Modelling Bank Performance: A Network DEA Approach

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September 2016

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Abstract: In this paper, we develop a bank network revenue function to evaluate banks' network revenue performance. The bank network revenue function, which extends the environmental revenue function and the two-stage network cost function, is constructed as the difference between total revenue and the reserves for possible loan losses to incorporate the roles played by non-performing loans in bank production. The second part of the paper then applies Nerlove's revenue inefficiency model. We consider revenue maximization in two stages. We apply this function to Japanese banks operating from September 2000 to March 2013.

Keywords: Data Envelopment Analysis; Bank revenue function; Japanese banks; non-performing loans; two stage network DEA

1. Introduction

The Japanese banks, and particularly Regional Banks, have been undergoing a long period of restructuring and consolidation. This process can be traced back to the late 1990s. The unique and unprecedented consolidation process of the Japanese banking system has attracted substantial research interest. There have been a number of recent studies that analyze bank efficiency in Japan, e.g. Fukao (2008), Fukuyama and Weber (2008, 2015a, 2015b), Hoshi and Kashyap (2010), Assaf et al. (2011), Mamatzakis et al. (2015), among others.

The research interest in bank efficiency has also been closely linked to the complex economic situation in Japan. The poorly functioning banking system, not only in the early 1990s, but also during the 2000s, contributed substantially to the slowdown of the Japanese economy. Furthermore, unusually low CPI and economic growth that have been negative or marginal to zero for a couple of decades, have undoubtedly affected bank performance. Recent studies by, e.g. Fukuyama and Weber (2008, 2015a, 2015b), Assaf et al. (2011), Barros et al. (2012), provide empirical evidence of the low performance in the Japanese banking sector. Montgomery and Shimizutani (2009) further show that costly structural and institutional reforms implemented by banks and the Japanese Government in the 1990s and early 2000s did not substantially reduce the high volume of non-performing loans (NPLs) on bank balance sheets.

This study differs from previous research on bank efficiency in general and the Japanese banking sector in particular in several ways. We provide a fresh look at the ongoing problems faced by the sector and propose an innovative framework to evaluate banks' network revenue efficiency. We address the following research questions that have not been addressed in previous Japanese banking research studies. First, we model and identify the variation (differences) between optimal and current bank revenue for the sector as a whole. This sort of analysis has been omitted from contemporary literature on bank efficiency.

Next, we examine behavioural differences in terms of optimal and current revenue, between Regional Banks I and Regional Banks II. Such an analysis gives an in-depth view of the differences between these two types of Regional Banks.[1] The applied model also allows us to identify how banks can adjust the individual inputs/outputs that maximize their revenue. We also estimate an optimal level of NPLs and compare these with the current volume of NPLs shown on bank balance sheets. Last, but not least, we examine a link between bank reserves and optimal and actual NPLs.

In terms of methodological contribution, we build on Data Envelopment Analysis (DEA) and the two-stage network model introduced by Fukuyama and Weber (2010) and Fukuyama and Matousek (2011). Fukuyama and Weber (2015a) considered a financial regulatory constraint along with NPLs in a two stage network, multi-period dynamic model. Fukuyama and Weber (2015b) further extended the framework into Luenberger indicators. The inclusion of NPLs directly into the model for estimating bank efficiency has been already well established. Fujii et al. (2014) and Assaf et al. (2013) clearly show that omitting NPLs from the model can provide biased results in bank efficiency analysis. So far research has linked only NPLs with technical efficiency. This paper extends the traditional concept in the following directions. A two-stage network model for analyzing bank efficiency is fully justified by the fact that bank

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1 In Section 2, we provide a detailed discussion about the structure of Japanese banks and other financial institutions.

deposits have to be 'produced' by banks. Thus, they enter into the production process at the second stage. The proposed model further shifts this type of research by introducing a two-stage network bank revenue function with NPLs. This is an important and novel contribution since we not only introduce NPLs into the two-stage network model, but also link NPLs with bank revenue and bank reserves. This model, therefore, allows us to estimate an optimal revenue that can be generated by banks with respect to bank reserves for NPLs. We determine bank optimal revenue and, at the same time, identify the optimal outputs in the production process. The results will then show differences between optimal and estimated revenues and inputs/outputs. The analysis has important managerial implications. We apply this model to Japanese Regional Banks to better understand the causes of low bank profitability and propose how this can be improved.

The second part of the paper then applies Nerlove's revenue inefficiency model, as introduced by Nerlove (1965). Following Nerlove (1965) we consider revenue maximization in two stages. The first stage is characterized by revenue maximization for a given production function, and in the second stage, maximum revenue is obtained by maximizing all possible production opportunities. The overall efficiency measures are broken down into allocative efficiency and technical efficiency, as Chambers et al (1996) show a clear advantage in using this type of model. Following this approach we analyze not only Nerlove's Revenue inefficiency but also the individual efficiencies. This allows us to identify the main source of bank inefficiency that provides banks and policymakers with important information about bank behaviour.

The remainder of the paper is organized as follows: Section 2 provides an overview of the Japanese banking system and the main challenges it faces; Section 3 contains the literature review; Section 4 provides the methodological concept of our analysis; Section 5 discusses data and empirical findings; and Section 6 summarizes our results and suggests areas for further research.

2. The Japanese Banks: An Overview

The Japanese banking sector can be classified as a bank-based financial system. Commercial banks play a primary role in providing finance to businesses and households. The structure of banks in Japan is rather complicated. Banks can be split up into several levels. The largest banks with international activities include City Banks and Trust Banks. The second important group of banking institutions in Japan are the Regional Banks. These are divided into groups: Regional Banks I; and the Second Association of Regional Banks (also known as Regional Banks II). The third group includes *Shinkin Banks* (Credit banks (CBs)) and *Shinyo Kumiai* (Credit Cooperatives (CCs)), small financial institutions serving mainly households and small businesses. Based on this classification we can broadly say that the first two groups belong to a category of commercial banks. *Shinkin Banks* and *Shinyo Kumiai* are a group of typical mutual/cooperative financial institutions. The Japanese banking system was crippled by the continuous misallocation of credits and the delayed disclosure of the true level of NPLs in the 1990s. The policy stance adopted by the Japanese Government and the Bank of Japan, which postponed the full disclosure of NPLs on the bank balance sheets, was self-destructive. Poor macroeconomic conditions and the inability of businesses to repay their debts rapidly deteriorated during the 1990s. Furthermore, NPLs undermined the overall performance of commercial banks. A similar view was presented by Fukao (2003, 2008), Peek and Rosengren (2005), Watanabe (2007), Hoshi and Kashyap (2010), among others, who argued that the volume of NPLs was unsustainable and caused major problems for the economy as a whole.

The financial crisis in Japan reached its height in the second half of 1997, when a large number of financial institutions declared bankruptcy almost on a daily basis. The turmoil squeezed liquidity in the financial market, since financial institutions preferred to deposit their money with the Bank of Japan, instead of allocating the money on the interbank market. The financial crisis and consequent consolidation process in the Japanese financial market can be split up into three phases (Fukao (2008) and Hoshi and Kashyap (2010) discuss this issue in depth). The first phase of the crisis occurred between 1991 and 1997 and was characterized by the bubble bursting and the beginning of gradual and reluctant interventions by the Japanese Government that hugely underestimated, in the early stage of the crisis at least, the true scale of the problems in the financial sector. The second phase, 1997–1999, can be labelled as the defining point of the near collapse of the Japanese financial market. Only then did the Government admit the true extent of the crisis, with the result that more systematic measures were implemented to rescue the system from complete collapse. Finally, the period from 1999 to 2003 was characterized by intensive consolidation of the banking sector, but the problems of credit misallocation and economic stagnation continued. Hoshi and Kashyap (2010) show that the problems within the financial market were not associated, in this phase, with the earlier bubble bursting, but were a direct consequence of the policy measures applied from the late 1990s onwards.

Montgomery and Shimizutani (2009) analyze the (in)effectiveness of recapitalization policies in the Japanese banking sector. They reported that 180 banks failed and the total cost of the credit losses reached USD 950 billion from 1990 to 2003. We observe the rapid decline in the number of banks operating in Japan from 1990 to 2008. The consolidation and recapitalization process through the merger of financially distressed banks has completely changed the structure of the financial market place.

Our analysis focuses on the activities of Regional Banks I and II that can be seen as a core banking segment within the Japanese financial system. The Japanese banking sector has faced severe systemic instability since the early 1990s. Several recapitalization programmes have been introduced by the Government in order to stabilize the system and restore lending activities. As extensively discussed by Packer and Zhu (2012), Japanese banks apply two sets of provisioning: general and specific provisions. Both types of provisions are tax-deductible and are part of Tier 2 capital. However, the Japanese banks are not allowed to use any discretionary changes to provisional requirements in response to macrofinancial conditions or sectoral considerations. The required provisions are estimated from the past three-year loss experience in each category. It is not a forward provisioning (dynamic) system that would act as counter-cyclical (Jiménez et al, 2012). The main regulatory changes that affected provisioning were changes in loan classification standards, which were particularly intense in the late 1990s and early 2000s, when Japan tightened its loan classification guidelines. Despite extensive discussions about the required changes in the provisioning practices in Japan there has not been any change since 2002. Fujii and Kawai (2010) discuss the underestimated volume of the provisions created by the banks in the late 1990s and early 2000s. The problems of inadequate provisions were addressed by the authorities mainly in the group of the large City Banks rather than in the Regional Banks.

Regional Banks in particular had a large proportion of NPLs on their balance sheets, low capitalization and financial losses caused mainly by deteriorated balance sheets. More than 40 per cent of problem loans held by Regional Banks between September 2008 and March 2009 were reclassified as normal (Hoshi, 2011). Although in 2007, Japanese banks' capital was finally claimed to have been restored (Hoshi and Kashyap, 2010), it is argued that a large number of bad debts were disguised until the end of March 2012, in response to the Act of Temporary Measures to Facilitate Financing for SMEs (Hoshi, 2011).

Recent studies by Halkos et al. (2016), Mamatzakis et al. (2015), Fukuyama and Weber (2010), among others, argue that that the Japanese Government's decision not to address the accumulating problems within the Regional Banks meant that the situation deteriorated still further. The fact is that a consolidation process should lead to the restoration of not only banks' intermediary functions, but also an improvement in the efficient allocation of credits within the economy. To date banks' activities are still restricted due to a lack of capital and accumulated NPLs.

Halkos et al. (2016) show that mergers and acquisitions (M&As) within the regional banking sector could be an appropriate way of restoring bank activities and efficiency. In Japan, however, M&A activity has not been seen as an effective instrument for bank consolidation. Although the regional banks came through the global financial crisis relatively unharmed their financial positions have been gradually eroding. This has been caused by a relatively narrow interest margin that has already caused some banks to become financially fragile. The reluctance to use M&As as a tool in bank restructuring and consolidation is part of the specific nature of the Japanese banking system.

3. Literature Review

The empirical research on Japanese banking is relatively rich in both quantitative and qualitative analyses. In the last two decades there have been a number of studies that analyze bank efficiency in Japan. As we discuss, Japanese banks have undergone more than a decade of different consolidation and restructuring processes as a consequence of the deep economic and banking crisis in the early 1990s. The recent studies focus on the link between NPLs and technical efficiency. The first published studies of Japanese banking, which include Fukuyama (1993, 1995), McKillop et al. (1996), Altunbas et al. (2000). Fukuyama (1993, 1995) argues that bank inefficiency was not caused by scale efficiency but predominantly by technical inefficiencies. Fukuyama (1995) shows that the economic crisis, when the asset bubble started to burst, had an impact on Japanese banks. However, he also points out that the impact on bank efficiency was different between City Banks and Regional Banks. McKillop et al. (1996) find that large Japanese banks can improve their efficiency by improving scale economies. Altunbas et al. (2000) also show that scale inefficiencies dominate X-inefficiencies within Japanese commercial banks.

The majority of studies of Japanese bank efficiency apply the DEA. Fukuyama and Weber (2005) adopt an indirect production approach to analyze indirect input allocative efficiency (or Luenberger output gain function) that is derived from the directional output distance function and the cost-constrained directional distance function. The study compares the output technical efficiency calculated relative to direct and indirect output possibility sets. It finds that on average indirect input allocative inefficiency increased from 1992 to 1997, and then declined in 1998, followed by greater inefficiency in 1999. A further study by Drake and Hall (2003) also applies the DEA to calculate technical and scale efficiency. The results reveal that City Banks do not fully utilize efficiency scale and those banks could not gain from reducing X-inefficiencies. A different methodological approach was introduced by Liu and Tone (2008). They developed a three-stage non-parametric approach to estimate bank efficiency during the period from 1997 to 2001. The results show a gradual increase in bank efficiency. Drake et al. (2009) apply a slacks-based measure to estimate bank efficiency during the period from 1995 to 2002. They also look at the differences between intermediation and production approaches, and the profit-based approach. Drake et al. (2009) reveal that different methodological approaches give different results.

The research studies on Japanese bank efficiency unambiguously show that unresolved or partial resolution of NPLs on bank balance sheets remain an important determinant of how to improve bank efficiency. In the last two decades there have been numerous studies which argue that NPLs caused the problem not only for banks but also that they are the main barrier to improving economic activities. Altunbas et al. (2000) find that the share of NPLs on Japanese banks' balance sheets negatively affect bank efficiency. Drake and Hall (2003) find that tackling the issue of NPLs is essential for improving bank efficiency. They show that the problem is particularly evident within the Regional Bank group. Watanabe (2007) shows a link between NPLs and the credit contraction in Japan in the late 1990s. Fukuyama and Weber (2008) also conclude that NPLs should be included in the studies on bank efficiency and cannot be ignored when carrying out efficiency analyses of Japanese banks. Barros et al. (2012) show that the inclusion of NPLs within the efficiency model provides bank managers and regulators with an additional dimension to their decision-making processes. Barros et al (2012) point out that Japanese banks still face problems with NPLs and that a further restructuring is needed.

Although there is anecdotal evidence about the negative impact of NPLs on Japanese bank efficiency, the current methodological research on bank efficiency with NPLs is still rather limited. The previous research on bank efficiency treated NPLs as covariates to estimate how they affect bank efficiency. For example, Mester (1993, 1996), Berger and De Young (1997), Uchida and Satake (2009) included NPLs as a proxy for asset quality. They find that NPLs have a negative impact on bank efficiency (Mester, 1993; Hughes and Mester, 1993). Berger and Mester (1997) propose the use of the ratio of NPLs to total loans as an environmental variable in their model. Their results support the hypothesis of so-called bad management that was introduced by Berger and De Young (1997). Resti (1998) uses a traditional DEA analysis to assess cost efficiency and technical efficiency of the post-merged Italian banks. The output variables try to deal with the issue of bad loans by using net of bad loans variable. Resti (1997, 1998) proposes an output variable – performing loans – that are defined as total loans minus non-performing loans. In addition, there is an additional variable that is calculated as the ratio of bad loans to total loans. This ratio is a proxy for measuring an Italian bank's risk.

However, the main drawback of those studies is the fact that they do not include NPLs directly in the production process. As we discuss in Section 4, banks may produce two types of loans (output). They can produce loans that consist of the good loans that are jointly produced with bad loans. The second type of loans that banks underwrite (produce) are only good quality loans. Färe et al. (1989) show that it is appropriate to analyze desirable outputs (loans) and undesirable loans (bad loans) asymmetrically. We need to penalize firms for producing undesirable outputs and credit the desirable outputs in the model. The proxy for bad (problem) loans is loan-loss provision, which is introduced in the DEA model of Charnes et al. (1990) as an indicator of risks in banking operation. It is emphasized that although in the DEA model uncontrollable inputs are held fixed, in effect, this is at a bank's discretion, as the management board is able to adjust the level of provision. Berg et al. (1992) introduce a model that captures NPLs directly in the bank production process using DEA. Chang (1999) uses a non-parametric approach to assess bank efficiency. But he extends the model by including risk to evaluate technical efficiencies of rural financial institutions in Taiwan. The proposed methodological framework treats risk as a joint but undesirable output. Chang (1999) uses three categories of risk indicators (non-performing loans, allowance for loan losses, and risky assets) and finds that regulations on controlling risky assets and loan loss reserves are effective, although regulation is more problematic than controlling loan quality. Park and Weber (2006) examine how NPLs should be treated in the production process. They show that NPLs need to be considered as a bank undesirable output. Studies published by Fukuyama and Weber, (2008, 2010); Akther, Fukuyama and Weber (2013); Barros et al. (2012), Fujii et al. (2014) further expand this strand of research on bank efficiency. Fukuyama and Weber (2008) argue that problem loans are a by-product of loan production, and appear only after a loan has been made. Therefore, bad loans should be treated as an undesirable output. The most recent study by Fukuyama and Weber (2015a) develops a dynamic two-stage network model of the production process. In the first stage of production banks deploy three desirable inputs (labour, physical capital, and equity capital) to produce two intermediate outputs-deposits and other raised funds, they also incorporate NPL into the model. The dynamic framework allows resources to be allocated over time to maximize the production of desirable outputs and simultaneously minimize the production of undesirable outputs. A further study by Fukuyama and Weber (2015b) proposes a dynamic network Luenberger productivity indicator for Japanese banks. Their dynamic approach also includes NPLs.

In relation to the present study, the methods presented by Fukuyama and Weber (2015a) and Fukuyama and Weber (2015b) have two distinct characteristics: (1) a production (input-output) framework in which information on exogenously determined prices is not required; and (2) a dynamic framework with carryovers. The present bank revenue function requires information on the exogenously determined prices of good and bad outputs. This information allows us to estimate revenue (in)efficiency and the corresponding decompositions into (in)efficiency components. Hence, this study requires additional data information but it provides an output target vector consistent with revenue maximization.

Regarding dynamics, Fukuyama and Weber (2015a,b) constructed dynamic performance measures with the use of additional information on carryover assets, which need to be carefully defined. The present study does not require carryovers because it is a static (non-dynamic) method. In any dynamic specification the length of time needs to be determined beforehand, but it is impractical to cover the lifetime of the asset (Emrouznejad and Thanassoulis 2005). The timescale affects the optimal path and efficiency estimates, and the present study avoids this limitation by the use of a static setting.

It is possible to extend our model into a productivity change setting with the revenue function, in which case the technologies should be price dependent. The results based on production and price-dependent technology specifications can be different and hence such an extension with a comparison of various methods will form the basis for interesting future research.

Fethi and Pasiouras (2010) show in their survey that the majority of empirical research studies on bank efficiency that use the DEA framework focus on bank technical efficiency and to some extent on cost efficiency. There is a research gap in studies that examine profit/revenue efficiency with DEA. The reasons behind this are listed as the shortage of a good quality of output prices. A further argument is that the breakdown of profit efficiency into technical efficiency and allocative efficiency is not a trivial problem. In addition, there is an extensive literature that tries to justify an appropriate selection of inputs/outputs in the production process. Following Berger and Humprey’s (1997) study, most empirical studies apply intermediation or a production approach to estimate bank efficiency. Further, Fethi and Pasourias (2010) provide evidence that the intermediation approach is the most used method in empirical research. One of the key issues is how to identify inputs/outputs correctly. In particular, what is the role of deposits in the production process? Drake et al. (2006, 2009) propose a modified approach called the profit-oriented approach. In this approach, revenue components are treated as outputs and cost components are defined as inputs. Most recent studies then introduce a two-stage approach. This approach overcomes the problem of the identification of deposits either as inputs or outputs. Studies by Fukuyama and Weber (2010), Fukuyama and Matousek (2011) and Holod and Lewis (2011) introduce a two-stage network system that treats deposits as an intermediate product in the bank production process.

Based on this brief literature review, we have clearly identified gaps in the literature.

First, the current studies that include NPLs directly within the model do not link NPLs with bank revenue and bank reserves. This has severe limitations since banks adjust their risk strategy to meet potential revenue and built up reserves. Second, the two-stage model overcomes the specific problems with the identification of deposits in the production process, as discussed by Fukuyama and Matousek (2011). Finally, there is a restricted number of studies that actually look at revenue efficiency in Japanese banks. Such an analysis undoubtedly contributes to policy decision debates regarding the impact of low revenue in the Regional Bank sector.

4. Methodology

4.1. Black-box Technology and Revenue Function

To provide the basics of black-box production technology, consider a production technology with an *N*-dimensional input vector $x \in \Re_+^N$, *M*-dimensional good output vector $y \in \Re_+^M$ and *L*-dimensional bad output vector $b \in \Re_+^L$. The bank production possibility set T is denoted by:

$$T = \left\{ (x, y, b) \in \Re_+^N \times \Re_+^M \times \Re_+^L \mid (y, b) \text{ can be produced from } x \right\} \tag{1}$$

Alternatively, *T* in (1) can be expressed as the output possibility correspondence $P : \Re_+^N \to P(x)$, denoted as:

$$P(x) = \left\{ (y, b) \in \Re_+^M \times \Re_+^L \mid (x, y, b) \in T \right\}, \quad x \in \Re_+^N \tag{2}$$

where $P(x)$, called output possibility set, represents all good and bad output vectors that can be produced from a given level of inputs $x \in \Re_+^N$. Hence, $(x, y) \in T \iff y \in P(x)$. We assume strong disposability of inputs (SD^x) and strong monotonicity of good outputs (SD^y):

$$\begin{array}{ll} \mathrm{SD}^x: & x' \geq x \in \Re_+^N \quad \Rightarrow \quad P(x) \subseteq P(x') \subseteq \Re_+^M \times \Re_+^L \\ \mathrm{SD}^y: & y \geq y' \in \Re_+^M \text{ and } (y,b) \in P(x) \subseteq \Re_+^M \times \Re_+^L \text{ for } x \in \Re_+^N \quad \Rightarrow \quad (y',b) \in P(x) \end{array} . \quad (3)$$

The SD^x property states that if the exogenous input vector is increased from x to x', then the original bank output possibility set $P(x)$ will be contained in the resulting bank output possibility set $P(x')$. The SD^y property states that if the good output vector is decreased from y to y', then y' can still be produced for a given level of exogenous inputs and bad outputs.

Now we distinguish between two types of good outputs in relation to bad outputs. One type consists of the good outputs jointly produced with bad outputs and the other is the good outputs whose production is not jointly a weak disposable with bad outputs. We segregate, with respect to b, the good output vector y into two types: (1) the good output vector $\dot{y} \in \Re_+^{\dot{M}}$ that causes production of bad outputs b; and (2) the good output vector $\ddot{y} \in \Re_+^{\ddot{M}}$ that does not, where $M = \dot{M} + \ddot{M}$. That is, $y = (\dot{y}, \ddot{y}) \in \Re_+^{\dot{M}} \times \Re_+^{\ddot{M}}$. Following Shephard (1970) and Färe, Grosskopf and Weber (2006), we assume that $\dot{y}$ and b are jointly weakly disposable[2]:

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[2] This study differs from Fukuyama and Weber (2015a) since our focus is on NPLs with the use of the bank revenue function. The unique feature of our methodology is that we estimate the price of NPLs as the ratio of reserves for possible loan losses to NPLs. These estimates allow us to gauge the bank revenue function which differs from the standard revenue function. From a methodological point of

$$\text{JWD}: \ (\dot{y}, \ddot{y}, b) \in P(x) \subseteq \Re_{+}^{\dot{M}} \times \Re_{+}^{\ddot{M}} \times \Re_{+}^{L} \text{ for } x \in \Re_{+}^{N} \text{ and } 0 \le \theta \le 1 \\ \Rightarrow (\theta \dot{y}, \ddot{y}, \theta b) \in P(x) \tag{4}$$

The JWD property states that proportionally reduced connected good outputs and bad outputs are technologically feasible given a fixed level of exogenous inputs and non-joint good outputs.

Relative to (2), the bank directional output distance function $\vec{D}_O(x,y,b;g)$ = $\vec{D}_O(x,\dot{y},\ddot{y},b;g^{\dot{y}},g^{\ddot{y}},g^{b})$ is denoted by:

$$\vec{D}_O(x,\dot{y},\ddot{y},b;g) = \max\left\{\beta \,\middle|\, (\dot{y}+\beta g^{\dot{y}}, \ddot{y}+\beta g^{\ddot{y}}, b-\beta g^{b}) \in P(x)\right\} \tag{5}$$

where $g^{\dot{y}} = (g_1^{\dot{y}}, g_2^{\dot{y}},...,g_{\dot{M}}^{\dot{y}}) \in \Re_{+}^{\dot{M}}$, $g^{\ddot{y}} = (g_1^{\ddot{y}}, g_2^{\ddot{y}},...,g_{\ddot{M}}^{\ddot{y}}) \in \Re_{+}^{\ddot{M}}$ and $g^{b} = (g_1^{b}, g_2^{b},...,g_{L}^{b}) \in \Re_{+}^{L}$ are directional vectors for good and bad outputs, respectively. Note that $g = \left(g^{\dot{y}}, g^{\ddot{y}}, g^{b}\right)$. Using (1) as the production technology, the bank revenue function is denoted as:[3]

$$R(x,\dot{p},\ddot{p},v) = \min_{\dot{y},\ddot{y},b}\left\{\dot{p}\dot{y}+\ddot{p}\ddot{y}-vb \,\middle|\, (\dot{y},\ddot{y},\mathrm{b}) \in P(x)\right\}, \quad \text{or} \\ R(x,p,v) = \min_{y,b}\left\{py-vb \,\middle|\, (y,b) \in P(x)\right\} \tag{6}$$

where $p = (\dot{p}_1, \dot{p}_2,...,\dot{p}_{\dot{M}}; \ddot{p}_1, \ddot{p}_2,...,\ddot{p}_{\ddot{M}}) \in \Re_{++}^{\dot{M}} \times \Re_{++}^{\ddot{M}}$ is a positive good output price vector and $v \in \Re_{++}^{L}$ is a positive bad output price vector. The inner products, $\dot{p}\dot{y}$ and $\ddot{p}\ddot{y}$, represent revenues from joint and non-joint good outputs, respectively. The inner product vb represents the cost associated to bad outputs. The objective $\dot{p}\dot{y}+\ddot{p}\ddot{y}-vb$ of (6) can be interpreted as an effective net benefit or revenue. The bank revenue function is a bank revenue extension of Färe, Grosskopf and Weber's (2006) environmental revenue function,

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view, our bank revenue function has the following characteristics: good outputs linked or unlinked to NPLs as discussed by Epure and Lafuente (2015).

[3] Since $p = (\dot{p}, \ddot{p})$, we have $R(x,\dot{p},\ddot{p},v) = R(x,p,v)$.

which does not distinguish the connected and unconnected outputs in their definition.

Similar to the dual relationship established by Färe, Grosskopf and Weber (2006), the bank directional output distance functions (5) and (6) can be recovered from each other as follows:

$$\begin{aligned} R(x,\dot{p},\ddot{p},v) &= \max_{\dot{y},\ddot{y},b}\left\{\dot{p}\dot{y}+\ddot{p}\ddot{y}-vb \,\middle|\, \vec{D}_O(x,\dot{y},\ddot{y},b;g)\geq 0\right\} \\ \vec{D}_O(x,\dot{y},\ddot{y},b;g) &= \min_{\dot{p},\ddot{p},v}\left\{\frac{R(x_o,\dot{p},\ddot{p},v)-\left(\dot{p}\dot{y}+\ddot{p}\ddot{y}-vb\right)}{\dot{p}g^{\dot{y}}+\ddot{p}g^{\ddot{y}}+vg^{b}}\right\} \end{aligned} \tag{7}$$

Equation (7) yields

$$\vec{D}_O(x,\dot{y},\ddot{y},b;g)\leq\frac{R(x_o,\dot{p},\ddot{p},v)-\left(\dot{p}\dot{y}+\ddot{p}\ddot{y}-vb\right)}{\dot{p}g^{\dot{y}}+\ddot{p}g^{\ddot{y}}+vg^{b}} \tag{8}$$

which becomes the basis of our Nerlovian efficiency decompositions that are presented in the next section.

4.2 Non-parametric Two-stage Network Technology and Revenue Function

In this section we develop a non-parametric or DEA two-stage network bank technology framework, where the term 'two-stage network bank technology' shows that all outputs of a bank's first stage enter into a second stage. Assume that there are J banks, Bank_j $(j=1,\ldots,J)$ with N exogenous inputs, $M=\dot{M}+\ddot{M}$ final good outputs, and Q intermediate products. Define the observed amounts of exogenous inputs, joint good outputs, non-joint good outputs, bad outputs and intermediate products of Bank_j by $x_{nj}>0$ $\left(n=1,\ldots,N\right)$, $\dot{y}_{\dot{m}j}>0$ $\left(\dot{m}=1,\ldots,\dot{M}\right)$, $\ddot{y}_{\ddot{m}j}>0$ $\left(\ddot{m}=1,\ldots,\ddot{M}\right)$, $b_{hj}>0$ $\left(h=1,\ldots,H\right)$ and $z_{qj}>0$ $\left(q=1,\ldots,Q\right)$, respectively. Define the intensity vectors for the two stages as $\lambda^1=(\lambda_1^1,\ldots,\lambda_J^1)\in\Re_+^J$ and $\lambda^2=(\lambda_1^2,\ldots,\lambda_J^2)\in\Re_+^J$ for the purpose of taking into account the two-stage structure in a non-parametric DEA framework (Figure 1).

The stage one technology is represented by:

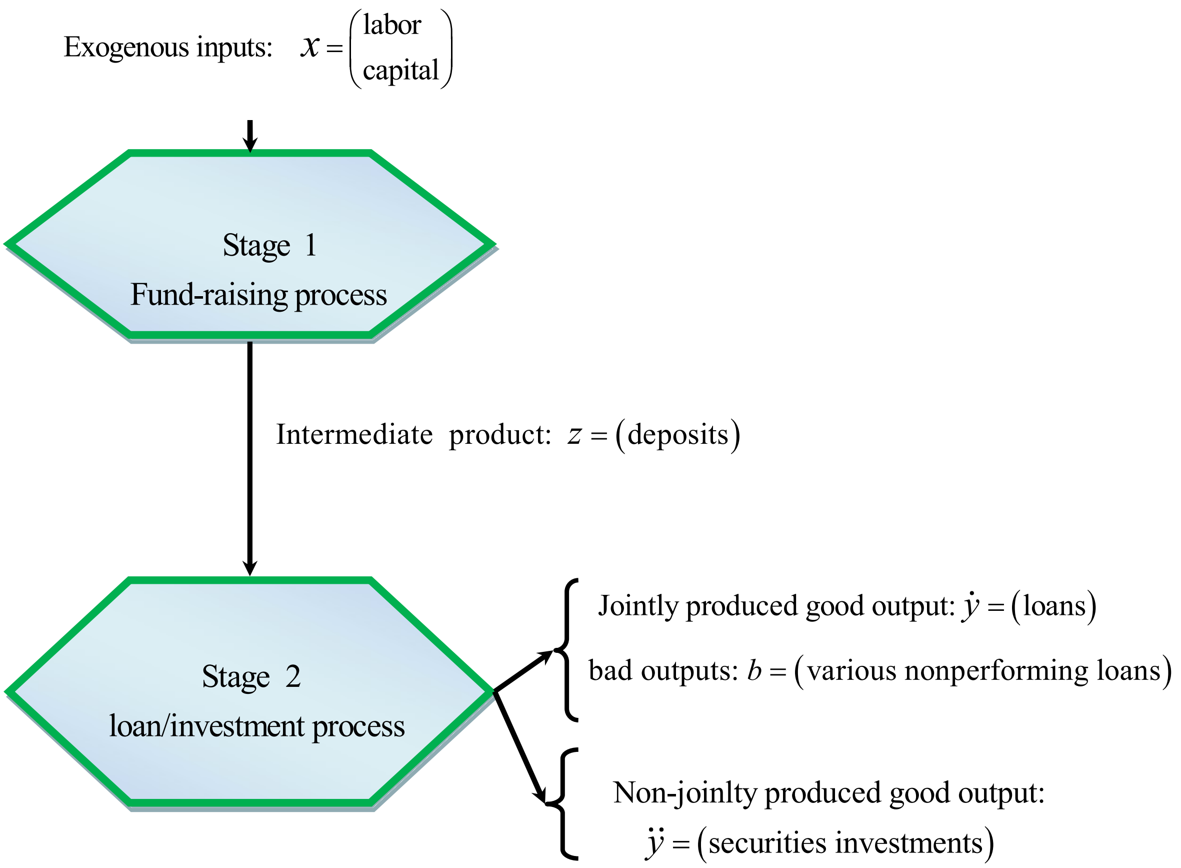
$$T^1 = \left\{ (x, z) \;\middle|\; x_n \geq \sum_{j=1}^{J} x_{nj}\lambda_j^1 \;\; (\forall n),\; \sum_{j=1}^{J} z_{qj}\lambda_j^1 \geq z_q \;\; (\forall q),\; \sum_{j=1}^{J} \lambda_j^1 = 1,\;\; \lambda_j^1 \geq 0 \;\; (\forall j) \right\} \tag{9}$$

and stage 2 technology by:

$$T^2 = \left\{ (z, \dot{y}, \ddot{y}, b) \;\middle|\; \begin{array}{l} \sum_{j=1}^{J} z_{qj}\lambda_j^2 \leq z_q \;\; (\forall q),\; \dot{y}_m \leq \sum_{j=1}^{J} \dot{y}_{\dot{m}j}\theta_j\lambda_j^2 \;\; (\forall \dot{m}),\, \ddot{y}_{\ddot{m}} \leq \sum_{j=1}^{J} \ddot{y}_{\ddot{m}j}\lambda_j^2 \;\; (\forall \ddot{m}) \\ b_l = \sum_{j=1}^{J} b_{lj}\theta_j\lambda_j^2 \;\; (\forall l),\; \sum_{j=1}^{J} \lambda_j^2 = 1,\; \lambda_j^2 \geq 0 \;\; (\forall j),\; 1 \geq \theta_j \geq 0 \;\; (\forall j). \end{array} \right\} \tag{10}$$

where each stage exhibits variable returns to scale. Note, that with the good outputs $\dot{y}$ are jointly produced with bad outputs *b*, which are implemented with the use of an abatement factor $\theta_j \in [0,1]$. See Kuosmanen (2005) for this abatement factor in a general setting. Note that Shephard (1974) and Färe and Grosskopf (2003, 2009) assumed $\theta_j = \theta \; (\forall j)$. Recently, Epure and Lafuente (2015) have distinguished between $\dot{y}$ and $\ddot{y}$ and developed a black-box DEA production model for a bank.

Figure 1. Two-stage Network Process for a Japanese Bank



The constraints associated with the intermediate product q are represented by $\sum_{j=1}^{J} z_{qj}\lambda_j^1 \geq z_q$ and $\sum_{j=1}^{J} z_{qj}\lambda_j^2 \leq z_q$ in Stage 1 and Stage 2, respectively, under the assumption of strong disposability. Combining these constraints, we can write $\sum_{j=1}^{J} z_{qj}\lambda_j^1 \geq z_q \geq \sum_{j=1}^{J} z_{qj}\lambda_j^2 \;\Leftrightarrow\; \sum_{j=1}^{J} z_{qj}\left(\lambda_j^1 - \lambda_j^2\right) \geq 0$ under the assumption that all the intermediate products are produced and consumed within a bank. Note that some of the intermediate products in Stage 1 can be wasted within a bank. The two-stage network production possibility set is given by:

$$NT = \left\{ (x, y, b) \;\middle|\; \begin{array}{l} x_n \geq \sum_{j=1}^{J} x_{nj}\lambda_j^1 \ (\forall n),\ \dot{y}_m \leq \sum_{j=1}^{J} \dot{y}_{\dot{m}j}\theta_j\lambda_j^2 \ (\forall \dot{m}),\ \ddot{y}_{\ddot{m}} \leq \sum_{j=1}^{J} \ddot{y}_{\ddot{m}j}\lambda_j^2 \ (\forall \ddot{m}), \\ b_l = \sum_{j=1}^{J} b_{lj}\theta_j\lambda_j^2 \ (\forall l),\ \sum_{j=1}^{J} z_{qj}\left(\lambda_j^1 - \lambda_j^2\right) \geq 0,\ \sum_{j=1}^{J} \lambda_j^1 = 1,\ \sum_{j=1}^{J} \lambda_j^2 = 1, \\ \lambda_j^1 \geq 0,\ \lambda_j^2 \geq 0 \ (\forall j),\ 1 \geq \theta_j \geq 0 \ (\forall j). \end{array} \right\} \quad (11)$$

Relative to (11), the directional bank output distance function for Bank_o is denoted as:

$$N\vec{D}\left(x_o, \dot{y}_o, \ddot{y}_o, b_o; g\right) = \max \left\{ \beta \;\middle|\; \begin{array}{l} x_{no} \geq \sum_{j=1}^{J} x_{nj}\lambda_j^1 \ (\forall n),\ \sum_{j=1}^{J} z_{qj}\left(\lambda_j^1 - \lambda_j^2\right) \geq 0, \\ \dot{y}_{\dot{m}o} + \beta g_{\dot{m}}^{\dot{y}} \leq \sum_{j=1}^{J} \dot{y}_{\dot{m}j}\theta_j\lambda_j^2 \ (\forall \dot{m}), \\ \ddot{y}_{\ddot{m}o} + \beta g_{\ddot{m}}^{\ddot{y}} \leq \sum_{j=1}^{J} \ddot{y}_{\ddot{m}j}\lambda_j^2 \ (\forall \ddot{m}), \\ b_{lo} - \beta g_l^b = \sum_{j=1}^{J} b_{lj}\theta_j\lambda_j^2 \ (\forall l),\ \sum_{j=1}^{J} \lambda_j^1 = 1,\ \sum_{j=1}^{J} \lambda_j^2 = 1, \\ \lambda_j^1 \geq 0,\ \lambda_j^2 \geq 0 \ (\forall j),\ 1 \geq \theta_j \geq 0 \ (\forall j),\ \beta : \mathit{free} \end{array} \right\} \quad (12)$$

where $g_{\dot{m}}^{\dot{y}}\left(\forall \dot{m}\right)$, $g_{\ddot{m}}^{\ddot{y}}\left(\forall \ddot{m}\right)$ and $g_l^b\left(\forall l\right)$ represent the inefficiency measurement directions for linked outputs, unlinked outputs and bad outputs, respectively. Since (12) is a non-linear programme, we transform it into a linear programme by Kuosmanen's (2005) transformation procedure. That is, setting $\Lambda_j^1 = \lambda_j^1 \ (\forall j)$, $\gamma_j = \left(1 - \theta_j\right)\lambda_j^2 \ (\forall j)$ and $\Lambda_j^2 = \theta_j\lambda_j^2 \ (\forall j)$, Equation (12) can be expressed as:

$$N\vec{D}\left(x_o,\dot{y}_o,\ddot{y}_o,b_o;g\right)=\max\left\{\beta\;\middle|\;\begin{array}{l} x_{no}\geq\sum_{j=1}^{J}x_{nj}\Lambda_j^1\;(\forall n),\;\sum_{j=1}^{J}z_{qj}\left(\Lambda_j^1-\Lambda_j^2-\gamma_j\right)\geq 0,\\ \dot{y}_{\dot{m}o}+\beta g_{\dot{m}}^{\dot{y}}\leq\sum_{j=1}^{J}\dot{y}_{\dot{m}j}\Lambda_j^2\;(\forall\dot{m}),\\ \ddot{y}_{\ddot{m}o}+\beta g_{\ddot{m}}^{\ddot{y}}\leq\sum_{j=1}^{J}\ddot{y}_{\ddot{m}j}\left(\Lambda_j^2+\gamma_j\right)\;(\forall\ddot{m}),\\ b_{lo}-\beta g_l^b=\sum_{j=1}^{J}b_{lj}\Lambda_j^2\;(\forall l),\;\sum_{j=1}^{J}\Lambda_j^1=1,\;\sum_{j=1}^{J}\left(\Lambda_j^2+\gamma_j\right)=1,\\ \Lambda_j^1\geq 0,\;\Lambda_j^2\geq 0\;(\forall j),\;\gamma_j\geq 0\;(\forall j),\beta:\mathit{free}\end{array}\right\}\quad(13)$$

Using (11) as the network technology, the network revenue function for Bank_o under assessment takes the form:

$$NR(x_o,\dot{p},\ddot{p},v)=\max\left\{\begin{array}{c}\sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}\dot{y}_{\dot{m}}\\ +\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}\ddot{y}_{\ddot{m}}\\ -\sum_{l=1}^{L}v_l b_l\end{array}\;\middle|\;\begin{array}{l} x_{no}\geq\sum_{j=1}^{J}x_{nj}\lambda_j^1\;(\forall n),\;\sum_{j=1}^{J}z_{qj}\left(\lambda_j^1-\lambda_j^2\right)\geq 0,\\ \dot{y}_{\dot{m}}\leq\sum_{j=1}^{J}\dot{y}_{\dot{m}j}\theta_j\lambda_j^2\;(\forall\dot{m}),\;\ddot{y}_{\ddot{m}}\leq\sum_{j=1}^{J}\ddot{y}_{\ddot{m}j}\lambda_j^2\;(\forall\ddot{m}),\\ b_l=\sum_{j=1}^{J}b_{lj}\theta_j\lambda_j^2\;(\forall l),\;\sum_{j=1}^{J}\lambda_j^1=1,\;\sum_{j=1}^{J}\lambda_j^2=1,\\ \lambda_j^1\geq 0,\;\lambda_j^2\geq 0\;(\forall j),\;1\geq\theta_j\geq 0\;(\forall j),\\ \dot{y}_{\dot{m}}\geq 0\;(\forall\dot{m}),\;\ddot{y}_{\ddot{m}}\geq 0\;(\forall\ddot{m}),\;b_l\geq 0\;(\forall l)\end{array}\right\}(14)$$

which can be thought of as a two-stage network DEA version of Färe, Grosskopf and Weber's (2006) parametric revenue function. The bank network revenue function $NR(x_o,\dot{p},\ddot{p},v)$ is also an extension of Fukuyama and Matousek's (2011) two-stage network cost function, which did not incorporate bad outputs. Similar to the transformation based on the directional bank output distance function, we set $\Lambda_j^1=\lambda_j^1\;(\forall j)$, $\gamma_j=\left(1-\theta_j\right)\lambda_j^2\;(\forall j)$ and $\Lambda_j^2=\theta_j\lambda_j^2\;(\forall j)$ to obtain a linear programme equivalent to (14) as

$$NR(x_o,\dot{p},\ddot{p},v)=\max\left\{\begin{array}{c|l} & x_{no}\geq\sum_{j=1}^{J}x_{nj}\Lambda_j^1\ \left(\forall n\right),\ \sum_{j=1}^{J}z_{qj}\left(\Lambda_j^1-\Lambda_j^2-\gamma_j\right)\geq 0, \\ \sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}\dot{y}_{\dot{m}} & \dot{y}_{\dot{m}}\leq\sum_{j=1}^{J}\dot{y}_{\dot{m}j}\Lambda_j^2\ \left(\forall\dot{m}\right),\ \ddot{y}_{\ddot{m}}\leq\sum_{j=1}^{J}\ddot{y}_{\ddot{m}j}\left(\Lambda_j^2+\gamma_j\right)\ \left(\forall\ddot{m}\right), \\ +\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}\ddot{y}_{\ddot{m}} & b_l=\sum_{j=1}^{J}b_{lj}\Lambda_j^2\ \left(\forall l\right),\ \sum_{j=1}^{J}\Lambda_j^1=1,\ \sum_{j=1}^{J}\left(\Lambda_j^2+\gamma_j\right)=1, \\ -\sum_{l=1}^{L}v_l b_l & \Lambda_j^1\geq 0,\ \Lambda_j^2\geq 0\ \left(\forall j\right),\ \gamma_j\geq 0\ \left(\forall j\right), \\ & \dot{y}_{\dot{m}}\geq 0\ \left(\forall\dot{m}\right),\ \ddot{y}_{\ddot{m}}\geq 0\ \left(\forall\ddot{m}\right),\ b_l\geq 0\ \left(\forall l\right) \end{array}\right\}. \quad (15)$$

Extending the duality results of Chambers, Chung and Färe (1999) and Färe, Grosskopf, Noh and Weber (2005), we can obtain the following inequality:

$$\frac{NR(x_o,\dot{p},\ddot{p},v)-\left(\sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}\dot{y}_{\dot{m}}+\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}\ddot{y}_{\ddot{m}}-\sum_{l=1}^{L}v_l b_l\right)}{\sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}g_{\dot{m}}^{\dot{y}}+\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}g_{\ddot{m}}^{\ddot{y}}+\sum_{l=1}^{L}v_l g_l^b}\geq N\vec{D}\left(x_o,\dot{y}_o,\ddot{y}_o,b_o;g\right) \quad (16)$$

The left-hand-side of (16) is a Nerlovian expression of a two-stage network version of revenue inefficiency (see (8)) and the right-hand side represents a two-stage network version of technical inefficiency. Defining the deviation between the left-hand side and the right-hand side of (16) as allocative inefficiency AE, we obtain the following decomposition:

$$\frac{NR(x_o,\dot{p},\ddot{p},v)-\left(\sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}\dot{y}_{\dot{m}}+\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}\ddot{y}_{\ddot{m}}-\sum_{l=1}^{L}v_l b_l\right)}{\sum_{\dot{m}=1}^{\dot{M}}\dot{p}_{\dot{m}}g_{\dot{m}}^{\dot{y}}+\sum_{\ddot{m}=1}^{\ddot{M}}\ddot{p}_{\ddot{m}}g_{\ddot{m}}^{\ddot{y}}+\sum_{l=1}^{L}v_l g_l^b}=N\vec{D}\left(x_o,\dot{y}_o,\ddot{y}_o,b_o;g\right)+\text{AIneff} \quad (17)$$

which states that normalized revenue inefficiency is broken down into directional output inefficiency and allocative inefficiency. The left-hand-side of (17) is a Nerlovian expression of revenue inefficiency.

5. Data and Empirical Results

The sample includes Regional Banks I and II that operated in Japan from 2001 to 2013. The source of our database is the Japanese Banks' Association (JBA). The database includes all operating banks and is more representative than data that are available from BankScope. The time period of our analysis is much longer than published by the previous research studies.

Empirical studies generally apply two approaches when measuring bank outputs and costs and these have been extensively discussed in Sealey and Lindley (1977), Berger and Humphrey (1997) and recently by Berger et al. (2007) and 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 transformers 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 apply here an innovative intermediation approach (Fukuyama and Matousek, 2011). In a bank context, we need to decide whether deposits (or raised funds) are an input or output because there is a controversy in the bank efficiency literature[4]. However, conventional efficiency analysis uses deposits either as an input or output. By contrast, the deposits are an output in the first stage of production and an input in the second stage in the two-stage network

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[4] Regarding the treatment of NPLs in efficiency analysis, in some banking efficiency literature NPLs are considered to be an input and performing loans an output. See Paradi et al. (2011). While Paradi et al.'s (2011) study considers bank branch efficiency performance measurement, the framework is also applicable to bank efficiency measurement.

model.

The input and output variables are in line with already established research on bank efficiency that uses DEA. In our study we apply the same definitions and variables as used by Fukuyama and Matousek (2011). The input vector includes the number of employees[5] and the second input is capital, which is defined as the book value of premises and fixed assets. In our model we include intermediate output that is represented by deposits. The output then includes loans and securities. Table 1 displays the list of all variables used in the model.

Table 1 Defined Inputs, Outputs and Prices

x_1	Labor	=Number of workers
x_2	Physical capital	= Premises and real estate
z_1	Intermediate product 1	=Deposits
$\dot{y}$	Performing loans (jointly produced good output) linked to NPLs	= Performing loans
$\ddot{y}$	Good output not linked to bads	= Securities investment
b	Bad output	= Nonperforming loans
$\dot{p}$	Price of $\dot{y}$	= (interest income) / $\dot{y}$
$\ddot{p}$	Price of $\ddot{y}$	= (interest income) / $\ddot{y}$
v	Price of b	= (Reserve for possible loan losses)/NPLs

We have also manually cleaned our dataset since some variables were missing. We deleted Bank of Nagasaki for September 2010, March 2011, September 2011, March 2012, September 2012 and March 2013 because it does not report the price of securities $\ddot{y}$ for these

[5] The number of employees for individual banks is available only on the Japanese webpage of JBA.

periods. We also deleted Bank of Ishikawa for the period September 2002 because x_1, b, reserves were not reported. Finally, we obtained variable labour (x_1) for Ishikawa Bank for September 2000 as the average of March 2000 and March 2001.

When we estimated eq. 13, some observations had zero optimal values for performing loans $\dot{y}$ and non-performing loans b, where $\dot{y}$ and b are singletons for our data. As an efficiency target, this is not acceptable because a commercial bank's main activity is lending. Therefore, we append the following in eq.13:

$$\dot{y} \geq \ddot{y}\,. \tag{18}$$

Examining our data set shows that all banks with the exception of the Tokyo Star Bank for September 2001 had results with performing loans greater than securities investments. Furthermore, Kansai Sawayaka Bank had $NR(x_o, \dot{p}, \ddot{p}, v) = \dot{y}^* = \ddot{y}^* = b^* = 0$ for March 2001. This is the only bank that shows such characteristics.

In the following part, we present the estimates of the model that we introduced in the previous section. As previously stated, the proposed two-stage network model captures a production process more comprehensively. In particular, we may quantify how banks have to change their business activities in order to maximize their revenue. Such an analysis provides more meaningful results than reporting standard efficiency levels.

Table 2 reports differences between optimal and actual levels of both outputs, non-performing loans and revenue. The term 'optimal' means that the optimal values are based on the bank revenue function with NPLs and are part of a bank's revenue. The introduced methodological framework gives an optimal amount of reserves for loan losses, which are the price of NPLs multiplied by the 'optimal' amount of NPLs derived from the bank revenue maximization.

We calculate these changes for individual years. This helps us to capture the dynamic behaviour of the observed banks. First, we report the results for both groups, i.e. Regional Banks I and II. The result presented shows that the banks, on average, operated close to the optimal level for the volume of loans (y1) and had only marginal room for expansion. In order to achieve an optimal level of loans, banks should have expanded their loans by 1 per cent and 4 per cent in 2001 and 2002, respectively. This is in contrast with the second output, securities, which are substantially below the optimal level. We can see that the banks could expand securities almost three times in the early 2000s. At the same time, the banks still faced a problem with NPLs. The average gap between optimal and actual levels of NPLs is estimated in 2000. The difference is -43 per cent. The output mix of y_1/y_2 has been reduced since 2005 because banks rapidly reduced lending activities. This had a positive effect on the volume of NPLs. However, these adjustments in banks' activities affected bank revenue when the gap between optimal and actually deteriorated. In 2012, bank revenue was 2.12 times lower than the optimal level. Our data indicates that banks benefited from the early restructuring policy implemented by the authorities in the early 2000s, see, for example, Montgomery and Shimizutani (2009), Hoshi and Kashyap (2010). That policy could have led to an improvement in the gap between optimal and actual that dropped in the following year to 1.44. Since then we can see again a gradual deepening between optimal and actual levels for revenue and both outputs. Our results show that the actual level of NPLs was lower than the optimal one. The gap was then gradually reduced and, from 2006, we can see that the actual volume of NPLs has been smaller than the optimal values, except for the years 2008 and 2009.

A further step in our analysis is to explore the differences between Regional Banks I and II. Although both groups conduct similar activities, we may expect that their efficiency levels differ. In particular, the restructuring process of Regional Banks II was not financially supported in the same way as Regional Banks I, because Regional Banks II had to cope with the accumulated loans by themselves.

We split our results into two groups. The first analysis concentrates on the period from 2001 to 2007, and the second covers the period from 2008 to 2013. Table 2 shows that Regional Banks I, on average, operated at almost an optimal level in terms of loans (y1) in 2001 and 2002. The gap between optimal and actual level in terms of loans was -10 per cent and 5 per cent in 2001 and 2002, respectively. This is similar to Regional Banks II, where the gap in the first two years of our analysis was 3 per cent and 11 per cent. We can also observe a gap between optimal and actual NPLs in the Regional Banks I segment. Regional Banks II show the gap of -0.41 and -0.44, respectively, between optimal and actual NPLs in 2001. It is further evident that both groups reported a large gap in the use of output y2 (securities). The gap is more pronounced in the Regional Banks II segment where the difference between optimal levels and actual levels of securities (y2) is almost 4.23 higher than in Regional Banks I. This finding can be partially explained by the fact that Regional Banks in general were historically more focused on lending activities compared to large City Banks. The results in the first years of our analysis also reflect the introduction of quantitative easing in Japan. This helped banks to get new funding for making loans but, on the other hand, it dried up their bonds and securities that were purchased by the Bank of Japan.

Table 2 Regional Banks (all) – Optimal vs Actual levels (% changes)

		opt-act(rev)	opt-act (y1)	opt-act(y2)	opt-act(bad)
2001	Average	3.93	-0.01	2.47	-0.43
	STD	19.54	0.36	2.48	0.34
2002	Average	5.61	0.04	2.82	-0.35
	STD	52.80	0.38	2.83	0.41
2003	Average	1.65	0.14	3.52	-0.27
	STD	59.73	0.41	3.85	0.47
2004	Average	0.62	0.12	2.92	-0.21
	STD	23.12	0.38	2.58	0.45
2005	Average	2.12	0.19	2.71	-0.20
	STD	21.17	0.38	2.41	0.38
2006	Average	1.44	0.11	2.34	-0.08
	STD	21.65	0.83	2.14	0.59
2007	Average	3.55	0.39	2.11	-0.10
	STD	12.02	0.46	1.70	0.37
2008	Average	2.35	0.29	2.48	0.06
	STD	17.57	0.39	2.15	0.37
2009	Average	1.88	0.23	1.70	0.45
	STD	16.63	0.45	1.70	0.50
2010	Average	1.27	0.28	1.77	-0.02
	STD	26.71	0.64	1.55	0.60
2011	Average	-0.12	0.53	1.67	0.50
	STD	38.15	0.47	2.09	0.12
2012	Average	3.50	0.47	2.09	0.12
	STD	12.18	0.61	2.03	0.61
2013	Average	3.33	0.47	2.28	0.19
	STD	8.47	0.56	2.02	0.53

Tables 3 and 4 indicate the successful reduction in the volume of NPLs by 2007. In addition, we observe from Tables 3 and 4 that bank revenues are quite different between Regional Banks I and II. It is obvious that bank revenues are well below an optimal level.

Although Regional Banks I performed relatively well, we observe that the gap between optimal and actual level was gradually narrowing until 2007. The banks operated only 27 per cent below estimated optimal level in 2007. Alternatively, the results for Regional Banks II indicate that these banks operated significantly below an optimal level in terms of bank revenues. This was particularly pronounced in the early 2000s when the gap reached the value of 3.61 in 2003. After this time we observe a gradual improvement in bank revenues and NPLs.

Table 3 Regional Banks I – Optimal vs Actual levels (% changes)

		opt-act(rev)	opt-act (y1)	opt-act(y2)	opt-act(bad)
2001	Average	0.60	-0.10	1.20	-0.41
	STD	14.27	0.35	0.97	0.38
2002	Average	0.78	0.05	1.36	-0.50
	STD	10.64	0.34	1.22	0.32
2003	Average	1.54	0.12	1.70	-0.43
	STD	21.89	0.38	1.66	0.41
2004	Average	-2.77	0.12	1.48	-0.40
	STD	21.80	0.37	1.32	0.39
2005	Average	-1.61	0.15	1.34	-0.36
	STD	21.73	0.33	1.22	0.38
2006	Average	-0.26	0.91	1.21	-0.16
	STD	28.85	1.28	1.18	0.73
2007	Average	2.38	0.32	1.21	-0.22
	STD	12.44	0.35	0.97	0.35
2008	Average	2.53	0.22	1.53	-0.05
	STD	5.79	0.33	1.08	0.33
2009	Average	3.53	0.23	1.26	-0.09
	STD	10.88	0.38	1.00	0.36
2010	Average	3.78	0.55	1.03	-0.14
	STD	17.65	1.14	1.02	0.50
2011	Average	3.34	0.32	1.11	-0.21
	STD	11.92	0.50	1.10	0.43
2012	Average	1.26	0.52	1.36	-0.01
	STD	6.66	0.57	1.62	0.50
2013	Average	2.01	0.40	1.73	0.11
	STD	2.16	0.45	2.04	0.50

Table 4 Regional Banks II – Optimal vs Actual levels (% changes)

		opt-act(rev)	opt-act (y1)	opt-act(y2)	opt-act(bad)
2001	Average	5.37	0.03	3.05	-0.44
	STD	21.38	0.36	2.71	0.33
2002	Average	-1.06	0.11	3.35	-0.29
	STD	26.75	0.37	3.07	0.43
2003	Average	1.62	0.24	4.23	-0.21
	STD	21.24	0.40	4.25	0.44
2004	Average	0.72	0.19	3.47	-0.14
	STD	21.08	0.35	2.74	0.44
2005	Average	3.61	0.27	3.25	-0.14
	STD	20.89	0.36	2.59	0.37
2006	Average	2.13	0.58	2.80	-0.04
	STD	18.12	0.76	2.28	0.53
2007	Average	2.82	0.45	2.47	-0.05
	STD	42.11	0.46	1.79	0.37
2008	Average	2.28	0.36	2.86	0.11
	STD	20.60	0.40	1.87	0.38
2009	Average	1.19	0.30	3.36	0.08
	STD	18.50	0.47	1.81	0.48
2010	Average	0.19	0.35	2.13	0.03
	STD	29.85	0.65	1.69	0.63
2011	Average	-1.66	0.32	2.28	-0.05
	STD	45.20	0.53	1.85	0.53
2012	Average	4.50	0.56	2.50	0.17
	STD	13.89	0.60	2.13	0.64
2013	Average	3.94	0.59	2.53	0.22
	STD	10.14	0.56	1.99	0.54

We also investigate how Regional Banks operated during the global financial crisis in reaction to the economic downturn. In the group of Regional Banks I we observe that the gap between the optimal and actual level of loans has rather improved compared to 2007. Although we see a gradual deterioration when the gap reached the value of 52 per cent and 40 per cent in 2012 and 2013. A similar pattern is observed in terms of securities (y_2) where we can clearly see an increase in 2013. Nevertheless banks manage to keep their NPLs well below an optimal level. We further observe that the proportion of held securities was rather marginal in the Regional Banks II group. So far we have discussed the estimated gap between optimal and actual levels of bank revenue, inputs and NPLs. In the following part we shed light on bank efficiency. As we discussed in our methodological section, we apply Nerlove's revenue inefficiency measure (NRI) that is further broken down into technical and allocative inefficiency. In Table 5 we report our results for the average value of NRI on a yearly basis and for both groups of banks, Regional Banks I and Regional Banks II. It is evident that the measured levels of NRI are relatively high, which indicates that Regional Banks operated below the optimal efficiency levels, although we observe an improvement in the Regional Banks I segment in the period from 2007 to 2011. In the case of Regional Banks I and II, there was an improvement particularly in 2009 and 2010. A further interesting finding is that the number of banks that show NRI higher than the average remains constant for Regional Banks I. There was only a marginal improvement in 2010, 2011 and 2013. In the Regional Banks II group, we also see the number of banks with NRI above average drops over the estimated period but this just reflects the lower number of Regional Banks II in the sample. In percentage terms there is no significant improvement.

Table 5 Nerlove's Inefficiency RB I and RBII

	RB I			RB II		
2001	NIE	Total	NIE>AVG	NIE	Total	NIE>AVG
Average	0.36	72	32	0.48	166	60
STD	0.21			0.36		
2002						
Average	0.48	64	27	0.52	172	79
STD	0.28			0.30		
2003						
Average	0.51	64	23	0.58	172	73
STD	0.29			0.30		
2004						
Average	0.47	63	22	0.55	165	67
STD	0.27			0.30		
2005						
Average	0.45	64	22	0.52	158	52
STD	0.34			0.28		
2006						
Average	0.41	64	26	0.50	159	69
STD	0.23			0.26		
2007						
Average	0.35	64	27	0.46	157	86
STD	0.19			0.25		

2008						
Average	0.37	63	24	0.52	154	72
STD	0.22			0.28		
2009						
Average	0.32	64	22	0.46	157	86
STD	0.20			0.24		
2010						
Average	0.31	64	22	0.43	148	76
STD	0.20			0.24		
2011						
Average	0.32	64	20	0.47	144	66
STD	0.20			0.26		
2012						
Average	0.39	64	25	0.55	144	44
STD	0.27			0.29		
2013						
Average	0.44	64	22	0.61	142	44
STD	0.37			0.36		

In Table 6 we break NRI down into technical inefficiency (TIE) and allocative inefficiency (AIE). We report that the main source of bank inefficiency is TIE in the segment of Regional Banks I (the number of banks that report TIE>AIE). TIE has gradually decreased over the analyzed period but we further observe a relatively difficult period since 2008. This may be the effect of the global financial crisis. Conversely, Regional Banks I report a gradual improvement of the analyzed period. Regional Banks II report rather opposite results. The largest number of banks show that the main source of their inefficiency is AIE. We observe that Regional Banks II improved their TIE until 2010. Then we observe a steep increase in TIE.

Table 6 Allocative Inefficiency (AIE) and Technical Inefficiency (TIE) and number of banks with AIE and number of banks with TIE

RB I	TIE	AIE	#AIE	#TIE	**RB II**	TIE	AIE	#AIE	#TIE
2001									
Average	0.23	0.13	26	44		0.22	0.26	97	60
STD	0.19	0.21	2eq			0.18	0.29		
2002									
Average	0.25	0.22	24	40		0.25	0.28	101	74
STD	0.20	0.28				0.19	0.17		
2003									
Average	0.26	0.24	28	36		0.26	0.32	111	61
STD	0.21	0.29				0.20	0.16		
2004									
Average	0.24	0.23	23	40		0.26	0.21	95	70
STD	0.18	0.30				0.19	0.30		
2005									
Average	0.25	0.20	23	41		0.25	0.27	95	63
STD	0.17	0.36				0.20	0.15		
2006									
Average	0.27	0.14	22	42		0.24	0.26	97	62

STD	0.20	0.25				0.20	0.16		
2007									
Average	0.22	0.13	21	43		0.22	0.24	103	54
STD	0.16	0.19				0.19	0.15		
2008									
Average	0.20	0.17	27	36		0.21	0.31	116	38
STD	0.14	0.19				0.18	0.20		
2009									
Average	0.17	0.32	22	42		0.20	0.26	101	52
STD	0.11	0.20				0.16	0.17		
2010									
Average	0.18	0.12	18	46		0.21	0.23	86	62
STD	0.13	0.19				0.17	0.15		
2011									
Average	0.19	0.12	19	45		0.20	0.26	91	53
STD	0.14	0.17				0.16	0.23		
2012									
Average	0.20	0.19	26	38		0.21	0.34	102	42
STD	0.14	0.26				0.16	0.22		
2013									
Average	0.17	0.26	38	26		0.21	0.40	111	32
STD	0.13	0.36				0.15	0.27		

Finally, we conducted a second stage regression analysis using the procedure developed by Chronopoulos et al. (2015) to identify the covariates of the Nerlovian revenue inefficiency. We briefly explain the two-stage regression analysis employed in this paper. Let $\hat{\theta}$ be an estimator of an unknown scalar parameter θ. Now we want to construct a two-sided confidence interval for θ. The $100(1-\alpha)\%$ basic bootstrap confidence interval with nominal coverage of $1-2\alpha$ is expressed as $\left[\hat{\theta}-\left(\hat{\theta}-\theta\right)_{1-\alpha}, \hat{\theta}-\left(\hat{\theta}-\theta\right)_{\alpha}\right]$, where $\left(\hat{\theta}-\theta\right)_{1-\alpha}$ is the $(1-\alpha)$-quantile of $\hat{\theta}-\theta$ and the left-hand and right-hand side terms in the brackets are lower and higher confidence bounds, respectively. The corresponding percentile confidence interval can be written as $\left[\hat{\theta}_{\alpha}, \hat{\theta}_{1-\alpha}\right]$, where $\hat{\theta}_{\alpha}$ is the α-quantile of $\hat{\theta}$. In this paper, we estimate the basic (rather than percentile) interval based on bootstrap, i.e., we estimate the following: $\left[\hat{\theta}^{*}-\left(\hat{\theta}^{*}-\theta\right)_{((1-\alpha)(B+1))}, \hat{\theta}^{*}-\left(\hat{\theta}^{*}-\theta\right)_{(\alpha(B+1))}\right]$, where B is the number of bootstraps and the subscripts in parentheses denote ordered values and $(1-\alpha)(B+1)$ is an integer. See Chronopoulos et al. (2015) for details.

The set of independent variables in our model includes: capitalization, which is defined as the ratio of total capital to assets and net interest margin (NIM) that is defined as net interest income to total loans and Industrial Index, Z-score, as a measurement of bank risk.[6] In addition we have a variable that measures the volume of bankrupt loans (BRL). We computed all the coefficients by using the proposed method. We also transformed the Nerlovian Revenue indicator (NR) into its adjusted indicator as[7] $adjNR = NR + 1$ so that the left-hand side of the regression is greater than, or equal to, one.

Table 7 Confidence Intervals: Efficiency Determinants

	Lower bound based on single bootstrap	Upper bound based on single bootstrap	Lower bound based on double bootstrap	Upper bound based on double bootstrap
(Intercept)	-0.469568564	1.373468476	0.84565149	1.167879794
Cap	-2.487593224	-1.348793457	-2.753389914	-2.753389914
NIM	-13.65430071	6.744571263	-7.051704043	-4.62213586
lnIndustrial.index	0.113158735	0.497840849	0.540162647	0.665990158

[6] Z-score is used as the determinants of bank risk-taking. See, for example, Lepetit and Strobel (2013).

[7] This condition is needed to use the dBoot.RData programme.

Z-score	-0.005139465	-0.003584962	-0.005566245	-0.005566245
lnBRL	-0.044387756	-0.012361133	-0.050634288	-0.050634288
Sigma	0.351725507	0.380552993	0.392106976	0.392106976

Table 7 presents for comparison reasons the confidence intervals of the coefficients of the effect of the exogenous (environmental) factors based on the standard single bootstrap procedure (see Simar and Wilson 2007) and double bootstrap procedure (see Chronopoulos et al. 2015). It is evident that in all cases the confidence intervals estimated using the single bootstrap procedure have a greater range compared to the ones estimated when applying the double bootstrap procedure. For the single bootstrap procedure, the lower interval is negative whereas the higher is positive. In fact as Chronopoulos et al. (2015, p. 661) suggest in cases where the sum of inputs and outputs are greater than 3 the convergence of the confidence intervals calculated with the single bootstrap procedure is non-monotonic, suggesting an increase in the coverage error. As a result, we adopt the confidence intervals calculated based on the double bootstrap procedure. The results suggest that all the signs of the coefficient are aligned with the related literature.

6. Conclusion

This paper contributes to current research on bank efficiency by introducing an advanced two-stage model to estimate bank revenue efficiency. The proposed model uniquely combines NPLs with the bank revenue function. The paper improves the established methodological concept of a two-stage model that has already been introduced in the bank efficiency literature (Fukuyama and Weber 2008, Fukuyama and Matousek 2011). The applied methodological approach allows us to compare optimal levels of revenue, NPLs and bank outputs with actual levels. Thus, we can identify banks that operate below their optimal capacity. The majority of studies on Japanese bank efficiency focus primarily on allocative efficiency. The paper goes further by implementing the concept of Nerlove's revenue indicator. The inclusion of NPLs in our model is justified by a number of recent studies, e.g., Assaf et al. (2013), Fujii et al. (2014), among others.

We show that Japanese Regional Banks have not achieved the optimal levels in their production processes. In terms of NPLs, it is evident that the gap between optimal levels and actual levels of NPLs have significantly decreased and became even positive from 2005 onwards. That reflects the restructuring process undertaken by the Regional Banks in the early 2000s when the banks' NPLs were written off. There is further evidence of a substantial gap between the optimal level and actual level of y_2 (securities and other earning assets). The results indicate that Regional Banks, and in particular Regional Banks II, should expand their activities in securities and other earning assets. Bank management should address this specific issue of underproduction. In terms of the output y_1 (loans) the bank can also expand their activities. But the reluctance of banks to expand their lending activities corresponds with the high levels of uncertainty about the financial stability of potential borrowers. Our analysis shows that Regional Banks I achieved suboptimal revenue. The peak gap between optimal and actual levels of bank revenue is 3.53 and 3.78 times lower than the optimal level in 2009 and 2010 respectively. This gap reduced in 2012 and 2013. We may assume that the estimated suboptimal revenue is not only because of banks' managerial policy and strategy, but also reflects economic uncertainties. The Regional Banks in particularly do not want to reduce the volume of newly created NPLs. We explore our results further in our analysis. We compare, for example, the differences between Regional Banks I and II in order to understand if there are some substantial differences. As previously mentioned, Regional Banks II are smaller and they did not receive substantial financial support from the Japanese Government during the consolidation process, as was the case with other banks. We confirm that both types of Regional Banks have recovered and created sufficient reserves to cope with potential NPLs. However, the gaps between optimal and actual revenue are substantially different between these two groups of banks. Regional Banks II show a much bigger difference. This might be explained further by their business activities and their limited exposure to other earning assets, compared to Regional Banks I.

An important contribution of the paper is the application of Nerlove's revenue indicator to analyze the revenue inefficiency of Regional Banks in Japan during the period from 2001 to 2013. Nerlove's inefficiency indicator allows us to disaggregate bank inefficiency into directional output inefficiency (technical efficiency) and allocative inefficiency. In addition we are able to identify whether revenue inefficiency is caused by technical or allocative inefficiency. We show that Regional Banks II exhibit relatively high degrees of AIE after 2011. The main source of bank inefficiency comes from allocative efficiency. These results indicate that bank managers have to improve the cost aspects of their operation. Based on the nature of Reginal Banks' activities, it is evident that banks have a large volume of fixed assets, particularly offices and branches. The optimalization of branches would also lead at the same time to further reduction of labour costs. It is well documented that the Japanese banks are quite labour cost inefficient, Barros et al. (2012). We also identify that the banks would benefit from higher exposure to other earning assets that could lead to revenue improvement. In addition, such an analysis can be easily applied to US and European banking, where banks are still affected by a large volume of NPLs.

An interesting direction for future research would be to examine the regional differences between Regional Banks I and II. The Japanese banks are still rather conservative in terms of credit expansion and further restructuring. Since Regional Banks operate within the prefectures we try to identify if there are geographical differences among the prefectures. This would also help to verify a hypothesis that banks' activities are determined by economic development across Japan. It would be interesting to confirm that the geographical location of those banks has an impact on their efficiency. One may expect that banks located in the prefectures with lower economic growth potential might show lower efficiency. Future data might also reveal current trends in the sector. So far the results show that banks are less efficient. This trend is probably caused by further economic instability that prevents banks from further expansion. As we show banks' outputs have potential for further growth. The suboptimal outputs thus have an impact on banks' revenues and might improve bank revenue and efficiency. Bank expansion, in terms of new loans and other earning assets, is also determined by the Bank of Japan and the use of its unconventional monetary policy tools. New data then could provide a deeper insight into the current trend about bank efficiency and revenue. Despite the fact that governments and central banks introduced a number of measures to restore economic growth, banks are rather reluctant to expand their business. We may, however, conclude that in terms of bank soundness that the banks have successfully consolidated and restructured their activities.

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