that low-interest rate policies affect banks' profits and profitability. *Samuelson* (1945) and *Hancock* (1985) show that the policy rate set by central banks is (in the long run) positively correlated with commercial banks' profits.

For banks to remain successful in a low-interest rate environment, more efficient use of resources is therefore crucial. The consolidation process in the Japanese banking sector can be understood as an expression of Japanese banks' efforts to increase their efficiency by achieving economies of scale and scope. However, despite these efforts previous empirical studies have shown that the Japanese banking sector has exhibited major technical and scale inefficiencies, with considerable differences among the various bank types (e.g. *Fukuyama* 1993; *McKillop* et al. 1996; *Altunbas* et al. 2000; *Drake/Hall* 2003; *Drake* et al. 2009; *Assaf* et al. 2011). However, few studies have attempted to understand the role of the Bank of Japan's monetary policy in contributing to this development.

Therefore, we aim to add to the literature by analysing if and how the Bank of Japan's low-interest rate policy has impacted the efficiency of Japanese banks. Based on micro-data we estimate output-oriented technical efficiency scores for Japanese banks in the period 1999–2005 and empirically test for the impact of the Bank of Japan's monetary policy and the banks' strategies to cope with the low-interest rate environment. We examine the impact of low-interest rate policy via banks' net interest margins.

Whereas the net interest margin is traditionally regarded as reflecting asset productivity (*Assaf* et al. 2011), we argue that it can also be used as an indicator of a bank's exposure to the low-interest rate environment and unconventional monetary policy. More recent papers show that the net interest margin is strongly influenced by the level and the slope of the yield curve (*Alessandri/Nelson* 2015; *Borio* et al. 2017). It is widely acknowledged that the Bank of Japan has affected both the level and the slope of the yield curve via conventional and unconventional monetary policy measures (*Yoshino/Taghizadeh-Hesary* 2016).

Our analysis also differs from previous studies on Japanese bank efficiency to the extent that our sample contains both commercial banks (city banks and regional banks) and cooperative banks (shinkin banks). *Fukuyama/Weber* 2009; *Assaf* et al. 2011 estimate efficiency scores only for shinkin banks. *Altunbas* et al. 2000; *Drake/Hall* 2003 focus only on commercial banks. Separate estimations for commercial banks and cooperative banks, however, only allow a comparison between banks of the same ownership type. A combined estimation permits a comparison between the different types of banks relative to the industry 'best practice' frontier.

The paper is organized as follows. Section 2 provides an overview of how the persistent low interest environment has affected Japanese banks' profits and how they adjusted to it. In Section 3 we analyze the development of Japanese banks' efficiency by estimating technical efficiency scores. In Section 4, we analyze the determinants of Japanese banks' efficiency, paying particular attention to the role of the net interest margin. Our conclusions are presented in Section 5.

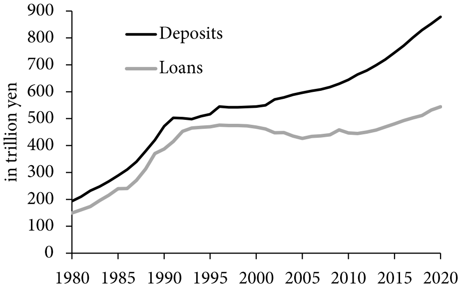
II. Japan's Low-Interest Rate Policy and the Banking Sector

The development of the Japanese banking sector since the 1998/99 Japanese financial crisis must be seen in the context of the protracted stagnation in the domestic economy (*Schnabl* 2015). During the Japanese bubble economy (1985–1990) domestic banks' credit to the private sector grew markedly, with credit slowly continuing to expand until 1998. With the Asian and Japanese financial crisis, a credit crunch set in (*Ishikawa/Tsutsui* 2005).The gradual erosion of the banks' traditional sources of income triggered a search for alternative revenues and a struggle to increase their efficiency through mergers and acquisitions (M&A).

1. Declining Income

The credit crunch, which lasted from 1998 until the advent of the Abenomics[3] in January 2013, had two origins. On the one hand, declining asset prices forced Japanese banks to reduce their risk exposure by curtailing outstanding credit to risky enterprises (*Koo* 2003). On the other hand, sluggish investment by the corporate sector and the need to deleverage lowered the demand by Japanese firms

[3] Abenomics refers to Japanese Prime Minister Shinzo Abe's three-pillared policy package to revive the Japanese economy, comprising monetary easing, fiscal expansion and structural reforms.



Source: Bank of Japan. Data consist of City Banks, Regional Banks I, Regional Banks II and Shinkin Banks.

Figure 1: Deposits and Loans of Japanese Commercial Banks

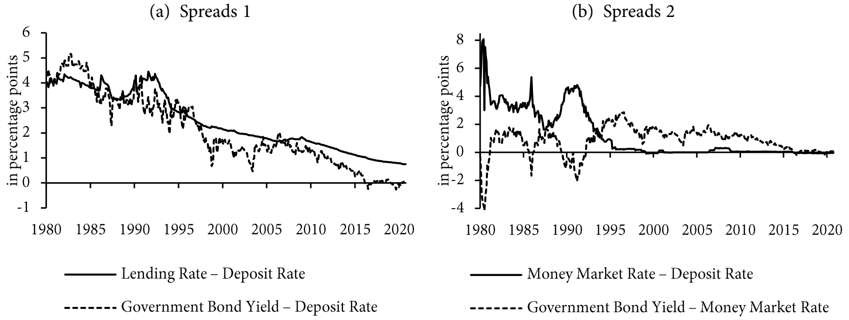
for loans, while simultaneously increasing their deposits at banks. In this context, the zero-interest rate policy and unconventional monetary policy measures can be understood as a form of subsidy for enterprises (in particular for large enterprises).[4] The resulting growth in cash reserves further reduced their demand for credit (*Gerstenberger* 2017).

As a result, the total amount of loans reflected on the balance sheets of banks[5] fell substantially. The increasing inflow of household and corporate deposits, combined with declining volumes of credit, led to a widening gap between loans and deposits (Figure 1). The credit business started to recover only from 2012 but without helping to reduce the gap. The loan-deposit ratio fell from almost 1 at the beginning of the 1990s to about 0.65 in 2020.

The stagnation in the traditional credit business became paired with declining margins in the loans and investment business. The Bank of Japan's monetary policy gradually depressed short-term money market rates, which finally dropped to zero in March 1999. The Bank of Japan continued to reduce interest rates at the

[4] The low-interest rate policy reduced the financing costs of enterprises by continuously depressing interest rates. In addition, the resulting depreciation of the yen subsidized the large export-oriented enterprises.

[5] *City banks* are large commercial banks that operate at a national and international level and have branches in all major cities in Japan. *Tier-one and tier-two regional banks* are mainly active in retail banking and focus on specific regions (e.g. one prefecture). They mainly engage in lending to the corporate sector, specifically small and medium enterprises (approximately 70 percent of all loans are granted to SMEs). Tier-one and tier-two regional banks have different histories. Therefore, statistics of the Japanese Bankers Association are aggregated in two different categories. Since the financial market liberalizations in the 1990s the business model of both groups is mainly the same. Today, the main difference between the two groups is that tier-two regional banks are significantly smaller. *Shinkin banks* are credit associations operating within a prefecture, managing deposits and providing loans to and from their owners (mainly SMEs).



Source: IMF, own calculations. Government bond yields on the 10-year government bonds. Interest rates on new contracts.

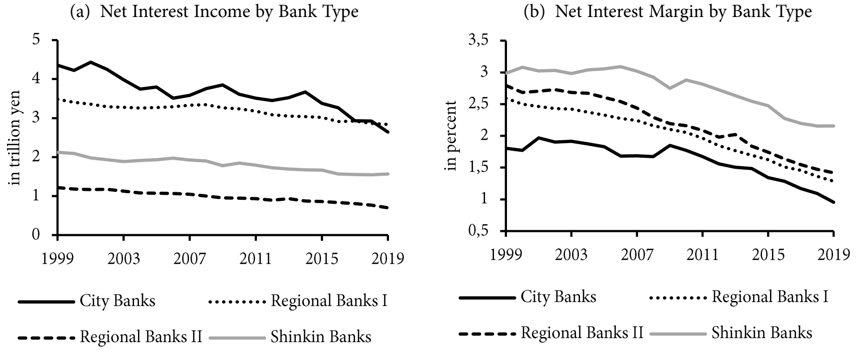
Figure 2: Interest Rate Spreads in the Japanese Banking Sector

long end of the yield curve through fast-growing bond purchases (*Yoshino/Taghizadeh-Hesary* 2016).[6] As a result, the spread between average lending and deposit rates (on new contracts) declined from an average of 3.5 percentage points during the 1980s to less than 1 percentage point in 2020, as shown in Figure 2a.

Japanese banks partially substituted the decline in lending to the private sector by the purchase of government bonds (see section 2.2). However, the margin between the government bond yield and the deposit rate declined from 3.5 percentage points in the 1980s to close to (or below) zero during the Abenomics period (Figure 2a). The scope for generating profits by transforming short-term borrowing in the money market into long-term lending also shrank. The transformation margin, i. e. the spread between the 10-year government bond yields and the money market rate, declined from a peak of 2 percentage points in 1996 to zero in 2015 (Figure 2b). Moreover, the passive margin, i. e. the difference between the money market rate and the average deposit rate, dropped from around 3 percentage points in the 1980s to zero by 2005 (see Figure 2b).

Japanese banks were not able to compensate the decrease in interest margins by boosting the lending volumes. Therefore, between 1999 and 2020 revenue from the traditional credit business (net interest rate income) decreased by 39.3 percent for large city banks, by 18.4 percent for tier-one regional banks, by 26 percent for tier-two regional banks, and by 42.2 percent for shinkin banks (Figure 3a). Banks' profitability, as measured by the net interest margin, has also considerably declined (Figure 3b). In addition to declining interest margins,

[6] The Bank of Japan cut short-term interest rate from 6 percent in 1991 to zero by March 1999. The size of the balance sheet of the Bank of Japan increased from 18 percent of GDP in January 1999 to 130 percent by the end of 2020, due to extensive bond purchases, in particular government bonds.



Source: Japanese Bankers Association, Shinkin Central Bank. Net interest income defined as interest income minus interest expenses. Net interest margin defined as net interest income over bank loans.

Figure 3: Net Interest Income per Bank Type

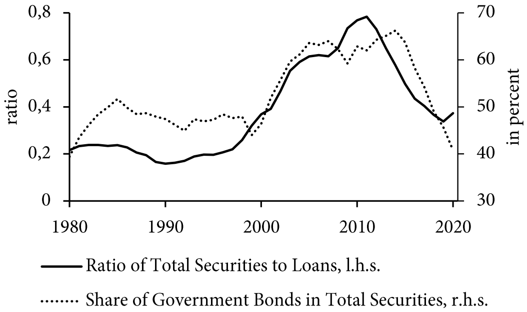
Japanese banks incurred high losses through writing off non-performing loans. This constituted an additional burden for Japanese banks until the start of the Abenomics.

2. Alternative Sources of Income and Adjustment of Costs

Additional revenue was initially generated by the substitution of credit to the private sector by the purchase of central and local government bonds. From 1999 to 2012, the share of government bonds in total assets increased from 5 percent to 27 percent for city banks, from 8 percent to 17 percent for tier-one regional banks, from 5 percent to 15 percent for tier-two regional banks and from 12 percent to 25 percent for shinkin banks. Figure 4 shows the increasing securities to loan ratio and the increasing share of government securities out of all securities, both for all banks.

The purchases of government bonds were lucrative until the start of the Abenomics. The shift in the Bank of Japan's monetary policy towards aggressive quantitative easing in 2013, however, made government bond yields more volatile and pushed them towards zero. The government bond purchases of the Bank of Japan strongly reduced the holdings of government bonds by commercial banks. By the end of 2020, the share of government bonds in total assets of banks had declined substantially.[7]

[7] For regional banks and shinkin banks, the decline in central government bond holdings has been widely compensated for by purchases of local government bonds (*Bank of Japan* 2016).



Source: Bank of Japan.

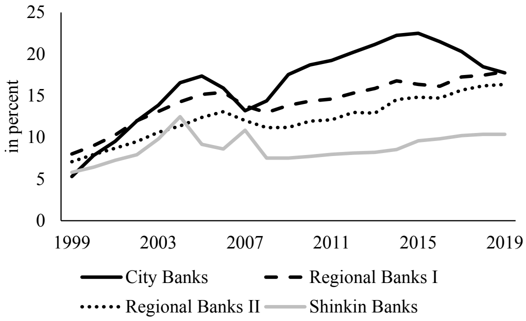
Figure 4: Investment Securities – All Banks

The financial deregulation in the late 1990s helped Japanese banks to generate higher revenues through fees and commissions. They developed new financial services and formed business alliances with non-bank companies (*Bank of Japan* 2006). Banks expanded their sales of investment trusts and private pension policies to households, and increased their corporate customer fees – for example, fees for the arranging syndicated loans and sales of derivatives to firms (*Bank of Japan* 2005).

Regional banks and shinkin banks ceased to follow a purely lending-based business model to embrace a more service-oriented business model. These banks started to provide services to corporate customers to resolve challenges such as establishing new business relationships, exploring new markets or finding business successors (*Ishikawa* et al. 2013). The highest increase in revenues from fees and commissions as share of total ordinary income (Figure 5) has been realized by the large city banks, which became strongly involved in the investment business and profited from having large, export-oriented enterprises as customers.

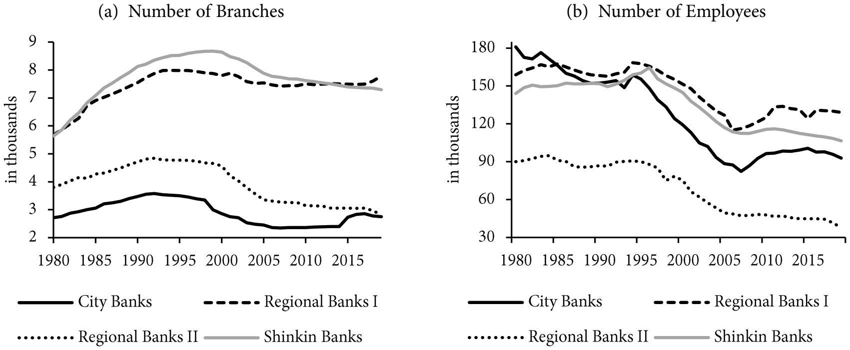
Depending on the ability to compensate for declining revenues Japanese banks had to cut their general and administrative expenses. The pressure to cut costs was stronger for the small shinkin banks and tier-two regional banks than it was for the larger tier-one regional banks and the city banks. Between 1999 and 2020, both personnel expenses and administrative costs were strongly reduced (*Schnabl* 2020).

The pressure to reduce costs came along with a process of concentration in the Japanese banking sector through mergers and acquisitions. *Hosono* et al. (2009) argue that one motive for Japanese banks to engage in M&As was to increase efficiency. As a result, the number of Japanese financial institutions (including city banks, trust banks, tier-one regional banks, tier-two regional banks and shinkin banks) declined from 606 in 1990 to 368 in 2019 (*Schnabl* 2020).



Source: Japanese Bankers Association, Shinkin Central Bank.

Figure 5: Fees and Commissions as Share of Ordinary Income by Bank Type



Source: Japan Financial Yearbook.

Figure 6: Number of Banks

For all four bank types the number of branches has declined steadily since the mid-1990s with the reduction being more severe for smaller banks (tier-two regional banks and shinkin banks) than for larger banks (Figure 6a). Also the number of regular employees was reduced more drastically in tier-two regional and shinkin banks than among other types of banks (Figure 6b).

The continuing pressure on profits because of the Bank of Japan's low-interest rate policy suggests that Japanese banks' efficiency should have increased because of the concentration process in the banking sector and other adjustment measures of the banks. However, the simultaneous decline in competition because of increasing concentration, combined with the persistent low-cost liquidity provision by the Bank of Japan might have reduced the pressure on Japanese banks to increase their efficiency.[8] In addition, the squeezing of profits may have reduced the banks' resources for implementing measures to enhance their efficiency. Hence, the impact of Japanese monetary policy crisis management on banks' efficiency is ambiguous from a theoretical point of view.

III. Development of Japanese Banks' Efficiency

As shown above, during the post-bubble period, the Bank of Japan's monetary policy has substantially changed the operating environment of Japanese banks. The gradual reduction of interest rates and the introduction of unconventional policy measures has eroded their traditional sources of income. For banks to remain profitable in a low-interest rate environment, a more efficient utilization of resources is crucial.

1. Concept of Efficiency Measures

To evaluate the development of Japanese banks' efficiency, we estimate for each bank i and each year t an output-oriented technical efficiency score, TE_{it}. This score reflects the bank's distance from a pre-specified benchmark, known as the efficiency frontier (*Farrell* 1957).[9] Technical efficiency can be defined as a bank's ability to produce a maximum set of outputs (such as loans, securities and operating income) given a set of inputs (such as deposits, employees and branches). *Farrell's* (1957) output-oriented technical efficiency score TE_{it} equals 1 when the bank operates at the 'best practice' frontier. Higher values than unity indicate inefficiency.[10] Following *Banker* et al. (1984), we further decompose a bank's overall technical efficiency score into pure technical efficiency (PTE_{it}) and scale efficiency (SE_{it}) with:

$$TE_{it} = PTE_{it} \times SE_{it} \tag{1}$$

The decomposition helps to identify whether Japanese banks' technical inefficiencies are the result of inefficient operations (measured by PTE_{it}) or alternatively from not operating at an optimal scale (measured by SE_{it}), or both. We are furthermore able to determine if Japanese banks are operating below, above or

[8] For instance, *Hosono* et al. (2009) provide evidence that M&As in the Japanese banking sector have not necessarily improved efficiency.

[9] *Farrel* (1957) decomposes a firm's *overall efficiency* (or *economic efficiency*) in *technical efficiency*, reflecting a firm's ability to produce a maximum set of outputs from a given set of inputs, and price efficiency (or *allocative efficiency*), reflecting a firm's ability to choose an optimal set of inputs given respective prices. We focus on *technical efficiency* of Japanese banks as input prices were not available.

[10] For details see Appendix A.

at their technically optimal scale.[11] Prior studies on the Japanese banking sector indicate that pure technical inefficiencies are more severe than scale inefficiencies, as Japanese banks have been following a gradual consolidation process ever since the bubble economy burst (*Fukuyama* 1993; *McKillop* et al. 1996; *Drake/Hall* 2003; *Azad* et al. 2014).

To compute efficiency scores TE_{it}, PTE_{it} and SE_{it} we use a linear programming technique that constructs the efficiency frontier by enveloping input/output data of a bank, with the nonparametric frontier being formed by the 'best practice' bank (*Drake* et al. 2006). The approach is referred to as *Data Envelopment Analysis* (DEA) (*Charnes* et al. 1978).[12] *Coelli* et al. (2005) note that DEA does not allow for random errors and is therefore sensitive to random variations in the data. As the method has no statistical foundation, the estimates cannot be assessed for statistical significance. We correct for these problems using a statistical model introduced by *Simar/Wilson* (1998) that allows to determine statistical properties of DEA estimators in the multi-input and multi-output case using a bootstrapping procedure. The computation of the bootstrap estimates allows making statistical inference on the efficiency scores, particularly, it allows for the construction of confidence intervals and dealing with endogeneity.

2. Input and Output Data

In modelling banks' production function, we follow the intermediation approach of *Sealey/Lindley* (1977) which considers banks as institutions which transform deposits into loans and into other earning assets, using labour and physical capital as inputs.[13] This is in line with previous studies of the Japanese banking sector (e.g. *Fukuyama* 1993; *Drake/Hall* 2003). The banks' activities are modelled in a three-input and two-output framework.

[11] Increasing (decreasing) returns to scale indicate that the bank is too small (big).

[12] An alternative method to construct the efficiency frontier is the Stochastic Frontier Analysis. It is a parametric method that imposes a functional form on the production frontier and estimates econometrically the function's parameters. However, it is susceptible to misspecification (*Coelli* et al. 2005).

[13] In contrast, the production approach assumes that banks primarily produce services for account holders (*Benston/Smith* 1976).

Table 1

Descriptive Statistics of Inputs and Outputs

	CB	RB I	RB II	SB	Total
(X1) Deposits (billion yen)	57,479	3,212	1,305	377	1,929
(X2) Physical Capital (billion yen)	568	45	21	6	24
(X3) Employees (number of)	15,067	2,028	1,091	399	988
(Y1) Loans (billion yen)	3,5710	2,261	977	205	1,237
(Y2) Securities (billion yen)	17,130	976	313	106	569

Source: Bankscope, annual reports of individual banks, Nikkei NEEDS database, Japanese Bankers Association. Values indicate sample mean per bank type. CB: city banks, RB I: tier-one regional banks, RB II: tier-two regional banks, SB: shinkin banks. Sample means per bank.

Table 2

Sample Structure of Efficiency Analysis

	CB	RB I	RB II	SB	Total
1999	9	48	26	254	337
2000	9	48	28	255	340
2001	7	48	32	266	353
2002	7	56	36	269	368
2003	7	58	38	271	374
2004	7	62	40	272	381
2005	6	62	40	272	380
2006	6	62	40	271	379
2007	6	61	39	271	377
2008	6	59	37	269	371
2009	6	61	37	269	373
2010	6	61	37	268	372
2011	6	61	40	267	374
2012	6	62	41	269	378
2013	5	61	39	267	372
2014	5	59	38	263	365
2015	5	57	37	190	289

Notes: CB: city banks, RB I: tier-one regional banks, RB II: tier-two regional banks, SB: shinkin banks

Following *Assaf* et al. (2011) and *Fukuyama/Weber* (2009), the inputs are total deposits and short-term borrowed funds (X1), physical capital (land, premises and fixed assets) (X2) and labour (number of employees) (X3).[14] The outputs are total loans and bills discounted (Y1), and securities issued (Y2). The inputs and outputs (excluding employees) are measured in yen and deflated using the GDP deflator provided by the World Bank. Table 1 shows descriptive statistics of inputs and outputs according to bank type.

To construct the dataset, we use information drawn from financial statements of individual banks provided by the BankScope database. The dataset is completed using data from the annual reports of individual banks, the Nikkei NEEDS database and information from the Japanese Bankers Association. Our final dataset for the efficiency analysis comprises 6,183 observations from 401 Japanese banks for the financial years 1999 to 2015. Our sample covers almost the full spectrum of bank types operating in Japan: it includes 16 city banks, 64 tier-one regional banks, 41 tier-two regional Banks and 280 shinkin banks.[15] The breakdown of the sample is shown in Table 2.[16]

3. *Results for Efficiency Scores*

Table 3 summarizes the annual mean efficiency scores for the Japanese banking sector over the period 1999 – 2015 as compiled by DEA.[17] Columns (1) to (3) list the average bias-corrected technical efficiency (*TE*), pure technical efficiency (*PTE*) and scale efficiency (*SE*) estimates. Columns (4) to (6) summarize the share of banks operating under increasing (IRS), constant (CRS) or decreasing returns to scale (DRS).

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[14] The number employees instead of personnel expenses were used as input variable since the data set for personnel expenses was very fragmented.

[15] Our analysis differs from other studies on Japanese bank efficiency to the extent that our sample contains both commercial banks (city banks and regional banks) and cooperative banks (shinkin banks). *Fukuyama/Weber* (2009) and *Assaf* et al. (2011) estimate efficiency scores only for shinkin banks. *Altunbas* et al. (2000) and *Drake/Hall* (2003) focus only on commercial banks. Separate estimations for commercial banks and cooperative banks, however, only allow a comparison between banks of the same ownership type. *Altunbas* et al. (2001) argue that a combined estimation permits a comparison between the different types of banks relative to the industry 'best practice' frontier. Other efficiency studies analysing both commercial and cooperative banks include for instance *Altunbas* et al. (2001) and *Weil* (2004). *Fukuyama/Weber* (2008) combine both regional and shinkin banks in their efficiency analysis on Japanese banks.

[16] Total numbers differ from the annual numbers in Table 2 due to different participation behaviour of banks in our sample. Banks which were involved in M&A are pre-merger treated as separate entities.

[17] We used the FEAR software by *Wilson* (2008) to obtain the bias-corrected efficiency scores.

Table 3 provides evidence that the Japanese banking sector experienced large inefficiencies across all sampled years. Relative to the constructed frontier, the average technical efficiency for all banks in our sample was around 1.27. Hence, Japanese banks could have increased output by around 27 percent had the inputs been used in the most efficient way. Over time the average technical efficiency of the Japanese banking sector increased considerably between the years 2000 and 2004 but deteriorated thereafter. Technical efficiency in particular has declined since 2010, especially after the introduction of the Abenomics in 2013.

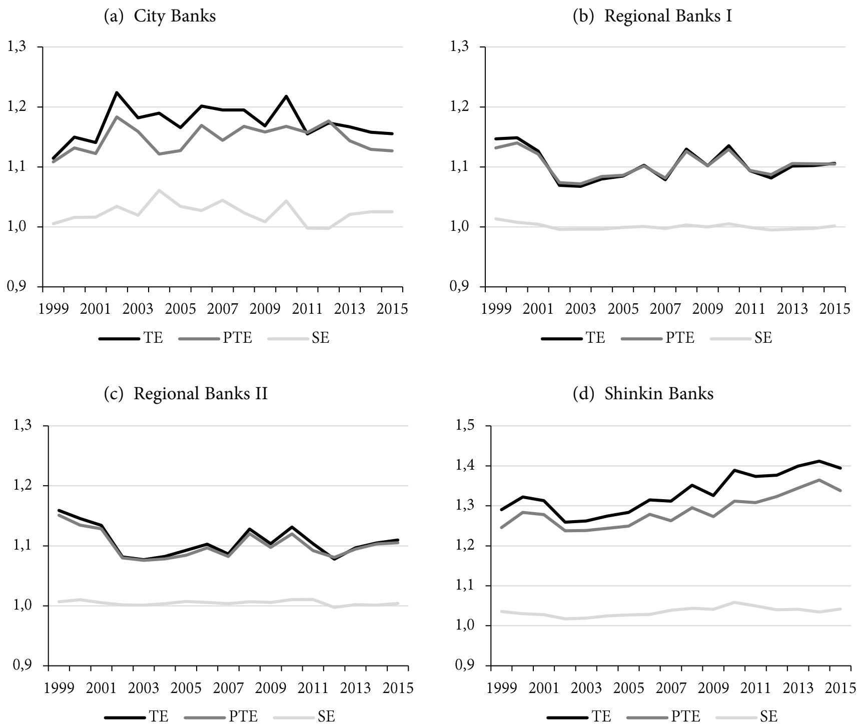
Table 3

Annual Mean Efficiency Scores of All Banks (1999–2015)

	(1) TE	(2) PTE	(3) SE	(4) IRS	(5) CRS	(6) DRS
1999	1.255	1.219	1.030	91 %	4 %	5 %
2000	1.279	1.247	1.026	86 %	4 %	10 %
2001	1.268	1.240	1.023	89 %	6 %	5 %
2002	1.212	1.196	1.013	88 %	5 %	7 %
2003	1.212	1.195	1.014	87 %	4 %	9 %
2004	1.221	1.198	1.019	90 %	4 %	6 %
2005	1.229	1.203	1.021	91 %	4 %	6 %
2006	1.256	1.229	1.022	92 %	3 %	4 %
2007	1.249	1.213	1.029	92 %	5 %	3 %
2008	1.292	1.249	1.034	91 %	4 %	6 %
2009	1.265	1.226	1.031	89 %	3 %	8 %
2010	1.319	1.261	1.046	91 %	3 %	6 %
2011	1.295	1.247	1.037	95 %	3 %	2 %
2012	1.293	1.256	1.028	88 %	5 %	7 %
2013	1.316	1.276	1.030	92 %	3 %	4 %
2014	1.326	1.292	1.026	86 %	5 %	8 %
2015	1.297	1.258	1.031	81 %	6 %	13 %
Average	1.269	1.235	1.027	89 %	4 %	6 %

Notes: Bias-corrected values based on bootstrapping procedure; *TE*: technical efficiency score; *PTE*: pure technical efficiency; *SE*: scale efficiency. Values above unity indicate inefficiencies. IRS/CRS/DRS: share of banks operating under increasing-returns-to-scale/constant-returns-to-scale/decreasing-returns-to-scale.

The mean pure technical efficiency score was 1.24, explaining the largest share of Japanese banks’ technical inefficiencies. This score implies that the output of the Japanese banking sector could have been 24 percent higher if the banks had operated at PTE frontier. Scale inefficiencies have been rather small, at an average of only 1.027. Thus, banks could have increased their output by only 2.7 percent if they had operated at an optimal scale. However, scale inefficiencies have been increasing since around 2007 despite an acceleration of the concentration process. According to the efficiency measure we used, 90 percent of the banks have operated under increasing returns to scale (i. e. below their optimal scale). This implies a further concentration potential. Only 6 percent or so have operated under decreasing returns to scale. These findings suggest that although the consolidation process in the Japanese banking sector has advanced since the 1990s, scale inefficiencies have not been resolved.



Notes: TE: technical efficiency score estimated assuming constant returns to scale; PTE: pure technical efficiency estimated assuming variable returns to scale; SE: scale efficiency estimated as the ratio TE/PTE; values above unity indicate inefficiencies, bias corrected values based on bootstrapping.

Figure 7: Annual Efficiency Scores by Bank Type (1999–2015)

Figure 7 shows the efficiency score estimates between 1999 and 2015 by bank type. City banks exhibited rather large technical inefficiencies compared with both types of regional banks. With an average technical efficiency score of 1.172 during the sample period, city banks could have increased their output by around 17.2 percent. Over time the efficiency development of city banks has been rather unsteady, with periods of significantly declining overall efficiency (e.g. 1999–2002, 2006, 2010) followed by periods of improvements (e.g. 2003–2005, 2006–2009, 2012–2015). Overall, technical efficiency and both components decreased between 1999 and 2015. The mean scale efficiency score corresponds to 1.024, with on average 40 percent of city banks operating under decreasing returns to scale – thus *above* their optimal scale. Our findings hence imply that the consolidation process of city banks into so-called “mega banks” has not necessarily increased their pure technical and scale efficiency.

Tier-one and tier-two regional banks have been – on average – the most efficient banks according to our measures. Both bank types attained a mean technical efficiency score of 1.10 for our observation period. For both types, scale inefficiencies have been rather small, such that any further consolidation among regional banks cannot be expected to improve their efficiency through scale effects. Furthermore, we find for both types of regional banks that pure technical efficiency increased considerably between 1999 and 2003 and has slightly decreased since 2003.

Shinkin banks have exhibited by far the largest inefficiencies relative to the industry’s ‘best practice’ frontier, with an average technical efficiency score of 1.33. Technical inefficiencies increased from 1.29 in 1999 to 1.39 in 2015, despite a substantial consolidation process. Shinkin banks’ inefficiencies are mainly driven by pure technical inefficiencies, however, scale inefficiencies are also larger than that of other bank types. The average scale efficiency score for shinkin banks is 1.035. According to the efficiency measure, roughly 96 percent of shinkin banks have operated below their optimal scale, meaning they are too small. Our findings of relatively large technical inefficiencies among shinkin banks is in line with previous efficiency studies and can be attributed to factors such as high amounts of non-performing loans, poor restructuring, the lack of market power and management failings (*Assaf* et al. 2011).

Summing up the results of our efficiency analysis, we find that despite their efforts to cut costs and improve efficiency through gaining economies of scale or scope, Japanese Banks’ technical inefficiencies could not be resolved in our observation period. Pure technical efficiencies and scale inefficiencies persist in the Japanese banking sector.

IV. Drivers of Japanese Bank Efficiency

Based on the efficiency measures compiled above, we trace the determinants of the banks' inefficiencies since the 1998–99 Japanese financial crisis. We test for the impact of proxies reflecting the Bank of Japan's monetary policy and the banks' strategies to cope with the low-interest rate environment.

1. Data and Estimation Framework

To identify the sources of Japanese banks' inefficiencies, we regress the efficiency estimates (described in Section 3) on a set of explanatory variables.[18] In particular we are interested in the impact of the Bank of Japan's monetary policy. We therefore include the net interest margin (*NIM),* defined as a bank's net interest revenue as share of its average total earning assets (in percent). Whereas the net interest margin is traditionally regarded as reflecting asset productivity (Assaf *et al.*, 2011), it can also be used as an indicator of a bank's exposure to the low-interest rate environment and unconventional monetary policy.

Busch/Memmel (2015), *Claessens* et al. (2017) and *Borio* et al. (2017) show empirically that banks' net interest margins significantly react to changes in interest rates triggered by central banks.[19] A positive coefficient of *NIM* in our estimation model would imply that an increase in the net interest margin would come along with a lower efficiency (i. e. increase inefficiency).[20] In contrast, a negative coefficient implies that an increase in the net interest margin would come along with a higher technical efficiency (i. e. reduce inefficiency). This means declining net interest margins would be associated with a loss in efficiency, either because the bank is less able or willing to increase efficiency.

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[18] For more information and an overview of efficiency studies using a two-stage approach see *Simar/Wilson* (2007). Studies on the Japanese banking sector using a two-stage approach include *Altunbas* et al. (2000), *Fukuyama/Weber* (2009) and *Assaf* et al. (2011).

[19] *Borio* et al. (2017) empirically show the link between monetary policy and banks' net interest margin based on a large set of international banks. They argue that the level of interest rates and the slope of the yield curve are positively linked to the net interest income. They show that this relationship is particularly strong at very low interest rate levels, pointing to non-linear effects.

[20] Higher values of $\widehat{TE_{it}}$ and $\widehat{PTE_{it}}$ indicate lower efficiency and higher inefficiency. Analysing the efficiency of shinkin banks, *Fukuyama/Weber* (2009) find that technical efficiency decreases as the net interest margin increases. *Fukuyama/Weber* (2008) argue '[…] that the cooperative nature of these banks allows managers to engage in expense-preference behaviour. Higher net interest margins might thus offer sufficient cushion to allow managers to indulge in such behaviour, rather than pursue efficiency with greater effort' [p. 285]. A decline in margins might thus incentivize banks to increase efficiency to mitigate a loss in revenue.

Furthermore, we include variables that reflect Japanese banks' adjustment measures to the low interest rate environment. As discussed in Section 2, Japanese banks have increasingly invested in securities – particularly government bonds – and have raised the share of non-interest income (fees and commissions). As proxies for changes in a bank's portfolio mix, we include the securities-to-loan ratio (*SECLOAN),* the share of government securities among total securities (*GOVSEC)* and the ratio of non-interest operating income to total operating income (*NIOI),* which is meant to capture the effect of banks' efforts to diversify their revenue structure. The impact of a bank's diversification strategy on its efficiency is theoretically ambiguous. A higher share of securities can have a positive impact on a bank's efficiency, because securities investment is associated with lower operating costs than the provision of loans as the latter involves evaluation and monitoring activities (*Sarmiento/Galán* 2015). However, simultaneously the expansion of non-interest income by providing more fee-based services and products involves more resources. Therefore, an adjustment of a bank's revenue structure might be associated with decreasing efficiency.

Moreover, we include control variables that were found to have a significant impact on Japanese bank efficiency: market share (*MS)*, non-performing loans (*NPL)*, the return on average assets (*ROAA)*, the equity ratio *(ER)* and bank size (*Fukuyama/Weber* 2009; *Assaf* et al. 2011). Market share is proxied by the ratio of deposits of bank *i* to total banking sector deposits; previous studies showed that the market share has a positive impact on efficiency (*Fukuyama/Weber* 2009). Non-performing loans are measured by risk-monitored loans divided by total loans. Non-performing loans are expected to have a negative impact on Japanese bank efficiency, as evidenced by previous studies (*Altunbas* et al. 2000). Furthermore, we expect the return on average assets to be positively correlated with bank efficiency (*Assaf* et al. 2011). The equity ratio is measured as equity over total assets and is expected to be positively correlated with bank efficiency (*Altunbas* et al. 2000).

Additionally, bank size is captured by a set of dummy variables to allow for non-linearities in the relationship between efficiency and bank size, with thresholds chosen following *Berger/Mester* (1997). The definitions of small, medium, large and huge banks and the distribution across the bank types are presented in Table 4.[21] Furthermore, we control for the distinct organizational and governance characteristics of the banks by including dummies for each bank type (*CB*,

[21] For a sample of Japanese commercial banks *Altunbas* et al. (2000) identify a positive impact of size – measured by total assets – on efficiency. However, for the case of Japanese shinkin banks *Fukuyama/Weber* (2009) find a negative relationship between size and bank's efficiency.

city banks; *RB I*, tier-one regional banks; *RB II*, tier-two regional banks; *SB*, shinkin banks).[22]

The data basis for our regression analysis is the dataset presented in section 3.2. Owing to missing data, the sample for our regression analysis is slightly smaller than the original sample and comprises 5,823 observations of 389 banks. Descriptive statistics of all explanatory variables are shown in Table 5.

Table 4

Bank Size Dummy Variables

	Definition	*CB*	*RB I*	*RB II*	*SB*
SMLBANK	TA < 114 billion Yen	0 %	0 %	0 %	23 %
MEDBANK	114 billion Yen ≤ TA < 1.14 trillion Yen	0 %	13 %	54 %	70 %
LARBANK	1.14 trillion Yen ≤ TA < 11.4 trillion Yen	20 %	86 %	46 %	7 %
HUGBANK	TA ≥ 11.4 trillion Yen	80 %	1 %	0 %	0 %

Notes: 114 billion Yen equal around 1 billion USD; TA: total assets, CB: city banks, RB I: tier-one regional banks, RB II: tier-two regional banks, SB: shinkin banks.

Table 5

Descriptive Statistics for Variables in the Regression Analysis

	Mean	*SD*	*Min*	*Max*
$\widehat{TE}$	1.25	0.16	1.00	2.22
$\widehat{PTE}$	1.21	0.14	1.00	2.16
MS	0.17	0.66	0.01	17.22
NPL	7.45	4.10	0.00	37.35
ROAA	0.09	0.45	–7.24	2.07
NIM	1.71	0.38	0.10	3.51
ER	5.41	1.96	–6.07	15.65
SECLOAN	0.51	0.28	–0.01	2.95
GOVSEC	0.38	0.21	–0.07	8.28
NIOI	0.07	0.47	–12.37	28.66

[22] The bank size dummy thresholds were chosen in a way as to avoid a multicollinearity problem with the bank-type dummies. All bank types include at least two different size groups.

To test the impact of the variables presented above we estimate the following model:

$$\hat{\theta}_{it} = \beta_0 + \beta_1 NIM_{it} + \beta_2 SECLOAN_{it} + \beta_3 GOVSEC_{it} + \beta_4 NIOI + \beta_5 MS_{it} + \beta_6 NPL_{it} + \beta_7 ROAA_{it} + \beta_8 ER_{it} + \beta_9 BTYPE_{it} + \beta_{10} BSIZE_{it} + \delta_t + \varepsilon_{it} \quad (2)$$

where the dependent variable $\hat{\theta}_{it}$ is either the estimated technical efficiency $\widehat{TE}_{it}$ or the estimated pure technical efficiency scores $\widehat{PTE}_{it}$ for bank i at time t.[23]

Furthermore, we are interested in whether the net interest margin's effect on bank efficiency differs by bank type. The differing efficiency development paths of the Japanese bank types between 1999 and 2015 as presented above might either reflect differences in their adjustment measures (e.g. portfolio shifts) or differences in how the declining net interest margin affected banks' efficiency. We therefore extend equation (2) by interacting *NIM* with the bank type variables:

$$\hat{\theta}_{it} = \beta_0 + \beta_1 NIM_{it} + \beta_2 NIM_{it} * BTYPE_{it} + \beta_3 SECLOAN_{it} + \beta_4 GOVSEC_{it} + \beta_5 NIOI + \beta_6 MS_{it} + \beta_7 NPL_{it} + \beta_8 ROAA_{it} + \beta_9 ER_{it} + \beta_{10} BTYPE_{it} + \beta_{11} BSIZE_{it} + \delta_t + \varepsilon_{it} \quad (3)$$

The estimation of (2) and (3) is subject to several econometric challenges. First, Simar and Wilson (2007) argue that the efficiency scores $\hat{\theta}_{it}$ calculated using DEA suffer from strong correlation as the calculation of a given efficiency score depends on all other observations in the data set. Second, the error term ε_{it} is by assumption correlated with the set of explanatory variables, as the input and output data (x_i and y_i) is correlated with them. This implies that conventional regression analysis cannot be applied to equations (2) and (3) as the basic assumption of error terms being identically and independently distributed is violated (*Odeck* 2009). Third, the estimated efficiency scores $\widehat{TE}_{it}$ and $\widehat{PTE}_{it}$ have a lower bound of 1. To overcome these three limitations *Simar* and *Wilson* (2007) propose a procedure based on a truncated regression model[24] complemented by

[23] $\widehat{SE}_{it}$ is determined by the bank's size. We therefore do not discuss the regression results for $\widehat{SE}_{it}$. This is in line with previous studies.

[24] Given the bounded nature of the dependent variables a truncated regression model would lead to more consistent and accurate estimates than Tobit or OLS models, which have traditionally been used in two-stage efficiency studies of the banking sector (e.g. *McKillop* et al. 2002; *Fukuyama/Weber* 2009).

bootstrapping simulations. In our second stage regression we therefore apply the algorithm proposed by *Simar/Wilson* (2007) using the *simarwilson* STATA command by *Tauchmann* (2016).

2. Estimation Results

Table 6 reports the estimation results for both technical efficiency $\widehat{TE}_{it}$ and $\widehat{PTE}_{it}$ scores as dependent variables. Column (1) and (3) show the results for our baseline model, column (2) and (4) the results for the extended model with interaction terms. The explanatory variables which have traditionally been used in the literature (*MS, NPL, ROAA, ER*) are in both models statistically significant with the expected signs, apart from the coefficient of *ROAA*, which has a positive sign. The results confirm findings of previous studies that a higher market share and a higher equity ratio is associated with a higher efficiency. Furthermore, a higher non-performing loan ratio is linked to a lower degree of efficiency. The positive coefficient of *ROAA* implies that a higher return on average assets is linked to a lower degree of efficiency.

The results of the baseline model show that the net interest margin has a statistically significant effect on bank efficiency. The negative coefficient implies that a higher net interest margin is linked to both a higher technical and pure technical efficiency. The decline in banks' net interest margin – as it occurred in our sample period – can thus be interpreted as having had a negative Japanese banks' efficiency development. The effect is rather large. Ceteris paribus, a 1-percentage-point decline in the net interest margin implies an increase in a bank's pure technical efficiency score by around 0.24 points, which captures a significant decline in efficiency.

The results of the extended model – column (2) and (4) – show that the impact of the net interest margin on banks' efficiency differs by bank type – the coefficients of the interaction terms are statistically significant for both technical and pure technical efficiency. In the extended model the coefficient of *NIM* captures the impact of the net interest margin on city banks' (pure) technical efficiency (reference category). The negative sign implies a positive impact of *NIM* on city banks' efficiency. Compared to the baseline model the impact is larger. The positive coefficients of the interaction terms imply that the positive impact of *NIM* is smaller for all other bank types. Based on the size of the coefficients we find that impact is smallest for tier-one regional banks, followed by tier-two regional banks and shinkin banks. Our results imply that the rather modest decline in regional banks' (pure) technical efficiency in the sample period as presented in Section 3 might have partly been the result of their comparatively low sensitivity to changes in the net interest margin.

Shifting their portfolio from loans to securities seems to have helped Japanese banks to mitigate the negative impact on efficiency. A higher securities-to-loans ratio (*SECLOAN)* is associated with higher technical as well as higher pure technical efficiency (negative coefficients, significant at the 1-percent level). Moreover, a higher share of government securities (*GOVSEC)* seems to have additionally boosted efficiency (negative coefficients, significant at the 1-percent level). This supports our assumption that in an environment of low private-sector loan demand – and therefore increasing competition in the loan market[25] – a switch to lending to the public sector (which is less resource-consuming) has been lucrative for Japanese banks. Furthermore, we find that the coefficient of the non-interest operating income to total operating income ratio (*NIOI*) is negative for both technical efficiency and pure technical efficiency, but not statistically significant.[26]

Table 6

Estimation Results

	(1) *TE*	*(2)* *TE (ext.)*	*(3)* *PTE*	*(4)* *PTE (ext.)*
MS	–0.0484*** [0.0171]	–0.0472*** [0.0175]	–0.1816*** [0.0291]	–0.1960*** [0.0346]
NPL	0.0021*** [0.0006]	0.0021*** [0.0006]	0.0024*** [0.0005]	0.0023*** [0.0005]
ROAA	0.0124** [0.0049]	0.0135*** [0.0047]	0.0225*** [0.0048]	0.0235*** [0.0047]
ER	–0.0213*** [0.0011]	–0.0215*** [0.0011]	–0.0219*** [0.0011]	–0.0219*** [0.0011]

(continue next page)

[25] As of the beginning of the 2000s, competition among banks in the loan business intensified, putting lending rates under pressure and further lowering interest margins. City banks have expanded their lending activities to rural areas, whereas regional banks have expanded to urban areas. Some regional banks have set up branches in neighbouring prefectures or major cities (*Bank of Japan* 2006, 2008, 2012).

[26] The negative coefficient is in line with findings of *DeYoung* (1994) for commercial banks in the U.S.

(Table 6 continued)

	(1) *TE*	*(2)* *TE (ext.)*	*(3)* *PTE*	*(4)* *PTE (ext.)*
NIM	–0.2030*** [0.0088]	–0.6037*** [0.1065]	–0.2416*** [0.0085]	–1.2585*** [0.2738]
NIM*RB I		0.5814*** [0.1106]		1.0157*** [0.2759]
NIM*RB II		0.5193*** [0.1117]		0.9845*** [0.2759]
NIM*SB		0.3974*** [0.1066]		0.8813*** [0.2739]
SECLOAN	–0.1848*** [0.0086]	–0.1854*** [0.0084]	–0.1225*** [0.0079]	–0.1232*** [0.0081]
GOVSEC	–0.0673*** [0.0115]	–0.0695*** [0.0111]	–0.0458*** [0.0104]	–0.0470*** [0.0106]
NIOI	–0.0032 [0.0039]	–0.0034 [0.0038]	–0.0047 [0.0038]	–0.0049 [0.0039]
MEDBANK	–0.0566*** [0.0050]	–0.0581*** [0.0050]	0.0481*** [0.0051]	0.0474*** [0.0050]
LARBANK	–0.1283*** [0.0097]	–0.1264*** [0.0097]	0.0383*** [0.0114]	0.0432*** [0.0114]
HUGBANK	–0.1539*** [0.0605]	–0.2112*** [0.0765]	0.1741** [0.0842]	–0.1970 [0.1865]
RB I	–0.1468** [0.0585]	–0.8497*** [0.1412]	–0.2042*** [0.0658]	–1.4251*** [0.3336]
RB II	–0.0949 [0.0610]	–0.7464*** [0.1496]	–0.1608** [0.0691]	–1.3693*** [0.3352]
SB	0.2715*** [0.0604]	–0.1672 [0.1356]	0.1460** [0.0689]	–0.8843*** [0.3311]
Constant	1.6709*** [0.0638]	2.1199*** [0.1372]	1.7456*** [0.0737]	2.7847*** [0.3316]
Observations	5,215	5,215	5,030	5,030

Notes: $\widehat{TE}_{it}$ and $\widehat{PTE}_{it}$ are the dependent variables. All models estimated using a truncated regression model. Negative coefficients indicate positive effect on efficiency and vice versa. Reference categories are SMLBANK and CB. Standard errors in brackets * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results with respect to the effect of banks size on efficiency are ambiguous. Small banks are used as reference group. For technical efficiency, the coefficients in both models are negative and statistically significant. This suggests that a larger bank size is linked to higher technical efficiency.[27] However, in the $\widehat{PTE}$ estimation models almost all bank-size dummies have a statistically significant positive coefficient. This indicates that larger banks have higher pure technical inefficiencies than small banks. The reversal of the coefficients' signs in the $\widehat{TE}$ and $\widehat{PTE}$ models model can be explained by the existence of scale inefficiencies that are captured in the $\widehat{TE}$ score, but not the $\widehat{PTE}$ score. This would imply that positive scale-efficiency effects of larger size over-compensate the negative size-effects on pure technical efficiency. These findings suggest that the ongoing consolidation process in the Japanese banking sector may have reduced scale inefficiencies by increasing the size of banks, but that this had the adverse side effect of increasing pure technical inefficiencies.

Furthermore, our estimation results also confirm our findings in Section 3 concerning the efficiency differences between the types of banks as shown by the dummy variables *RBI*, *RBII* and *SB*. With city banks used as a reference group, tier-one regional banks emerge as the most efficient bank type in all models. In addition, tier-two regional banks show a statistically significant higher technical and pure technical efficiency than city banks, although the gap is smaller than for tier-one regional banks. In contrast, shinkin banks exhibit larger technical and pure technical inefficiencies in the baseline models than any other type of bank. However, when controlling for the bank type specific impact of the net interest margin in the extended model the results change. The difference in technical efficiency become statistically insignificant and pure technical efficiency of shinkin banks turns out to be higher compared to city banks.

V. Conclusion

Since the bursting of the Japanese bubble economy, and increasingly since the Japanese financial crisis, Japanese banks have been under a persistent pressure to adjust. We show that the Bank of Japan's monetary policy helped to prevent a financial meltdown in the short term. However, the expansionary monetary policy has compressed interest margins as the traditional source of income for Japanese banks, which previously strongly favored credit provision to households and enterprises. Furthermore, mergers have become an important driving force for gradual consolidation within the Japanese banking sector, which has led to a drop in the number of banks, branches and regular employees. These trends

[27] The negative coefficients of *MEDBANK*, *LARBANK* and *HUGBANK* mean that technical inefficiencies are lower compared to the reference category *SMLBANK*.

suggest that the banks' technical efficiency should have improved due to the pressure to mitigate the income losses and to gain economies of scale in the consolidation process.

Given the assumption that the Bank of Japan's monetary policy decisions have affected the net interest margin of Japanese banks, our analysis provides evidence that the Bank of Japan's low-interest rate policy and unconventional monetary policy measures have come along with declining efficiency in the Japanese banking sector. Despite substantial efforts by banks to increase their efficiency, the erosion of traditional sources of income is identified as having triggered losses in technical efficiency. A lower degree of competition because of greater concentration, and the persistent provision of low-cost liquidity by the Bank of Japan might have contributed to the decline.

In particular, our analysis suggests that among city banks that have formed large financial conglomerates (so-called 'mega banks'), the concentration process seems to have come along with reduced efficiency. For small regional and shinkin banks, even a drastic consolidation process seems not to have been enough to achieve sufficient efficiency gains.

The expected persistence of the expansionary monetary policy by the Bank of Japan is likely to accelerate the concentration process among banks. This is because the interest rate margin can be expected to become further depressed, and the role of public bonds as an instrument to stabilize profits will decline further due to the Bank of Japan's government bond purchases. However, as our analysis has shown, concentration is accompanied by declining pure technical efficiency which is linked to welfare losses. Therefore, we recommend considering a gradual exit from ultra-expansionary monetary policy. This could ensure more efficient allocation of capital in the Japanese economy, based on competition among banks rather than low-cost liquidity provision by the central bank.

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A. Appendix

A1. Estimating Efficiency Scores

We assume as set of banks each producing y outputs using x inputs. The production technology is given by S and models the transformation of inputs $x \in \mathbb{R}_{+}^{N}$, into outputs $y \in \mathbb{R}_{+}^{M}$. Hence, S models the set of all feasible input/output vectors:

(4) $$S = \{(x, y) : x \text{ can produce } y\}\ )$$

Farrell's (1957) output-oriented measure of technical efficiency models the maximum proportionate increase in output y for a given set of input x and technology S:[28]

(5) $$\theta(x, y) \equiv sup\{\theta : (\theta y) \in S\}$$

where $\theta(x, y)$ is greater than or equal to 1. Note, that the Farrell output-oriented technical efficiency measure is equivalent to the reciprocal of *Shephard's* (1970) output distance function:

(6) $$D \quad (x, y) \equiv inf\{\theta : (x, y / \theta) \in S\}$$

with $D_O(x, y) \leq 1$ (*Färe* et al., 1985). Figure 10 illustrates the technical efficiency concept for the one-input-one-output case using output-oriented measures. Bank A, B, C and D produce output y using input x and an unknown technology S. The line S_{CRS} represents the technology frontier assuming constant-returns-to-scale. Following *Farrell's* (1957) definition bank A is technically efficient as it lies at the technology frontier S_{CRS} and produces the optimal output y_A^* given input x_A. Bank B, C and D are technically inefficient as their output are below their optimal levels y_B^*, y_C^* and y_D^*. *Farrell's* (1957) output-oriented score of technical efficiency correspond to the ratios:

(7) $$\cdot TE_B^{CRS} = 0\,y_B^* \,/\, 0\,y_B\,,$$

(8) $$TE_C^{CRS} = 0\,y_C^* \,/\, 0\,y_C$$

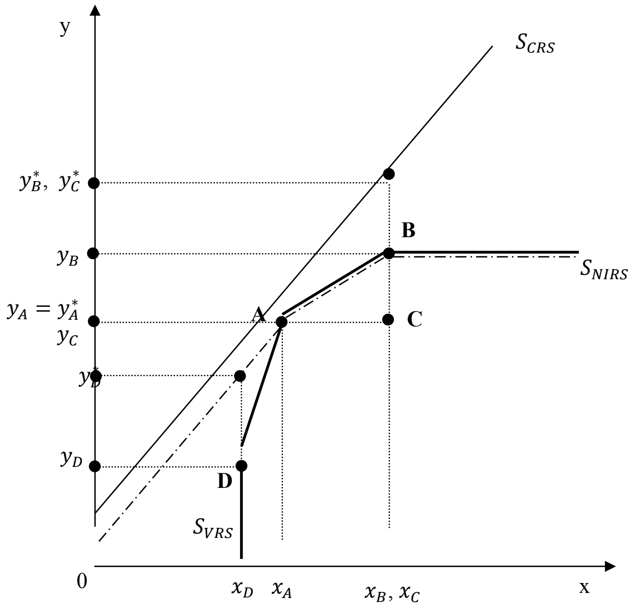
(9) $$TE_D^{CRS} = 0\,y_D^* \,/\, 0\,y_D\,.$$

[28] Input-oriented efficiency measures focus on the optimal (i.e. minimal) set of inputs for a target output set.

The technical efficiency score $TE = 1$ if the bank operates at the best practice frontier, and $TE > 1$ if the bank exhibits technical inefficiency.

Charnes et al. (1978) and *Banker* et al. (1984) extend the technical efficiency concept and propose a decomposition of *TE* into pure technical efficiency (*PTE*) and scale efficiency (*SE*) by relaxing the constant-returns-to-scale assumption for the underlying technology:

(10) $$TE = PTE \times SE$$



Notes: Illustration of output-oriented technical efficiency measure and components. Lines S_{CRS}, S_{VRS} and S_{NIRS} correspond to the constant-returns-to-scale, variable-returns-to-scale and non-increasing-returns-to-scale production frontiers, respectively.

Figure 8: Output-Oriented Technical Efficiency Measure

Assuming banks A, B, C and D are using a variable-returns-to-scale technology,[29] as indicated in Figure 8 by the S_{VRS} frontier, bank A, B and D would be technically efficient as all three are operating at the production frontier $\left(TE_A^{VRS} = TE_B^{VRS} = TE_D^{VRS} = 1\right)$). However, banks B and D are technically inefficient as regards to the constant-returns-to-scale frontier S_{CRS} ($TE_B^{CRS} > 1$ and

[29] Variable-returns-to-scale encompasses both decreasing as well as increasing-returns-to-scale.

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$TE_D^{CRS} > 1$). The reason for the difference is that B and D are not operating at their optimal scale, hence they exhibit scale inefficiencies. TE^{VRS} an hence be regarded as measuring pure technical efficiency *PTE*. The scale efficiency measure corresponds to:

(11) $$SE = \frac{TE^{CRS}}{TE^{VRS}}$$

As regards to our example illustrated in Figure 10 the (overall) technical efficiency score (*TE*), the pure technical efficiency score (*PTE*) and the scale efficiency score (*SE*) of bank C corresponds to:

(12) $$TE_C = TE_C^{CRS} = 0y_C^* / 0y_C,$$

(13) $$PTE_C = TE_C^{VRS} = 0y_B / 0y_C$$

(14) $$SE_C = 0y_C^* / 0y_B$$

Although the scale efficiency score enables to determine whether scale inefficiencies exist or not, it does not indicate whether the bank is operating under increasing or decreasing returns to scale. To determine the nature of the scale inefficiencies a third technology frontier with the assumption of non-increasing-returns-to-scale must be imposed (line S_{NIRS} in Figure 10) and efficiency scores TE^{NIRS} have to be estimated accordingly (*Coelli* et al. 2005; *Banker* et al. 1984). The nature of scale inefficiencies is determined by comparing TE^{NIRS} and TE^{VRS}. If $TE^{NIRS} = TE^{VRS}$ the bank exhibits decreasing-returns-to-scale, if $TE^{NIRS} \neq TE^{VRS}$ it is operating under increasing-returns-to-scale.[30] Referring to our example banks C and B depict decreasing-returns-to-scale and bank D increasing-returns-to-scale.

[30] Note that output- and input-oriented models may lead to different results in the findings of the nature of scale inefficiencies. See *Golany/Yu* (1997) for how to treat this problem.