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Productivity and efficiency analysis of *Shinkin* banks: Evidence from bootstrap and Bayesian approaches

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ABSTRACT

This paper analyzes the productivity and efficiency of *Shinkin* banks and the various prefectures in Japan, over the period from 2000 to 2006. We obtain estimates of efficiency growth and productivity growth, using the bootstrapped Malmquist index, and estimates of efficiency using the Bayesian distance frontier approach. We confirm that the efficiency growth and productivity growth of *Shinkin* banks did not improve significantly over the period of this study. In addition, we show that the efficiency of *Shinkin* banks is homogenous, with little variation across the banks analyzed. Methodologically, we also prove that a failure to impose theoretical regularity on the distance function could lead to false conclusions about the average efficiency or efficiency ranking of *Shinkin* banks. The study also includes an analysis of the correlates of productivity and efficiency growth, and provides efficiency and productivity estimates of the prefectures in which the banks are located.

1. Introduction

Due to the important economic contribution of the Japanese banking industry and the continuous fluctuation of its performance, several studies have recently focused on the productivity and efficiency analysis of Japanese banks. Japan has experienced major turbulence in the last two decades, caused by the uncontrolled credit expansion, lack of capital and the extremely large volumes of non-performing loans (Ohashi and Singh, 2004). The financial difficulties have catalyzed systematic changes within most parts of the banking industry, including the credit associations (*Shinkin* banks) sector, which has decreased in size by around 25% between 1998 and 2006. A series of government initiatives and regulatory reforms have helped to restore investor confidence in the system. However, the industry continues to suffer from serious problems related to the weak macroeconomic performance, high volume of non-performing loans and the continuing deflation. The internal management failings and the flawed corporate governance have also continuously affected the performance of Japanese banks.

All the above issues motivate the present study. Our aim is to offer two important extensions to the current performance literature on Japanese banks. The study first adopts a new focus by analyzing the efficiency growth and productivity growth of Japanese credit associations (*Shinkin* banks). This important segment of the Japanese banking industry has not received extensive research attention, despite having a specific and important position in the regional financial markets (Satake and Tsutsui, 2002; Hosono et al., 2006). *Shinkin* banks are also one of the main financial intermediaries for small and medium-sized enterprises and households in Japan. In the literature, most previous studies have focused on the commercial banking sector in Japan (Uchida and Satake, 2009; Drake et al., 2009). The lack of empirical research on *Shinkin* banks is probably due to the difficulties in obtaining financial data on a representative sample of these banks. The data set in this study is original in the sense that it includes every *Shinkin* bank currently operating in Japan.

Thus, with its original data and new focus, this study presents an important extension to the existing literature. An important difference between this study and most other related studies is that here we use more robust and innovative methodologies to obtain the desired estimates of productivity and efficiency. To measure efficiency growth and productivity growth, we use the bootstrapped Malmquist index, which has several advantages over

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the traditional Malmquist index, particularly as it provides statistical insights into the degree of efficiency growth and productivity growth.

As the efficiency growth results obtained by the Malmquist index only reflect the growth in efficiency between two-time periods, we also aim here to reflect the actual efficiency standing of *Shinkin* banks. The present literature investigating efficiency has generally been dominated by two methodologies: the non-parametric Data Envelopment Analysis (DEA), and the parametric Stochastic Frontier (SF) approach. DEA is a relatively flexible method that can account for multiple inputs and outputs. However, being a non-stochastic procedure, it is highly sensitive to the selection of inputs and outputs and does not provide any insight into the statistical significance of the efficiency results. It is possible to avoid these problems with the SF approach, which is a statistical method, and thus accounts for the error of measurements. However, the method is again difficult to use in the banking industry, since it can only account for one output.

As most banks operate in a multiple-output context, we adopt here the distance function to obtain the efficiency estimates. It is an attractive variation on the SF method, as it can simply allow the inclusion of multiple outputs. While some studies in the banking literature use the distance function, they mostly suffer from on common limitation in that they fail to incorporate the theoretical regularity conditions (monotinicity and curvature) into the estimation of the distance function. Furthermore, only a few studies report the degree to which their estimated distance function violates these properties.

Thus, in order to account for the above limitations, we develop the model in this study by imposing the theoretical regularity conditions. We also adopt the Bayesian approach to estimate the distance function. The literature clearly illustrates the merits of the Bayesian and sampling theory approaches to inference (Geweke, 1986; Poirier, 1995). For this paper, one of the important advantages of Bayesian methodology is that it allows us to provide exact finite sample results for non-linear functions of the unknown distance function parameters. It is also more convenient for imposing quasi-convexity and quasi-concavity constraints on the parameters of distance functions.

We present the results of this paper in three steps. In the first step, we provide bootstrapped Malmquist measures of efficiency growth and productivity growth. In the second step, we analyze the determinants of productivity growth, using a bootstrapped truncated regression, and in the third step, we provide annual efficiency measures of *Shinkin* banks, using the Bayesian distance frontier approach. The remainder of this paper is organized as follows. Section 2 discusses the role and importance of credit associations in the Japanese banking system. Section 3 outlines the literature review, followed by the research hypotheses, data and methodology in Sections 4–7. Section 8 discusses the empirical results and Section 9 provides a conclusion of the main findings.

2. Fundamental characteristics of *Shinkin* banks

Shinkin banks or credit associations (CAs) are mutual (cooperative) financial institutions. These banks are generally smaller than city and regional banks and focus on local communities through supporting the business activities of local small and medium-sized enterprises (SMEs). They operate under the regulatory rules imposed on other banks and their clients have the same deposit protection scheme as large banks. Other distinctive features of *Shinkin* banks can be summarized as follows:

(i) Membership is limited to small and medium companies and individuals residing in a determined geographical area;
(ii) Only small and medium companies in the CA's geographical service area can borrow funds;
(iii) Loans are limited to one loan per customer;
(iv) Membership is limited in certain aspects, i.e., the number of workers per firm and the amount of capital per member;
(v) Management policy is decided in the general representatives' meeting, with a system of one vote per member.

Shinkin banks can provide only up to 20% of total loans to non-members (Hosono et al., 2006). CAs operate throughout Japan (at prefecture level) and may collect deposits from the public. Table 1 shows the relative size of private financial institutions in Japan. Interestingly, total loans and total deposits of CAs are much larger than second regional banks and trust banks, but are substantially smaller than city banks and regional banks.

The activities of *Shinkin* banks, like other financial institutions in Japan, suffered in the past from the insufficient volume of capital and large volume of non-performing loans. The government, recognizing the need to ease or eliminate the bottlenecks within the financial institutions, enacted the Financial Rehabilitation Law and the Financial Function Strengthening Law in 1998. However, the government did not extend its support to *Shinkin* banks under the terms of these laws until 2006. The only prior support was through financial assistance (JPY 595.6 billion) that was made by the deposit insurance to those *Shinkin* banks that merged or that acquired failed *Shinkin* banks between 1999 and 2002. *Shinkin* banks themselves started the consolidation process via mergers and acquisitions. As a direct consequence of these activities, the number of *Shinkin* banks has decreased significantly between 2000 and 2006.

3. Current gaps in the literature

Several studies in recent years focused on the efficiency and productivity analysis of Japanese banks using simple and advanced methodologies, and testing several interesting hypotheses (e.g. impact of ownership on efficiency; impact of size on efficiency, im-

Table 1
Relative size of private financial institutions in 2008. Source: "Economics Statistics Monthly" (Bank of Japan), "Financial Statements of all banks" (Japanese Bankers Association), "Shinkin Central Bank Monthly Review" (Shinkin Central Bank), "Main accounts of National Credit cooperatives" National Central Association of Credit cooperatives.

	No.	Loans and discounts outstanding (banking accounts)	Deposits	Assets (banking accounts)
City banks	6	2,128,980	2,707,135	415,541,661
Regional banks	64	1,485,468	1,961,177	224,747,484
Second regional banks	45	429,309	555,619	61,215,264
Trust banks	7	322,933	351,869	62,319,938
Long-term credit banks	2	93,067	76,943	168,260
Credit banks	282	635,433	1,137,275	1,204,216
Credit cooperatives	164	93,828	163,300	175,306

Note: JPY 100 millions.

pact of consolidation on efficiency, etc.). From a review of these studies, it is clear, however, that the literature suffers from two important gaps that deserve more attention.

Firstly, and despite the importance of *Shinkin* banks (credit associations) to the Japanese economy, only few productivity and efficiency studies analyze the performance of these banks. Some of the key studies include Fukuyama (1996), who investigate the technical and scale efficiency of credit banks (for the fiscal year 1992), and Fukuyama et al. (1999), who examine the overall efficiency and productivity growth of credit cooperatives (during the period 1992–1996). Results from both these studies highlighted that foreign-owned cooperative banks are more efficient and enjoy a higher productivity growth than locally owned cooperative banks.

In line with the above studies, Hosono et al. (2006) also present the motives and consequences behind the consolidation of *Shinkin* banks. In particular, the authors analyze the profitability and efficiency of banks that merged during the analyzed period (1984–2002), concluding that less profitable and less cost-efficient banks are more likely to be the target of a more efficient bank. The two most recent studies on *Shinkin* banks include Fukuyama and Weber (2008b, 2009). The first examines whether the difference in organizational structure between *Shinkin* banks and regional banks have an impact on technical efficiency, while the second focuses on the DEA methodology and tests whether slack is an important source of inefficiency. It is possible to derive two main conclusions from these studies: First, regional banks are less efficient in absolute terms than *Shinkin* banks; and second, banks with higher percentage of "non-performing loans" are less efficient.

Apart from the above studies, most other efficiency and productivity studies on Japanese banks focus on the commercial banking sector (Uchida and Satake, 2009; Drake et al., 2009). In most cases, the available studies on *Shinkin* banks also use outdated data and limited methodologies. In the next section, we elaborate on how the present study differentiates in terms of its methodologies. The period analyzed in this study (2000–2006) is also unique and cover several interesting changes in the structure of *Shinkin* banks. Around this period, for example, the number of *Shinkin* banks fell from 386 to 292, due to a strong consolidation process. The deposit insurance also offered a large amount of financial assistance (1595.6 billion yens) to those *Shinkin* banks that merged or acquired failed *Shinkin* banks.

Thus, there is a rich context in which to verify whether the efficiency growth or productivity growth of *Shinkin* banks have actually improved. In particular, given the lack of evidence in the literature, and the economic importance of *Shinkin* banks, the Japanese government and banking associations would most likely be interested in obtaining some fresh evidence on the performance of these banks. The continuous challenges of these banks caused by their small size and the high percentage of non-performing loans also justify the need for more updated evidence on their performance.

Methodologically, there is also room for improvement in the literature. As already highlighted, this study introduces a more innovative approach to the measurement of efficiency growth and productivity growth of *Shinkin* banks. We use the bootstrapped Malmquist index, which, in contrast to the traditional Malmquist index, provides statistical insights into the degree of productivity and efficiency change.

The study also introduces a more advanced approach to obtain the efficiency estimates. A review of previous studies on Japanese banks, and particularly *Shinkin* banks, reveals that most adapted efficiency methodologies are non-parametric in nature. Particularly, the DEA method seems to be the most popular (Drake and Hall, 2003; Drake et al., 2009), probably due to its simplistic assumption and its flexibility in accounting for multiple inputs and outputs. However, the simplicity of the DEA method often comes at a cost. The method is non-statistical in nature and thus does not provide much insight into the market structure and banks' behavior. In the case of outliers in the data, it can also lead to biased results. The stochastic frontier (SF) method is an attractive alternative to DEA, as it involves the estimation of a specific parameterized function that takes into account the measurement error in the data. However, the SF method is again subject to criticism, as it can only accommodate for one output.

One variation of the SF method is the parametric distance frontier method, which can maintain the statistical advantage of the SF method while also allowing for multiple outputs. The distance function is popular in several banking studies, but mainly outside the Japanese context. In the majority of cases, studies that estimate a distance function also ignore the theoretical regularity conditions that need to be imposed on this function. Microeconomic theory clearly argues that a distance function needs to satisfy the regularity conditions of monotonicity and curvature, since a failure to account for these conditions might seriously affect the efficiency results (O'Donnell and Coelli, 2005).

In the present paper, we aim to address this important gap in the literature by estimating a distance function that satisfies the theoretical regularity. We show the importance of monotonicity and curvature conditions by comparing the efficiency results from two distance functions: one that satisfies these conditions, and one that does not satisfy these conditions. We impose regularity with the Bayesian approach, using the random-walk Metropolis–Hastings algorithm. As already highlighted, the Bayesian approach is more convenient for imposing quasi-convexity and quasi-concavity constraints on the parameters of distance functions, which are difficult to impose using traditional econometric approaches.

Thus, by introducing a distance function that satisfies the theoretical requirement, the study provides a more accurate reflection on the efficiency of *Shinkin* banks. Moreover, the results contribute significantly to the banking literature, since most previous studies have ignored these theoretical conditions and therefore, there is a lack of evidence as to whether they have a significant impact on the efficiency results.

4. Research hypotheses

We propose several research hypotheses in line with the literature gaps identified above. As already highlighted, the period analyzed in this study (2000–2006) has a critical importance. Around this period, for instance, there was a consolidation process, which resulted in a decrease in the number of *Shinkin* banks from 386 to 292. In order to stabilize the local banking system, the government injected a large amount of financial assistance through the deposit insurance guarantees to those *Shinkin* banks that merged or acquired weak or failing *Shinkin* banks. While the consolidation process is still ongoing, all the banks in our data have already completed the process.

In the literature, many studies indicated that the consolidation process is beneficial as it drives inefficient banking organizations from the market and facilitates increased efficiency or productivity in those organizations that survive. While this might also be true for *Shinkin* banks, we hypothesize here that the efficiency growth and productivity growth of these banks have not improved significantly over the period of study. This is because recent evidence indicates that these banks still suffer from productivity and efficiency-related problems such as the high volume of non-performing loans and internal management failings (Ito and Harada, 2004; Hosono et al., 2006). Moreover, the consolidation process did not include appropriate restructuring by the government or the banks themselves. In addition, since *Shinkin* banks are small, they still do not have sufficient market power to raise loan interest rates, even if bank consolidations make the loan market more concentrated.

Finally, we also report here that Fukuyama and Weber (2009) have also recently indicated that the performance of *Shinkin* banks has only slightly improved between 2000 and 2005. Thus, while some positive trends occurred in the *Shinkin* banking sector over the period of this study, most of the negative characteristics still exist and, as a result, might be deterring further efficiency growth or productivity growth in the sector. Following all the above arguments, thus we hypothesize the following:

H1. The efficiency growth and productivity growth of *Shinkin* banks have not improved significantly over the period of study.

We test this hypothesis with the bootstrapped Malmquist index, which provides statistical properties of the efficiency growth and productivity growth results, and thus allows us to check whether the change in these two components was significant over the period of study.

It is also common when estimating the Malmquist index to regress the efficiency growth and productivity growth results on a vector of exogenous variables, as this would provide some explanations to the sources of efficiency and productivity variations between the banks analyzed. Here, we include variables representing market share, market concentration, returns on assets (ROA), number of bank branches and net interest margin (NIM).

As *Shinkin* banks operate in a competitive environment, it is of interest to estimate whether the market share and concentration ratio have any impact on the performance of these banks. Previous studies indicate that both variables have a positive impact on the performance of banks. The number of bank branches, ROA and NIM has also a positive impact on the performance of banks (Berger et al., 1997; Hirtle, 2007; Portela and Thanassoulis, 2010). In line with previous research, banks with higher ROA, should be on average more productive and efficient. Previous research has also showed that net interest margin (NIM) is an important determinant of bank performance (Park and Weber, 2006). Thus, here we hypothesize that:

H2. The efficiency growth and productivity growth of *Shinkin* banks correlate positively with the market share, market concentration, economic growth, ROA, and the net interest margin.

Finally, and as previously mentioned, another aim of this study is to estimate the efficiency of *Shinkin* banks, using the Bayesian distance frontier model. More importantly, our goal is to introduce a methodological hypothesis, which can set the stage for more accurate estimation of the distance function in the banking literature. Earlier, we pointed out that most banking studies using a distance function in the banking literature tend to overlook the theoretical conditions. Previously, O'Donnell and Coelli (2005) emphasized that ignoring the regularity condition might lead to significant differences in the efficiency scores and efficiency ranking of the analyzed firms. We provide here further evidence on this important methodological issue by estimating two separate models: one that is estimated subject to regularity conditions (i.e. constrained model); and one that is estimated without any regularity conditions (i.e. unconstrained model). Following the literature arguments, we hypothesize the following:

H3. The average efficiency scores and efficiency ranking of *Shinkin* banks derived from the constrained and unconstrained distance frontier models are significantly different.

5. Data

We compiled our dataset from the financial statements of 291 *Shinkin* banks operating in Japan between 2000 and 2006 ($7 \times 291 = 2037$ observations). Empirical studies generally apply two approaches to measure bank outputs and costs in banking (Sealey and Lindley, 1977; Berger and Humphrey, 1997; De Jonghe and Vander, 2008; Sturm and Williams, 2008; Lensink et al., 2008; Berger et al., 2009; Kauko, 2009). The production approach considers that banks produce accounts of various sizes by processing deposits and loans, incurring capital and labour costs. The intermediation approach defines banks as a transformer of deposits and purchased funds into loans and other assets. The application of these two approaches usually depends on the availability of data and the purpose of the study. We define outputs and inputs of *Shinkin* banks in line with Fukuyama and Weber (2009). Inputs consist of total deposits, labour and physical capital (land, premises and fixed assets) and outputs comprise loans and securities. Table 2 provides descriptive statistics of all these variables.

Note that we also collected data on the variables needed to test Hypothesis 2. We define the market share as the total deposit of individual bank *i* divided by total deposits of all *Shinkin* Banks. Concentration ratio is the sum of the top five market shares.

6. Measuring efficiency growth and productivity growth: The bootstrapped Malmquist index

Färe et al. (1994a,b) originally introduced the Malmquist productivity index (*MI*) to measure the total factor productivity (TFP) change for a particular firm in two periods. In contrast to other indexes such as the Tornqvist and Fisher, the main advantage of the Malmquist index is that it does not require price data. An added benefit of the index is that it allows the decomposition of TFP into two components: one describing the efficiency growth and the other reflecting the technological growth:

$$MI = EC \times TC, \tag{1}$$

where *MI* represents the total productivity change, *EC* represents the total efficiency change and the term *TC* represents the technical change between two periods t_1 and t_2, $t_1 < t_2$. The first is the change in the firm's location relative to the frontier between the two periods, while the latter is an indicator of the distance covered by the efficient frontier from one period to another. Note that $MI > 1$ denotes productivity increase, while $MI < 1$ denotes productivity decline. The same applies for the other components: $EC > 1$ indicates an increase in efficiency and $TC > 1$ indicates an increase in technology.

The computation of the Malmquist index usually follows the DEA methodology (see Appendix A for more details), which is a non-parametric approach to derive the productivity and efficiency

Table 2
Descriptive statistics

Variable	Mean	Median	St.Dev	Min	Max
Loan	200,935,724	107,323,000	261,720,816	10,037,000	2,010,555,000
Securities	81,828,488	46,599,000	102,118,691	316,000	799,233,000
Number of FTE	398.25	263.00	386.99	45.00	2666.00
Deposits	328,655,622	185,866,000	402,797,359	30,350,000	3,322,019,000
Total assets	357,673,053	201,845,000	434,044,758	34,961,000	3,545,670,000

estimates. Despite its simplicity and flexibility, the method is non-statistical, and thus in many cases, the efficiency estimates sensitive to the random variations in the data. Here, we correct for this problem by using the bootstrap approach (Simar and Wilson, 1999). The basic idea of bootstrapping is to approximate the distribution of the estimator via re-sampling and recalculation of the parameter of interest. The re-sampling is based on assumptions about the true Data Generating Process (DGP) underlying the observed sample. Following the bootstrapping procedure, the confidence intervals can then be calculated and used to test whether productivity or efficiency changes are significant (i.e. significantly greater or less than unity at the desired level of significance). The percentile method is usually the most common method for obtaining confidence intervals. In the case of the Malmquist index, the method consists of approximating the distribution of $\widehat{MI}-MI$ using the distribution of $MI_b^*-\widehat{MI}$, where $\widehat{MI}$ are the DEA estimates of the Malmquist index, MI_b^* are the bootstrap estimates of the index and MI is the true unknown index. Thus, the bootstrap estimate of the $(1-\alpha)$ confidence interval for the Malmquist index is as follows:

$$\widehat{MI}-\hat{b}_\alpha \leqslant MI \leqslant \widehat{MI}-\hat{c}_\alpha, \tag{2}$$

where $\hat{b}_\alpha$ and $\hat{c}_\alpha$ are bootstrapped values defining the confidence interval. If Eq. (1) does not include the value, then the Malmquist is significantly different from unity at the α% level. It is also possible to improve this confidence interval using a bias-corrected approach, as suggested by Simar and Wilson (1999). The authors argue that DEA results is biased in small samples, so shifting the bounds of the interval by the factors $2*\widehat{bias}^*$ will ensure that the empirical bootstrap distribution centres on the bias-corrected estimate. Simar and Wilson (1999) expressed the bias-corrected estimate of the index as:

$$\widetilde{MI}=\widehat{MI}-\widehat{bias}[\widehat{MI}]=2\times\widehat{MI}-\frac{1}{B}\sum_{b=1}^{B}MI_b^*, \tag{3}$$

where

$$\widehat{bias}[\widehat{MI}]=\frac{1}{B}\sum_{b=1}^{B}MI_b^*-\widehat{MI}.$$

Note that the same approach also applies for all the other Malmquist components.

7. Measuring efficiency: The Bayesian output distance function

7.1. Output distance function

Before introducing the output distance function, we first define the production technology:

$$P(x)=\{y\in R_+^M : x \text{ can produce } y\} \tag{4}$$

which represents the set of all output vectors, $y\in R_+^M$, which can be produced using the input vector $x\in R_+^P$. We assume that this technology satisfies the axioms detailed in Färe et al. (1994c), including convexity, strong disposability, closeness and boundedness. According to Färe and Primont (1995), it is possible to describe the technology in (4) using an output distance function:

$$D_0(x,y)=\min\{\theta : (y/\theta)\in P(x)\} \tag{5}$$

which is non-decreasing, positively linearly homogenous and convex in y. It takes the value of less than, or equal to, one if the output vector, y, is an element of the feasible production set, $P(x)$. That is, $D_0(x,y)\leqslant 1$ if $y\in P(x)$. Moreover, $D_0(x,y)=1$ if (x,y) belong to the "frontier" of the production possibility set.

In order to estimate efficiency, we need to parameterize and calculate the parameters of an output distance function. Here we choose $D_0(x,y)$ as a translog function, which is a flexible functional form and often used in the banking literature. For the case of M outputs and P inputs, we write the translog output distance function as:

$$\begin{aligned}\ln D_0 = \beta_0 &+ \sum_{m=1}^{M}\beta_m \ln y_m + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn}\ln y_m \ln y_n \\ &+ \sum_{p=1}^{P}\gamma_p \ln x_p + 0.5\sum_{p=1}^{P}\sum_{j=1}^{P}\gamma_{pj}\ln x_p \ln x_j \\ &+ \sum_{p=1}^{P}\sum_{m=1}^{M}\delta_{pm}\ln x_p \ln y_m, \quad i=1,2,\ldots,N,\end{aligned} \tag{6}$$

where $\beta_0, \beta_m, \beta_{mm}, \gamma_p, \gamma_{pj}$, and δ_{pm} are unknown parameters. The restriction required to impose homogeneity of degree 1 in outputs is:

$$\sum_{m=1}^{M}\beta_m+\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mm}\ln y_n+\sum_{m=1}^{M}\sum_{p=1}^{P}\delta_{pm}\ln x_p=1, \tag{7}$$

which can be met if $\sum_{m=1}^{M}\beta_m=1$, $\sum_{n=1}^{M}\beta_{mm}=0$ for all n, and $\sum_{m=1}^{M}\delta_{pm}=0$ for all p and those conditions required to ensure symmetry are:

$$\begin{aligned}&\beta_{mn}=\beta_{nm} \quad m,n=1,2,\ldots,M,\\ &\text{and}\\ &\gamma_{pj}=\gamma_{jp} \quad p,j=1,2,\ldots,P.\end{aligned} \tag{8}$$

Alternatively, one can express the homogeneity and symmetry condition by normalising the distance function by one of the outputs (Lovell et al., 1994). If the Mth output is arbitrarily chosen, then the model can be written as:

$$\begin{aligned}\ln(D_0/y_m) = \beta_0 &+ \sum_{m=1}^{M}\beta_m \ln(y_m/y_M) \\ &+ 0.5\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\beta_{mm}\ln(y_m/y_M)\ln(y_n/y_M) \\ &+ \sum_{p=1}^{P}\gamma_p \ln x_p + 0.5\sum_{p=1}^{P}\sum_{j=1}^{P}\gamma_{pj}\ln x_p \ln x_j \\ &+ \sum_{p=1}^{P}\sum_{m=1}^{M-1}\delta_{pm}\ln x_p \ln(y_m/y_M).\end{aligned} \tag{9}$$

It is also possible to write the model in a more compact form as:

$$\ln(D_o)-\ln(y_M)=TL(\mathbf{x},\mathbf{y}/y_M,\boldsymbol{\beta}) \tag{10}$$

or alternatively as:

$$-\ln y_M = TL(\mathbf{x},\mathbf{y}/y_M,\boldsymbol{\beta})+u, \tag{11}$$

where $u=-\ln D$ is a non-negative term that captures the effect of technical inefficiency. Introducing an error term to (8) transforms the model into a stochastic frontier framework, and thus makes it possible to capture the effect of the data noise:

$$-\ln y_M = TL(\mathbf{x},\mathbf{y}/y_M,\boldsymbol{\beta})+v+u \tag{12}$$

which is similar in form to the well-established stochastic frontier model of Aigner et al. (1977). For more details on the advantages of the stochastic frontier model, see Coelli et al. (1998).

7.2. Monotonicity and curvature

So far, we have only imposed homogeneity constraints on the model in (6). However, to satisfy economic theory, the output distance function has also to satisfy the regularity condition of monotonicity and curvature. Monotonicity requires that $D_0(x,y)$ is non-decreasing in x and non-decreasing in y, which can be written as:

$$s_p \equiv \frac{\partial D_o(x,y)}{\partial x_p} \leqslant 0 \tag{13}$$

and

$$r_m \equiv \frac{\partial D_o(x,y)}{\partial y_m} \geqslant 0. \tag{14}$$

Curvature, on the other hand, requires that the output distance function $D_0(x,y)$ is quasi-convex in x and convex in y. The quasi-convexity in x can be achieved by ensuring that all the principal minors of the bordered Hessian matrix $\mathbf{F}$, formed by the first- and second-order derivative of, $D_0(x,y)$ are negative.

For convexity constraint, the function $D_0(x,y)$ will be convex in y if, and only if, all the principal minors of the following Hessian matrix are non-negative:

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1M} \\ h_{21} & h_{22} & \cdots & h_{2M} \\ \vdots & \vdots & \cdots & \vdots \\ h_{1M} & h_{2M} & \cdots & h_{MM} \end{bmatrix},$$

where

$$h_{mn} = \frac{\partial^2 D_0(x,y)}{\partial y_m \partial y_n}. \tag{15}$$

For more details on this issue, see Rao and Bhimasankaran (1992) and O'Donnell and Coelli (2005).

7.3. Bayesian estimation

The Bayesian approach is an attractive alternative to the use of sampling theory in the estimation of technical efficiency, as it can provide exact statistical inferences on the efficiency results and the parameters of the model. As we stated before, another reason for using the Bayesian estimation method relates to its capability of imposing the regularity conditions (i.e. the convexity/quasi-convexity and concavity/quasi-concavity properties) on the distance function.

To illustrate the Bayesian approach, we first write the stochastic frontier distance function in a simplified form as:

$$\mathbf{q}_{it} = \mathbf{X}_i'\boldsymbol{\beta} + \mathbf{v}_i + u_i\mathbf{j}_T, \tag{16}$$

where $\mathbf{j}_T$ is a $T \times 1$ unit vector, $\mathbf{q}_{it} = (-\ln y_{Mi1}, \ldots, \ln y_{MiT})$, $\mathbf{X}_{it}$ is a $T \times (K+1)$ vector containing the logarithms of the input variables and output ratios, $\boldsymbol{\beta}$ is a vector of parameters (including the intercept), $\mathbf{v}_i = (v_{i1}, \ldots, v_{iT})'$ are independent random variables with zero means and constant variance , and u_i is a non-negative term that captures the effect of technical inefficiency.

The Bayesian theorem requires choosing prior for the model parameters and specifying the likelihood of the model. Here we assume that $\mathbf{v}_i$ is normally distributed, while u_i's are drawn from exponential distributions[1] with a common unknown parameter λ. We also follow Koop et al. (1997) and O'Donnell and Coelli (2005) and we adopt an independent prior for h ($p(h) \propto h^{-1}$) and the following prior for $\boldsymbol{\beta}$:

$$p(\boldsymbol{\beta}) \propto I(\boldsymbol{\beta} \in R_j), \tag{17}$$

where $I(\cdot)$ is an indicator function which takes the value of one if an argument is true and zero otherwise, and R_j is the set of permissible parameters for imposing both monotinicity and curvature[2]. For the remaining parameter, λ we impose the following proper prior:

$$p(\lambda^{-1}) = f_G(\lambda^{-1}|1, -\ln(r^*)), \tag{18}$$

where r^* is the prior median technical efficiency and is most commonly set at a value of 0.875 (Koop et al., 1997).

The joint-prior pdf for the model as well as the likelihood function are expressed in O'Donnell and Coelli (2005). The posterior corresponding to this prior is intractable and must be analyzed using simulation methods. In particular, a Gibbs sampler with data augmentation can be setup for this model (see Koop et al., 1995, 1997; O'Donnell and Coelli, 2005), involving the following conditional distributions:

$$p(\lambda^{-1}|\mathbf{q}, \boldsymbol{\beta}, h, \mathbf{u}) \propto f_G(\lambda^{-1}|N+1, \mathbf{u}'\mathbf{j}_N - \ln(\tau^*)), \tag{19}$$

$$p(h|\mathbf{q}, \boldsymbol{\beta}, \mathbf{u}, \lambda^{-1}) \propto f_G(h|NT/2, 0.5[\mathbf{q} - \mathbf{X}\boldsymbol{\beta} - (\mathbf{I}_N \otimes \mathbf{J}_T)\mathbf{u}]'[\mathbf{q} - \mathbf{X}\boldsymbol{\beta} - (\mathbf{I}_N \otimes \mathbf{J}_T)\mathbf{u}]), \tag{20}$$

$$p(\boldsymbol{\beta}|\mathbf{q}, h, \mathbf{u}, \lambda^{-1}) \propto f_N(\boldsymbol{\beta}|\mathbf{b}, h^{-1}(\mathbf{X}'\mathbf{X})^{-1}) \times I(\boldsymbol{\beta} \in R_j), \tag{21}$$

$$p(\mathbf{u}|\mathbf{q}, \boldsymbol{\beta}, h, \lambda^{-1}) \propto f_N(\mathbf{u}|\bar{\mathbf{q}} - \overline{\mathbf{X}}\boldsymbol{\beta} - (Th\lambda)^{-1}\mathbf{j}_N, (Th)^{-1}\mathbf{I}_N \times \prod_{i=1}^{N} I(u_i \geqslant 0), \tag{22}$$

where $\mathbf{b} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'[\mathbf{y} - (I_N \otimes \mathbf{j}_T)\mathbf{u}]$ is $(K+1) \times 1$. Bayesian inferences are mainly derived using Gibbs sampling computational techniques, which involves taking sequential random draws from the above conditional distributions. It is simple to sample from the gamma distributions (19) and (20). However, sampling from the truncated multivariate normal distribution (21) can be accomplished using the simple accept–reject algorithm or the Metropolis–Hasting (M–H) algorithm. Here we follow O'Donnell and Coelli (2005) and Feng and Serletis (2009) and we adopt the Metropolis–Hasting (M–H). The usual criticism of the accept–reject algorithm is that it requires a large number of candidate draws before finding one that is acceptable.

8. Empirical results and discussion

8.1. Efficiency growth and productivity growth

Table 3 reports the average bootstrap estimates[3] of the changes in efficiency and productivity. We do not report the results of individual banks, but these can be obtained from the authors upon request. It was clear that out of 291 *Shinkin* banks, only 81 banks experienced an increase in productivity ($MI > 1$), and 124 banks experienced an increase in efficiency. On average, neither efficiency nor productivity improved significantly, as evidenced from the confidence intervals of the average efficiency growth and productivity growth in Table 3. The degree of growth is significant if the confidence interval excludes unity. However, as in our case both intervals pass through unity, this leads to the conclusion that the growth in both efficiency and productivity was not significant over the period of study.

Based on the above, we accept Hypothesis 1. This finding is probably due to our earlier discussion of the problems that still face *Shinkin* banks and affect their growth in efficiency and productivity. In particular, we mention here the high percentage of non-performing loans, poor restructuring, management failings and the lack of market power. Previous studies identified these factors as potential sources of low productivity and efficiency in Japanese

[1] The exponential distribution is usually the most common in the Bayesian stochastic frontier framework, as it is a flexible distribution and results in robust estimates (van de Broeck et al., 1995).

[2] For details on how to impose monotinicity and curvature, see Section 7.2.

[3] We used the FEAR software by Wilson (2009) to obtain the bootstrap estimates.

Table 3
Average productivity, efficiency and technical changes of *Shinkin* banks (2000–2006).

	EC	TC	TFP
Average	1.0021	0.9951	1.0012
	(0.8734, 1.0123)	(0.8351, 1.0152)	(0.9835, 1.0351)
Min.	0.9460	0.9790	0.9430
Max.	1.0490	1.1310	1.1310

*EC, efficiency change; TC, technical change; TFP, total productivity change.
*Numbers between parentheses represent the lower and upper bound of the confidence intervals.

Table 4
Productivity and efficiency growth per prefecture (2000–2006).

No	Prefecture	EC	TC	TFP
1	Hokkaido	1.0420**	1.0178	1.0595**
2	Aomori	1.0460**	0.9554**	0.9970
3	Akita	1.1267**	0.9423**	1.0617**
4	Yamagata	1.0194**	0.9252**	0.9414**
5	Iwate	0.9604**	0.9619**	0.9239**
6	Miyagi	0.9810**	0.9342**	0.9158**
7	Fukushima	1.0075	0.9710**	0.9778
8	Gunma	1.0199	0.9677**	0.9866
9	Tochigi	0.9297**	0.9748**	0.9047**
10	Ibaragi	0.8945**	0.9720**	0.8705**
11	Saitama	0.9720**	0.9953	0.9658**
12	Chiba	0.9882	0.9824	0.9700**
13	Kanagawa	0.9814**	0.9880	0.9691**
14	Niigata	0.9711**	0.9547**	0.9273**
15	Yamanashi	0.9425**	0.9645**	0.9097**
16	Nagano	0.8900**	0.9900	0.8810**
17	Tokyo	0.9904	0.9741**	0.9648**
18	Toyama	0.9565**	1.0016	0.9580**
19	Ishikawa	0.9856**	0.9492**	0.9352**
20	Fukui	0.9882**	0.9816	0.9696**
21	Shizuoka	0.9885	0.9776**	0.9666**
22	Gifu	1.0001	0.9864	0.9860**
23	Aichi	0.9954	1.0065	1.0019
24	Mie	0.9720**	1.1556**	1.1270**
25	Shiga	1.0007	0.9730**	0.9743**
26	Kyoto	0.9703**	1.0150	0.9847**
27	Oosaka	0.9945	0.9496**	0.9450**
28	Nara	0.9583**	1.0417**	0.9983
29	Wakayama	0.9417**	1.0047	0.9450**
30	Hyogo	1.0072	0.9916	0.9990
31	Tottori	0.9843**	0.9313**	0.9177**
32	Shimane	1.0603**	0.9288**	0.9850**
33	Okayama	0.9689**	0.9824	0.9519**
34	Hiroshima	1.0013	0.9683**	0.9695**
35	Yamaguchi	0.9861**	0.9503**	0.9366**
36	Tokushima	0.9730**	0.9225**	0.8970**
37	Kagawa	0.9915	1.0605**	1.0520**
38	Ehime	0.9924	0.9606**	0.9512**
39	Kochi	0.9960	1.4035**	1.4000**
40	Fukuoka	0.9989	0.9473**	0.9464**
41	Saga	0.9465	0.9148**	0.8658**
42	Nagasaki	1.0100	0.9080**	0.9165**
43	Kumamoto	1.0138**	0.9123**	0.9248**
44	Ooita	0.9553**	0.9230**	0.8827**
45	Miyazaki	0.9994	0.9542**	0.9540**
46	Kagoshima	1.0060	0.9137**	0.9190**
47	Okinawa	1.0100**	0.9130**	0.9220**

EC, efficiency change; TC, technical change; TFP, total productivity change.
** The change is significantly different from unity at the 5% level.

and other international banks (Fukuyama and Weber, 2008a,b). The main positive trend during the period of this study was the financial support from the government to boost the consolidation process and establish some financial balance in the system. However, any significant increase in performance was not expected, as all the traditional problems in the *Shinkin* banking industry remained present. In addition, the consolidation process did not include appropriate restructuring by the government or the banks themselves. In accepting Hypothesis 1, we also support Fukuyama and Weber (2009) who have recently argued that low productivity is a common problem in Japanese financial institutions, particularly mutual financial institutions or regional banks, due to the slow adoption of new products and technologies in comparison to other developed financial institutions in Europe or USA.

To provide stronger macro implications of our results, we also report in Table 4 the average productivity and efficiency growth scores across the various prefectures in which the banks are located. Results indicate that over the period of this study, the average productivity across prefectures is below "1", which signifies a productivity decline. The least productive prefecture is Nagano, while the most productive prefecture is Mie. Similarly, with reference to efficiency, only seven of forty-seven prefectures have experienced a positive efficiency growth, while only three prefectures have achieved a positive technological growth. Further support to these results appears in Table 5, which presents the average productivity growth per annum. As is clear, the prefectures have mostly experienced an annual productivity regress, though not always at a significant level. There was also no clear improvement in productivity, as is evident from the consistent level of the average productivity from year to year. These results thus confirm again the above conclusion on individual banks that the *Shinkin* banks did not experience a significant increase in productivity and efficiency over the period of this study.

8.2. Correlates of efficiency growth and productivity growth

As explained in Section 4, we aim to provide here further explanation of the sources of efficiency and productivity growth variations at *Shinkin* banks. Specifically, we regress the Malmquist efficiency and productivity scores on the following variables: market share on deposit (MSD), number of branches, returns on assets (ROA), net interest margin (NIM), and concentration ratio of deposits for the five largest *Shinkin* banks. All these variables have an important impact on the growth in efficiency and productivity (Fukuyama and Weber, 2008a,b, 2009).

To estimate the regression, we use the bootstrapped truncated regression model of Simar and Wilson (2007). The authors provided simulation evidence that the truncated regression model can lead to more accurate and consistent estimates than the Tobit regression model, traditionally used in most banking studies. Table 6 lists the results.

We see that all variables are statistically significant with the expected signs, apart from the coefficient of net interest margin, which has a negative sign. Thus, we accept Hypothesis 2 for all variables except the net interest margin. NIM is an indicator of the amount by which the interest earned on a bank's portfolio exceeds the interest paid on deposits or borrowed funds. Most often, NIM reflects asset productivity, since a high NIM is indicative of the effective use of earning assets and a sensible mix of interest-bearing liabilities. Probably, NIM is not highly influential in the case of *Shinkin* banks as they often utilize unnecessary deposits (Fukuyama and Weber, 2009).

Thus, the highly significant variables include market share on deposit (MSD), number of branches and returns on assets (ROA). The positive impact of market share and market concentration agree indirectly with the efficient structure hypothesis (ESH) that firms with superior production technology and/or managerial skills have lower costs and higher profits, which result in the acquisition of market share and an increase in concentration. Similarly, the number of branches is also indicative of the size and market power and thus, its positive impact is a *priori* expected. From the result, it

Table 5
Annual productivity growth per prefecture.

No.	Prefecture	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
1	Hokkaido	0.9604**	1.0318**	1.0063	1.0206**	1.0024	1.0265**
2	Aomori	0.9604**	1.0512**	1.0200	1.0058	0.9616**	1.0100
3	Akita	0.9960	1.0497	1.0007	0.9877	1.0320	0.9963
4	Yamagata	0.9610**	1.0162	0.9896	0.9838	1.0018	0.9894
5	Iwate	0.9593**	1.0257	0.9796**	0.9857	0.9824**	0.9886
6	Miyagi	0.9244**	1.0004	1.0056	1.0008	1.0010	0.9916
7	Fukushima	0.9945	1.0261	0.9891	0.9974	0.9749**	0.9984
8	Gunma	0.9519**	1.0010	0.9950	1.0158	1.0157	1.0093
9	Tochigi	0.9132**	0.9505**	0.9838	1.0068	1.0193	1.0195
10	Ibaragi	0.9735**	0.9780**	0.9680**	0.9785**	0.9740**	0.9820
11	Saitama	0.9878	1.0145	0.9888	0.9818	0.9805	1.0240
12	Chiba	0.9668**	1.0068	0.9876	1.0034	0.9720**	1.0400**
13	Kanagawa	0.9725**	1.0159	0.9971	1.0083	0.9865	0.9926
14	Niigata	0.9463**	0.9785**	0.9904	0.9973	1.0111	0.9979
15	Yamanashi	0.9678**	0.9817**	0.9677**	0.9835**	0.9765**	1.0163**
16	Nagano	1.0030	0.9360**	0.9660**	1.0050	0.9750**	0.9787**
17	Tokyo	0.9562**	0.9992	1.0024	0.9890	0.9913	1.0192**
18	Toyama	0.9820	1.0093	0.9975	0.9828	1.0030	0.9804
19	Ishikawa	0.9706**	0.9970	0.9712**	0.9994	0.9904	1.0064
20	Fukui	0.9896	0.9948	1.0074	1.0056	0.9806**	0.9930
21	Shizuoka	0.9714**	0.9912	1.0051	1.0009	0.9927	0.9964
22	Gifu	0.9737**	0.9970	0.9907	0.9941	1.0034	1.0224
23	Aichi	0.9563**	1.0292	1.0107	1.0017	0.9933	0.9991
24	Mie	1.0344	1.0574**	0.9870	1.0108**	0.9826	1.0124
25	Shiga	0.9667**	1.0160	1.0120	0.9930	0.9807	0.9980
26	Kyoto	0.9803	0.9760**	0.9803	1.0063	1.0077	1.0370**
27	Oosaka	0.9693**	0.9626**	0.9767**	1.0068	1.0052	1.0198
28	Nara	0.9350**	1.0047	0.9507**	1.0337**	0.9877	1.0497**
29	Wakayama	0.9257**	0.9767**	1.0093	0.9877**	1.0327	1.0037
30	Hyogo	0.9648**	0.9959	1.0145	0.9975	0.9985	1.0222**
31	Tottori	0.9600**	0.9707**	1.0020	0.9977	0.9797**	0.9960
32	Shimane	0.9763**	0.9890	1.0203	0.9880	1.0123	1.0118**
33	Okayama	0.9218**	1.0175	0.9848	1.0274**	0.9990	1.0024
34	Hiroshima	0.9635**	0.9835**	1.0110	0.9978	1.0155	1.0095
35	Yamaguchi	0.9583**	1.0086	0.9913	0.9764**	0.9689**	1.0251**
36	Tokushima	0.9500**	0.9910	0.9555**	1.0425**	0.9775**	0.9845**
37	Kagawa	0.9745**	1.0145	1.0325**	1.0160**	0.9735**	1.0075
38	Ehime	0.9438**	0.9946	1.0070	0.9868	1.0088	0.9950
39	Kouchi	1.0380	1.0495	1.0855**	1.0350**	1.0960**	1.0365**
40	Fukuoka	0.9374**	1.0093	0.9789**	1.0053	1.0008	1.0168**
41	Saga	0.9633**	0.9550**	0.9930	0.9753**	0.9800**	0.9975
42	Nagasaki	0.9890	1.0405	1.0060	0.9600**	0.9675**	0.9530**
43	Kumamoto	0.9488**	1.0208	0.9773	0.9705**	1.0025	1.0140**
44	Ooita	0.9443**	0.9730**	0.9643**	0.9873	0.9917	1.0127**
45	Miyazaki	0.9426**	1.0056	0.9838	1.0066	0.9896	1.0280**
46	Kagoshima	0.9237**	1.0063	0.9990	0.9677**	1.0003	1.0287**
47	Okinawa	0.9720**	0.9170**	1.0190**	1.0040	1.0330**	1.0090
	Average	0.9643**	1.0004	0.9949	0.9982	0.9960	1.0074

** The change is significantly different from unity at the 5% level.

Table 6
Bootstrapped truncated regression model.

Variable	Productivity growth			Efficiency growth		
	Coefficient	Std. error	*T*-statistic	Coefficient	Std. error	*T*-statistic
Constant	−0.6974	0.0999	−6.9810**	−0.3974	0.0989	−4.0182**
MSD	0.905	0.3952	2.2900*	0.625	0.1952	3.2018**
No. of branches	3.47E−05	1.40E−05	2.4820**	3.23E−05	1.38E−05	2.4820**
ROA	1.3092	0.5011	2.6127**	1.2102	0.5120	2.3637*
NIM	−0.0008	0.0003	−2.6666**	−0.0006	0.0002	−3.0012**
CRD5	3.1376	0.9991	3.1404**	2.9232	0.8791	3.3252**

MSD: market share on deposit, ROA: returns on assets, NIM: net interest margin, CRD5: concentration ratio of deposits for the five largest *Shinkin* banks.
** Significant at the 1% level.
* Significant at the 5% level.

also seems that the business nature of *Shinkin banks'* is dependent on an extensive branch network.

Therefore, the above variables provide some explanation to the variation in efficiency growth and productivity growth between individual *Shinkin* banks. In other words, banks with better values in these variables seem to enjoy higher performance.

8.3. Efficiency estimation

Finally, we analyze the efficiency of *Shinkin* banks. In Hypothesis 3, we stated that one of the major weaknesses in the current literature is that the distance function used in previous studies on *Shinkin* banks or other international banking sectors suffers from the violations of the theoretical regularity conditions. Therefore, we also aim in this study to address this important gap by imposing the theoretical regularity conditions and verifying the consequence of violating those conditions.

In order to test Hypothesis 3, we estimate two Bayesian models, one that is constrained (i.e. subject to theoretical regularity) and one without any constraints. We obtain the estimates by generating 60,000 observations, and then discarding the first 20,000 as a "burn-in". We first perform regularity tests on the unconstrained model by checking the posterior mean of (13) and (14) and the principal minors of **F** and **H**, for each of the 2037 observations in our sample. The results, summarized in Table 7, indicate that only one of the five monotonicity conditions are satisfied and that the curvature conditions are violated in all observations. These validate previous results obtained by O'Donnell and Coelli (2005) and Feng and Serletis (2009), and confirm that the unconstrained model does not meet the theoretical requirement.

Next, we estimate the constrained model by imposing those conditions explained in Section 7.2. Again, Table 7 reports the monotonicity and curvature violations. As it is clear, with the constrained model all the regularity conditions are satisfied in all of the 2037 observations. Table 8 presents the parameter estimates of the model. Although the parameter estimates of the unconstrained model are not reported here, in general we found that the constrained model has smaller posterior standard deviations and narrower Bayesian credible intervals. This finding is in line with Feng and Serletis (2009),and O'Donnell and Coelli (2005), who found that imposing the regularity constraints has the effect of reducing the variances of the estimated marginal pdfs.

Table 7
Regularity violations of the unconstrained model.

Unconstrained model		Constrained model	
Monotonicity conditions	Violations (%)	Monotonicity conditions	Violations (%)
$s_1 \leqslant 0$	20.23	$s_1 \leqslant 0$	0
$s_2 \leqslant 0$	15.63	$s_2 \leqslant 0$	0
$s_3 \leqslant 0$	0	$s_3 \leqslant 0$	0
$r_1 \geqslant 0$	5.23	$r_1 \geqslant 0$	0
$r_2 \geqslant 0$	1.12	$r_2 \geqslant 0$	0
Curvature conditions	Violations (%)	Curvature conditions	Violations (%)
The principal minors of **F** are negative	100	The principal minors of **F** are negative	0
H is positive semidefinite	13.12	**H** is positive semidefinite	0

Table 8
Posterior estimates of model parameters.

Parameters	Mean	SD	90% Posterior coverage region	
β_0	0.1589	0.0111	0.1325	0.1923
β_1	0.7612	0.1811	0.5312	0.7855
β_{11}	0.1265	0.0135	0.1121	0.1632
γ_1	−0.1138	0.0650	−0.1232	0.0521
γ_2	−0.4145	0.0876	−0.6321	−0.3321
γ_3	−1.3489	0.5880	−1.5200	−1.2831
γ_{11}	0.2183	0.1640	−0.0121	0.2231
γ_{12}	−1.1836	0.1402	−1.2321	−1.1532
γ_{13}	−1.3371	0.1923	−1.6550	−1.2832
γ_{22}	0.7985	0.3321	0.5328	0.8950
γ_{23}	−0.8617	0.0612	−0.9923	−0.5110
γ_{33}	0.8249	0.2912	0.6621	0.9533
δ_{11}	0.0636	0.2317	−0.1250	0.1123
δ_{21}	−0.1346	0.0232	−0.1621	−0.1191
δ_{31}	0.0955	0.0216	0.0220	0.1321

Thus, after confirming that the unconstrained model violates the monotonicity and curvature, we also investigate whether a failure to impose the theoretical regularity conditions will also have a significant impact on the efficiency of *Shinkin* banks. We test first the ranking of efficiency, by calculating the Spearman rank order correlation between the constrained and unconstrained models. If the Spearman rank order correlation is equal to "−1", then there is a perfect negative correction, if it is equal to "1", there is a perfect positive correlation and if it is equal to "0", there is no correlation. In line with Feng and Serletis (2009), we also bootstrap the Spearman rank order correlation in order to determine whether the correlation coefficient is significantly different from one at the 1% level. Table 9 reports the results.

As is clear, the Spearman rank order correlation is significantly different from one for all years in the sample, since the confidence intervals do not go through unity. This indicates that the ranking of efficiency of *Shinkin* banks is significantly different between the constrained and unconstrained models. In what follows we also investigate the impact of imposing theoretical conditions on the average efficiency of *Shinkin* banks. Table 10 reports the results. We confirm from the 5% and 95% percentile that there is a significant difference in efficiency between the constrained and unconstrained models. Furthermore, the average efficiency from the unconstrained model is always less than the constrained model, which is not surprising given the restrictions imposed on the production technology set (O'Donnell and Coelli, 2005).

Thus, based on all the above, we support Hypothesis 3 that the average efficiency and efficiency ranking of *Shinkin* banks derived from the constrained and unconstrained distance frontier models is significantly different. Since we also proved that the unconstrained model violates the theoretical regularity, we report in Table 11 the average efficiency results obtained from the constrained model. As is shown, the average efficiency scores of *Shinkin* banks have remained almost consistent over the period of study, with very minor changes. The average efficiency score of all *Shinkin* banks between 2000 and 2006 is 86.05%, ranging from a minimum of 80.73% to a maximum 90.11%.

This homogeneity in efficiency provides further support to the Malmquist results, which found that the efficiency did not grow significantly over the period of this study. In Table 12, we report the efficiency scores across the different prefectures. The average technical efficiency for all prefectures is 87.02%. We found that fifteen out of forty-seven prefectures have an efficiency score lower

Table 9
Spearman rank order correlation.

Year	Coefficient	Confidence interval
2000	0.8732	(0.7679, 0.9232)
2001	0.8821	(0.7721, 0.9311)
2002	0.8321	(0.7311, 0.8911)
2003	0.9132	(0.7829, 0.9433)
2004	0.8763	(0.7932, 0.9111)
2005	0.9352	(0.8211, 0.9512)
2006	0.9432	(0.8432, 0.9732)

Table 10
Average efficiency difference between the constrained and unconstrained models.

Year	Average efficiency difference	5% and 95% Percentile
2000	−0.0832	(−0.0942, −0.0621)
2001	−0.0321	(−0.4522, −0.0211)
2002	−0.0411	(−0.0355, −0.0311)
2003	−0.0532	(−0.0681, −0.0475)
2004	−0.0622	(−0.0713, −0.0511)
2005	−0.0555	(−0.0611, −0.0432)
2006	−0.0561	(−0.0601, −0.0411)

Table 11
Annual efficiency scores of *Shinkin* banks.

Year	Average efficiency
2000	0.8632
2001	0.8721
2002	0.8771
2003	0.8632
2004	0.8532
2005	0.8432
2006	0.8521

than the average score. The standard deviation across the analyzed prefectures is again small, confirming the previous finding by Fukuyama and Weber (2009) that most prefectures operate under a homogenous level of performance. Finally, whilst the results are not reported here, we confirmed that the efficiency of prefectures similarly did not improve significantly over the period of study, thus again providing further support to Hypothesis 3.

Table 12
Average efficiency scores by prefecture 2000–2006.

No.	Prefectures	Average efficiency	SD	90% Posterior coverage region	
1	Hokkaido	0.8840	0.0191	0.7698	0.9213
2	Aomori	0.9089	0.0192	0.7734	0.9295
3	Akita	0.8731	0.0193	0.7977	0.9510
4	Yamagata	0.8591	0.0195	0.7820	0.9453
5	Iwate	0.8803	0.0199	0.8051	0.9621
6	Miyagi	0.8762	0.0195	0.8030	0.9515
7	Fukushima	0.8840	0.0200	0.8000	0.9616
8	Gunma	0.9195	0.0194	0.7870	0.9523
9	Tochigi	0.8997	0.0198	0.8201	0.9758
10	Ibaragi	0.8644	0.0196	0.8313	0.9739
11	Saitama	0.8853	0.0199	0.8051	0.9609
12	Chiba	0.8846	0.0194	0.8034	0.9595
13	Kanagawa	0.8669	0.0195	0.7890	0.9509
14	Niigata	0.8796	0.0200	0.8039	0.9649
15	Yamanashi	0.8773	0.0198	0.8033	0.9606
16	Nagano	0.8325	0.0203	0.8604	0.9999
17	Tokyo	0.8836	0.0197	0.8067	0.9619
18	Toyama	0.6904	0.0202	0.8126	0.9694
19	Ishikawa	0.8837	0.0202	0.8079	0.9641
20	Fukui	0.8629	0.0198	0.7870	0.9426
21	Shizuoka	0.8958	0.0199	0.8160	0.9756
22	Gifu	0.8784	0.0198	0.7930	0.9561
23	Aichi	0.8786	0.0199	0.7974	0.9634
24	Mie	0.8598	0.0195	0.7839	0.9451
25	Shiga	0.8865	0.0191	0.7823	0.9450
26	Kyoto	0.8885	0.0205	0.8137	0.9730
27	Oosaka	0.8977	0.0202	0.8220	0.9719
28	Nara	0.9157	0.0200	0.8299	0.9869
29	Wakayama	0.8446	0.0198	0.7729	0.9266
30	Hyogo	0.8961	0.0198	0.7959	0.9548
31	Tottori	0.8860	0.0200	0.8147	0.9688
32	Shimane	0.8672	0.0202	0.7772	0.9464
33	Okayama	0.8797	0.0202	0.8006	0.9572
34	Hiroshima	0.9112	0.0208	0.8255	0.9891
35	Yamaguchi	0.8889	0.0200	0.8070	0.9600
36	Tokushima	0.8396	0.0184	0.7694	0.9264
37	Kagawa	0.8394	0.0191	0.7744	0.9334
38	Ehime	0.8542	0.0194	0.7847	0.9470
39	Kochi	0.8867	0.0203	0.8118	0.9688
40	Fukuoka	0.8758	0.0202	0.7999	0.9628
41	Saga	0.8599	0.0198	0.7738	0.9389
42	Nagasaki	0.8583	0.0196	0.7791	0.9332
43	Kumamoto	0.8655	0.0198	0.7832	0.9420
44	Ooita	0.8951	0.0209	0.8210	0.9768
45	Miyazaki	0.8910	0.0203	0.8066	0.9767
46	Kagoshima	0.9171	0.0195	0.8044	0.9491
47	Okinawa	0.8798	0.0215	0.7940	0.9938

9. Concluding remarks

The present paper provides new evidence on the performance of *Shinkin* banks and the various prefectures in Japan, using more robust and innovative methodologies. We base the analysis on three interesting hypotheses that address important research gaps in the extant literature.

Firstly, we accept the first hypothesis that the efficiency growth and productivity growth of *Shinkin* banks have not improved significantly over the analyzed period (2000–2006). We test this hypothesis with the bootstrapped Malmquist index, which provides statistical properties and confidence intervals of the degree of efficiency growth and productivity growth. We argue that this finding is most probably due to the traditional problems that still face *Shinkin* banks and affect their efficiency and productivity, which include factors such as the high percentage of non-performing loans, poor restructuring, management failings and the lack of market power. In addition, we highlight that the consolidation process during the analyzed period was not accompanied by appropriate restructuring from the government or the banks themselves.

In line with Hypothesis 2, we also introduce to the analysis several variables to explain further the sources of efficiency growth and productivity growth variations at *Shinkin* banks. Specifically, we regress the efficiency and productivity scores on the following variables: market share on deposit (MSD), number of branches, returns on assets (ROA), net interest margin (NIM) and concentration ratio of deposits for the five largest *Shinkin* banks. We demonstrate from the results that apart from NIM, all the other variables are important contributors to the efficiency growth and productivity growth of *Shinkin* banks.

In the last step, we apply the Bayesian distance frontier approach to provide efficiency measures of *Shinkin* banks. In line with Hypothesis 3, we aimed to verify whether ignoring the theoretical regularity conditions on the distance function could have a significant impact on the efficiency results. This interesting hypothesis could also serve efficiency studies outside the *Shinkin* banking context, particularly as the theoretical regularity conditions have been widely ignored in the literature. Our results confirm that these theoretical regularity conditions are highly essential, since a failure to impose them led to a significant difference in the efficiency results. This finding should thus set the stage for a more generalized use of the distance function in the banking literature. With regard to the efficiency of *Shinkin* banks, we show that the average efficiency scores of *Shinkin* banks remained practically consistent over the period of study, with minor changes. This provides further support to the Malmquist results, which indicate that the efficiency growth did not increase significantly over the period of this study.

Different policies also emerge from the study. First, we show that the efficiency growth and productivity growth of *Shinkin* banks have not improved significantly, and thus, aggressive policies are required to foster higher performance improvement at these banks. The correlates of efficiency growth and productivity growth analyzed in this study also relate to policy formulation. The negative impact of NIM might be because *Shinkin* banks with high margins generally utilize unnecessarily many deposits (and labour and capital) to produce too few loans and securities investments. Fukuyama and Weber (2005, 2009) also provided evidence that the "cooperative nature of these banks allows managers to engage in expense-preference behavior. Higher net interest margins might thus offer sufficient cushion to allow managers to indulge in such behavior, rather than pursue efficiency with greater effort". Thus, as NIM has a significant negative impact on both the efficiency growth and productivity growth of *Shinkin* banks, policymakers should focus on controlling the impact of high NIM. Future policies should also strengthen the return on assets, since it contributes to higher performance. Finally, the results indicate that larger size contributes to better performance at *Shinkin* banks. Specifically, banks with higher market share, wider branch network, and higher concentration appear to be more efficient and productive. Thus, these factors might also need to be part of the policy agenda of *Shinkin* banks, particularly those banks that do not have high and competitive values on these factors.

Appendix A. The Malmquist Productivity Index

Following Färeet al. (1994c), the index can be calculated between two periods t and $t+1$ as the geometric mean of the t and $t+1$ indices:

$$MI^{t,t+1} = \left[\frac{D_0^t(x^{t+1},y^{t+1})}{D_0^t(x^t,y^t)}\frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^{t+1}(x^t,y^t)}\right]^{1/2}, \tag{A.1}$$

where $D_0^t(x^{t+1},y^{t+1})$ represents the distance from the period $t+1$ observation to the period t technology. Improvements of productivity over time are signalled when $MI_0^{t,t+1}$ is larger than one, where decreases in productivity are signalled when $MI_0^{t,t+1}$ is less than one. The index in (A.1) can also be further decomposed into two components: efficiency change and technological change, as:

$$MI^{t,t+1} = \underbrace{\frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^t(x^t,y^t)}}_{\text{Efficiency change}}\underbrace{\left[\frac{D_0^t(x^{t+1},y^{t+1})}{D_0^{t+1}(x^{t+1},y^{t+1})}\frac{D_0^t(x^t,y^t)}{D_0^{t+1}(x^t,y^t)}\right]^{1/2}}_{\text{Technological change}}, \tag{A.2}$$

where the first component in the above represents the efficiency change (i.e. change in the bank location relative to the technology between the two periods) and the second component represents the technological change (i.e. change in technology location between the two periods).

As indicated in (A.2), the estimation of the Malmquist index and its components requires the estimation of four distance functions: $D_0^t(x^t,y^t)$, $D_0^{t+1}(x^{t+1},y^{t+1})$, $D_0^t(x^{t+1},y^{t+1})$ and $D_0^{t+1}(x^t,y^t)$. DEA is the common method used in the literature to estimate these distance functions. The method was illustrated in (A.3) and can be expressed in the case of $D_0^t(x^t,y^t)$, for example, as:

$$\begin{aligned}
&[D_o^t(x_i^t,y_i^t)]^{-1} = \max\ \theta\\
&\text{s.t.}\quad \theta y_{im}^t \le \sum_{k=1}^{L}\lambda_k^t y_{mk}^t,\quad m=1,\ldots,M,\\
&\sum_{k=1}^{L}\lambda_j^t x_{kp}^t \leqslant x_{ip}^t,\quad p=1,\ldots,P,\\
&\lambda_i^t \geqslant 0,\quad i=1\ldots,L,
\end{aligned} \tag{A.3}$$

where $\mathbf{x}_i^t=(x_{i1}^t,\ldots x_{ip}^t,\ldots,x_{iP}^t)'\in\mathbb{R}_+^{\mathbb{P}}$ and $\mathbf{y}_i^t=(y_{i1}^t,\ldots,y_{im}^t,\ldots,y_{iM}^t)'\in\mathbb{R}_+^{\mathbb{M}}$ are the input and output vectors corresponding to bank i, $i=1,\ldots,L$, in period t, respectively. The distance function $D_o^{t+1}(y^{t+1},x^{t+1})$ can also be computed in similar fashion by substituting $t+1$ for t. Finally, $D_o^t(x^{t+1},\ y^{t+1})$ can be computed as follows:

$$\begin{aligned}
&[D_o^t(x_i^{t+1},y_i^{t+1})]^{-1} = \max\ \theta\\
&\text{s.t.}\quad \theta y_{im}^{t+1} \leqslant \sum_{k=1}^{L}\lambda_k^t y_{mk}^t,\quad m=1,\ldots,M,\\
&\sum_{k=1}^{L}\lambda_j^t x_{kp}^t \leqslant x_{ip}^{t+1},\quad p=1\ldots,P,\\
&\lambda_i^t \geqslant 0,\quad i=1\ldots,L.
\end{aligned} \tag{A.4}$$

Note that $D_o^{t+1}(x_i^t,y_i^t)$ can be computed in similar fashion by substituting $t+1$ for t. For more detail on the Malmquist index, see Coelli et al. (1998).

References

Aigner, D.J., Lovell, C.A.K., Shmidt, P., 1977. Formulation and estimation of stochastic frontier production models. Journal of Econometrics 6, 21–37.
Berger, A.N., Humphrey, D.B., 1997. Efficiency of financial institutions: International survey and directions for future research. European Journal of Operations Research 98, 175–212.
Berger, A.N., Leusner, J.H., Mingo, J.J., 1997. The efficiency of bank branches. Journal of Monetary Economics 40, 141–162.
Berger, A.N., Hasan, I., Zhou, M., 2009. Bank ownership and efficiency in China: What will happen in the world's largest nation? Journal of Banking and Finance 33, 113–130.
Coelli, T., PrasadaRao, D.S., Battese, G.E., 1998. An Introduction to Efficiency and Productivity Analysis. Kluwer, Boston.
De Jonghe, O., Vander, R.V., 2008. Competition versus efficiency: What drives franchise values in European banking. Journal of Banking and Finance 32, 1820–1835.
Drake, L., Hall, M., 2003. Efficiency in Japanese banking: An empirical analysis. Journal of Banking and Finance 27, 891–917.
Drake, L., Hall, M., Simper, R., 2009. Bank modelling methodologies: A comparative non-parametric analysis of efficiency in the Japanese banking sector. Journal of International Financial Markets Institutions and Money 19, 1–15.
Färe, R., Grosskopf, S., Lindgren, B., Roos, P., 1994a. Productivity developments in Swedish hospitals: A Malmquist output index approach. In: Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M. (Eds.), Data Envelopment Analysis: Theory, Methodology, and Applications. Kluwer, Boston.
Färe, R., Grosskopf, S., Norris, M., Zang, Z., 1994b. Productivity growth, technical progress, and efficiency change in industrialized countries. American Economic Review 84, 66–83.
Färe, R., Grosskopf, S., Lovell, C.A.K., 1994c. Production Frontiers. Cambridge University Press, Cambridge.
Färe, R., Primont, D., 1995. Multi-Output Production and Duality: Theory and Applications. Kluwer, Boston.
Feng, G., Serletis, A., 2009. Efficiency, technical change, and returns to scale in large US banks: Panel data evidence from an output distance function satisfying theoretical regularity. Journal of Banking and Finance 34, 127–138.
Fukuyama, H., 1996. Returns to scale and efficiency of credit associations in Japan: A non parametric frontier approach. Japan and the World Economy 8, 259–277.
Fukuyama, H., Guerra, R., Weber, W.L., 1999. Efficiency and ownership: Evidence from Japanese credit cooperatives. Journal of Economics and Business 51, 473–487.
Fukuyama, H., Weber, W.L., 2005. Estimating output gains by means of Luenberger efficiency measures. European Journal of Operational Research 164, 535–547.
Fukuyama, H., Weber, W.L., 2008a. Estimating inefficiency, technological change and shadow prices of problem loans for regional banks and *Shinkin* banks in Japan. The Open Management Journal 1, 1–11.
Fukuyama, H., Weber, W.L., 2008b. Japanese banking inefficiency and shadow pricing. Mathematical and Computer Modelling 48, 1854–1867.
Fukuyama, H., Weber, W.L., 2009. A directional slacks-based measure of technical inefficiency. Socio-Economic Planning Sciences 43, 274–287.
Geweke, J., 1986. Exact inferences in the inequality constrained normal linear regression model. Journal of Applied Econometrics 1, 127–141.
Hirtle, B., 2007. The impact of network size on bank branch performance. Journal of Banking and Finance 31, 3782–3805.
Hosono, K., Sakai, K., Tsuru, K., 2006. Consolidation of Cooperative Banks (*Shinkin*) in Japan: Motives and Consequences. Discussion Paper, Research Institute of Economy, Trade and Industry (RIETI).
Ito, T., Harada, K., 2004. Bank fragility in Japan, 1995–2003. Working Paper, CESifo.
Kauko, K., 2009. Managers and efficiency in banking. Journal of Banking and Finance 33, 546–556.
Koop, G., Steel, M., Osiewalski, J., 1995. Posterior analysis of stochastic frontier models using Gibbs sampling. Computational Statistics 10, 353–373.
Koop, G., Osiewalski, J., Steel, M., 1997. Bayesian efficiency analysis through individual effects: Hospital cost frontiers. Journal of Econometrics 76, 77–105.
Lensink, R., Meesters, A., Naaborg, I., 2008. Bank efficiency and foreign ownership: Do good institutions matter? Journal of Banking and Finance 32, 834–844.
Lovell, C.A.K., Richardson, S., Travers, P., Wood, L.L., 1994. Resources and functionings: A new view of inequality in Australia. In: Eichhorn, W. (Ed.), Models and Measurement of Welfare and Inequality. Springer-Verlag Press, Berlin.
O'Donnell, C., Coelli, T., 2005. A Bayesian approach to imposing curvature on distance functions. Journal of Econometrics 126, 492–523.
Ohashi, K., Singh, M., 2004. Japan's Distressed Debt Market. Working Paper, International Monetary Fund, Washington, DC.
Park, K.H., Weber, W.L., 2006. Profitability of Korean banks: Test of market structure versus efficient structure. Journal of Economics and Business 58, 222–239.
Poirier, D.J., 1995. Intermediate Statistics and Econometrics: A Comparative Approach. The MIT Press, Cambridge, MA.
Portela, M.C.A.S., Thanassoulis, E., 2010. Malmquist-type indices in the presence of negative data: An application to bank branches. Journal of Banking and Finance 34, 1472–1483.
Rao, A.R., Bhimasankaran, P., 1992. Linear Algebra. McGraw Hill, New Delhi.
Satake, M., Tsutsui, Y., 2002. *Shinkin* banks in Kyoto: Analysis based on the efficient structure hypothesis. In: Yuno, T. (Ed.), Regional Finance: A Case of Kyoto. Nippon Hyoron Sha, Tokyo.

Sealey Jr., C., Lindley, J., 1977. Inputs, outputs, and a theory of production and cost at depositary financial institutions. Journal of Finance 32, 1251–1266.
Simar, L., Wilson, P.W., 1999. Estimating and bootstrapping Malmquist indices. European Journal of Operational Research 115, 459–471.
Simar, L., Wilson, P.W., 2007. Estimation and inference in two-stage, semi-parametric models of production processes. Journal of Econometrics 136, 31–64.
Sturm, J.E., Williams, B., 2008. Characteristics determining the efficiency of foreign banks in Australia. Journal of Banking and Finance 32, 2346–2360.
Uchida, H., Satake, M., 2009. Market discipline and bank efficiency. Journal of International Financial Markets, Institutions and Money 19, 792–802.
van de Broeck, J., Koop, G., Osiewalski, J., Steel, M., 1995. Stochastic frontier models: A Bayesian perspective. Journal of Econometrics 46, 39–56.
Wilson, P., 2009. FEAR: Frontier Efficiency Analysis with *R*. University of Clemson, US.