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Heterogeneous effect of the global financial crisis and the Great East Japan Earthquake on costs of Japanese banks

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A B S T R A C T

The effect of financial and economic ctarises depends on bank technology, which includes risk attitude and business model. The paper focuses on Japanese banking and examines how technology distinctions determined impact of the 2007–2009 global financial crisis and the economic recession that followed the Great East Japan Earthquake of 2011. Assuming that different types of technology correspond to different cost quantiles, we use panel data quantile regressions to establish a link between efficiency, economies of scale/scope and the effects of the two crises. The analysis reveals technological heterogeneity and shows that the impact of profitability, non-traditional activities and non-performing loans in the two crises differs between high-cost and low-cost banks. Finally, we contrast the business models and risk-taking behavior of Japanese and European banks.

1. Introduction

The way, in which financial and economic crises impact the banking sectors of a country, depends to a large extent on the capital structure, risk-taking behavior and business practices of its banks (Caprio and Honohan, 2014). A choice-theoretic structural approach, which treats a bank as a firm and assigns it a certain optimization problem, interprets these factors as major components of banking technology (Hughes and Mester, 2014). Differences in technology, linked to differences in risk and risk management, have determined how the EU banks respond to financial crises (Bertay et al., 2013; Koutsomanoli-Filippaki and Mamatzakis, 2011). Overall, the assessment of technological heterogeneity is essential for diversified regulation to support viability of the banking sector.

This paper focuses on Japan, where the financial system is mediated to very great extent by banks: banks hold a large share of the country's finances and bank deposits constitute almost half of household assets (Uchida and Udell, 2014). Banks are important intermediaries for enterprise financing and play a decisive role in cushioning economic shocks in Japan (Hoshi and Yasuda, 2015; Yamori et al., 2013). Until now assessment of the sustainability of Japanese banks in crises, the impact of consolidation and bank risk has been carried out using standardized or case-by-case approaches. For instance, government decisions on capital injections to banks during the global financial crisis were based on broadly stated profitability targets and the contents of stock underwriting, with careful examination of each application by the (Endo, 2013). We believe that considerations of technological heterogeneity would offer helpful additional guidance for policy measures.

Such heterogeneity, which has been formally shown for banks in the EU (Koutsomanoli-Filippaki and Mamatzakis, 2011; Behr, 2010), is likely to impact production of banks in Japan. Indeed, mean estimates point to a link between weak balance sheets and loans of Japanese banks (Hosono and Miyakawa, 2014), which indicates that managerial performance (determined by technology) is associated with bank outputs. Risk exposure of Japanese banks is related to growth of deposits, and lending supply is a nonlinear function of bank capital (Nishiyama et al., 2006; Tsuru, 2003). Finally, there are established relations between the total factor

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productivity or overall financial conditions of banks and investment outcomes in Japan (Miayakawa et al., 2011; Hosono and Masuda, 2005). Despite this, numerous analyses of banking costs in Japan focus on the mean estimates.[1]

We assume that different types of technology correspond to different cost quantiles, i.e bank technology has consequences for the ability to minimize costs (Koutsomanoli-Filippaki and Mamatzakis, 2011). The analysis exploits a conditional quantile regression approach, which does not extrapolate the mean tendency to the tails of the distribution and thereby avoids bias (Hendricks and Koenker, 1992; Koenker and Bassett, 1978). Overall, quantile regressions provide more robust estimates than the classic approaches, which model optimal technology with non-parametric or parametric frontier methods (Bernini et al., 2004).[2] Moreover, linear quantile regressions have a property of equivalence to any monotonically increasing transformation, which is a useful feature for estimating log-linearized functions and inefficiency residuals.[3] Statistically different values of the coefficients for banking variables and annual effects, obtained in regressions for low-cost and high-cost quantiles, would indicate heterogeneous impact of the crises for different levels of banking technologies (Koenker, 2005).

The contribution of this paper is threefold. The paper is an application of a quantile regression approach for measuring longitudinal costs and efficiency in banking and, in particular, in the Japanese banking industry. Secondly, we link the 2007–2009 global financial crisis and the 2011 Great East Japan Earthquake with banking costs, focusing on the significance of bank and macro economic variables, as well as the time period corresponding to each of the crises, across various quantiles of the cost function. Finally, using a second-stage sensitivity analysis, the paper ties bank risk and heterogeneity to the cost function. For this purpose, we examine the association between cost inefficiency, economies of scale/scope for different quantiles and a range of risk variables.

The novelty of our findings is the establishment of technological heterogeneity in Japanese banking: results of the statistical tests show that there is a more efficient production path (low-cost quantiles) and a less efficient production path (high-cost quantiles). The technology distinction is particularly reflected in different relationships between costs, on the one hand, and, on the other hand, bank business model (proxied by number of branches and index of product diversity), risk-taking behavior (for instance, equity capital), and regional environment (loans in gross regional product). Business growth from scale economies has a different relationship to profitability, credit risk (liquidity or loan loss provisions) and business model (e.g. proxied by the securities-to-assets ratio) at banks in each technological group (See a qualitative summary of our findings in Table A1 in the Appendices). Technological heterogeneity may explain the different effects of the global financial crisis and the post-earthquake economic recession, which we find at high-cost and low-cost Japanese banks. For instance, profitability (measured by net interest margin) played a bigger role in supporting business growth during the financial crisis and the post-earthquake recession at high-cost banks than at low-cost banks.

The technological heterogeneity may be linked to managerial opportunities for cost-efficient production and quality of capital (Beccalli et al., 2015; Hosono and Miyakawa, 2014). Technology differences may also be associated with the “skimming hypothesis”, when cost efficiency is achieved through less stringent loan monitoring and fewer resources, spent on credit underwriting (Koutsomanoli-Filippaki and Mamatzakis, 2011). The phenomenon was observed during the global financial crisis in Japan, when banks granted loans to small- and medium-sized enterprises.

In contrast with U.S. and European banks, we find that in Japan higher return-on-equity is related to higher cost inefficiencies. Arguably, Japanese banks play a social role in the economy and have a more conservative business model, which is crucial for depositor sentiments. Therefore, the traditional banking model helped to overcome the global financial crisis in Japan (Kamikawa, 2013).

Our study builds upon three streams in the preceding literature. Firstly, we exploit measures of economies of scale and scope under multi-product technology, developed by Panzar and Willig (1977). We use duality conditions of Shephard (1970) and cost functions with risk-taking behavior, proposed by Hughes et al. (1996); Hughes and Mester (1998, 2013) and recently applied by Beccalli et al. (2015). Secondly, we follow the approaches in productivity analysis, given the special features of Japanese banking. Thirdly, there is enormous research on classic parametric and non-parametric efficiency measurement in banking, inspired by Farrell (1957);[4] as well as a gradually developing methodology of quantile regressions, which provides for an ordered set of technological relationships and is increasingly used in banking (Mamatzakis et al., 2012; Koutsomanoli-Filippaki and Mamatzakis, 2011; Behr, 2010; Koenker, 2004).

To the best of our knowledge, applications of quantile regressions in banking are limited to simulation analysis and cross-section estimates (Behr, 2010). Our contribution consists in using the (Canay, 2011) fixed effects panel data model and modifying the (Parente and Santos Silva, 2016) approach for clustered standard errors in the longitudinal data with quantile regressions. It should be noted that some literature incorporates quantile regression approaches into estimation of parametric and nonparametric efficiency (Koutsomanoli-Filippaki and Mamatzakis, 2011; Wheelock and Wilson, 2009; Aragon et al., 2005; Cazals et al., 2002). However, exploiting quantile regressions in such analyses does not eliminate limitations of the parametric/nonparametric methods.

The remainder of the paper is organized as follows. Section 2 outlines the structure of the Japanese banking system and describes how the global financial crises and the post-earthquake economic recession played out in Japan. Section 3 specifies quantile regressions and the cost function. The data and variables are given in Section 4. Section 5 discusses the estimates across quantiles. Conclusions are summarized in the light of international comparison and policy issues in Section 6.

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[1] See review of specifications and outline of estimates in Tables C1–C2 the Appendices.

[2] Nonparametric methods rely on linear optimization techniques to construct a hull of observations (Charnes et al., 1978) and, therefore, regard the observations on the constructed frontier as fully efficient, do not account for measurement error, are sensitive to outliers and require large sample size for estimations. An alternative parametric method, that of stochastic frontier analysis, imposes distributional or other assumptions on the error term (Aigner et al., 1977). See the debate in the *Journal of Econometrics* 1980: 13(1).

[3] In this paper we exploit the fact that $Q_\tau(\ln y|x) = \ln(Q_\tau(y|x))$.

[4] See reviews in Paradi and Zhu (2013), Paradi et al. (2011), Thanassoulis et al. (2008) and Greene (2008).

2. Background on Japanese banking

2.1. Major segments

The Japanese banking system consists of national banks ("city banks"), regional banks, trust banks, long-term credit banks, as well as credit cooperatives, foreign banks and postal savings bank. The segmentation is historically related to bank-firm relationships, so that larger banks provided loans to larger, and (presumably), more reputable and transparent companies (Uchida et al., 2007). Moreover, the segmentation was enforced by the government for ease of regulation, so the ban on consolidation across commercial banking, trust banking, long-term credit banking, securities and insurance was abolished only by the 1997 revision of the Antimonopoly Law (Harada and Ito, 2008). While competition on deposit markets is not constrained by bank category, lending may still be segmented despite bank deregulation: large banks have entered the market for loans to small- and medium-sized enterprises (SMEs), but still take second place in this business compared with regional/second-tier banks (Uchida et al., 2007). The distinct roles of banks in each bank charter in Japan is similar to the industry equilibrium in the U.S., where larger and smaller banks focus on different types of business, obeying the predictions of economic theory on the comparative advantages of large and small institutions (DeYoung, 2014).

Japan's city banks are the largest in size, having nationwide and overseas branches. City banks hold half of private loans and deposits, and constitute a major group in the Japanese banking industry (Hoshi and Kashyap, 2004). Accordingly, city banks are supported by the regulating authorities based on a "too-big-to-fail" logic. This explains a series of mergers and acquisitions, with a sharp decline in the number of these institutions (from 13 till 5) in 1990–2013 (Hosono et al., 2007, Hoshi and Kashyap, 2004).[5]

Regional banks include regional banks proper and second-tier regional banks. Both types of banks usually operate domestically and in a specific prefecture, although this is not a hard and fast rule. The banks in the second category are former regional mutual banks, which provide financing to SMEs. These mutual banks were transformed in 1989 and became subject to the Banking Act (Uchida et al., 2007). While the number of regional banks has remained stable over the last two decades, consolidation of second-tier regional banks has reduced their number from 68 in 1990 to 42 in 2010. The second-tier banks are still focused on SME financing, which may explain their larger share of non-performing loans compared with other bank charters (Financial Services Agency, 2015b).

Trust banks prioritize trust services but may also supply other banking products, for example money and loan trusts, which may be regarded as medium-term/long-term time deposits (Trust Companies Association of Japan, 2015; Uchida and Udell, 2014). There were no more that three long-term credit banks, still existing in 2000–2006,[6] and they offered long-term corporate debenture and supplemented short-term lending by other banks (Uchida and Udell, 2014).

The different types of Japanese banks (city, regional, long-term credit and trust institutions) are all subject to the Banking Act and can all offer all types of products, although they may specialize. Accordingly, in this paper we pool data across banks following the common approach in the productivity analysis of Japanese banking (Harimaya, 2008; Glass et al., 1998; McKillop et al., 1996; Tachibanaki et al., 1991; Kasuya, 1986).[7] Such analysis assumes that all types of banks have similar technology. We cluster standard errors in the fixed effects model at the groupwise-level on the basis of bank charter in order to account for bank specialization.

2.2. Regulators

The main bodies responsible for regulation and supervision of the Japanese banking sector are the Bank of Japan, the Financial Services Agency of Japan and the Deposit Insurance Corporation off Japan.

The Bank of Japan (BOJ) is a privately owned central bank, founded in 1882 and reorganized in 1942. The role of the BOJ was mostly confined to guidance until the 1997 revision of the Banking Act gave it more authority. The Bank now implements measures with direct impact on financial institutions in addition to its general macroeconomic role. In particular, it has responsibility for bank monitoring, supplies liquidity to banks as a "lender of last resort" (Uchida and Udell, 2014) and provides banks with subordinated debt as part of anti-crisis policies (Bank of Japan, 2016).

The Financial Services Agency (FSA) was set up as the Financial Supervisory Agency in 1998 and operated first under the Prime Minister and later – under the government's Financial Reconstruction Committee. It was renamed as the Financial Services Agency in 2000 and put under the control of the Ministry of Finance before becoming an external body of the Cabinet Office in 2001. The main responsibilities of the FSA are: financial monitoring and inspections; supervision of financial institutions (including the disposal of failed institutions); strategic directions and guidelines (e.g. setting benchmark indices, reviewing risk management practices at banks).

The Deposit Insurance Corporation of Japan (DICJ) was set up in 1971 on the model of the Federal Deposit Insurance Corporation in the U.S. The Resolution and Revitalization department of the DICJ responds to financial crises (such as that of the 2007–2009 and the aftermath of the 2011 earthquake) by actions as purchase of the assets of financial institutions and provision of capital injections.

[5] The decrease was from 9 to 5 in the period analyzed in our paper.

[6] But later were acquired or nationalized/privatized.

[7] Japanese credit cooperatives focus mainly on lending to very small companies and are usually studied as a separate group. Consequently, we do not include these banks in the analysis. See Glass et al. (2014), Barros et al. (2009), Fukuyama et al. (1999), Fukuyama (1996) for efficiency estimates with credit associations and credit cooperatives, using conventional parametric/non-parametric approaches.

2.3. The global financial crisis

The global financial crisis came to Japan in the second half of 2007, with a steady decline of the Nikkei stock index, as foreign investors sold the shares of Japanese corporations (Endo, 2013; Kamikawa, 2013). Overall, the financial crisis hit Japan through losses in equity and securities portfolios, while the subprime component was almost absent (Uchida and Udell, 2014; Fujii and Kawai, 2010). Nonetheless, Japanese banks began to experience losses on their subprime products from December 2007 (Financial Services Agency, 2008).

The impact of the global financial crisis evolved into acute in 2008 for economic reasons (Endo, 2013). Access of Japanese corporations to capital markets became more limited owing to the Lehman shock and slowdown of the world economy, and the corporations had to borrow from banks (Kamikawa, 2013). Exports and domestic demand shrank due to slowdown of trade and the domestic economy (Ciro, 2012; Kawai and Takagi, 2009). Small and medium-size enterprises, which depended on exports, had to apply for loans to maintain their cash position (Ogura, 2016; Yamori et al., 2013). The resulting expansion of SME lending during the crisis caused an increase of non-performing loans, since profitability of SMEs was impaired by the deteriorating economic environment. Negative economic growth, especially in 2008, led to huge capital losses and a sharp decline in the profitability of banks (Fujii and Kawai, 2010).

Although Japan's exports showed some growth in August–September 2009, private consumption remained low in 2009 despite a progress in business sentiment (Bank of Japan, 2009) and bank profitability did not improve until December 2009–March 2010 (Financial Services Agency, 2010). GDP returned to growth in 2010 and the Bank of Japan announced steady recovery of the national economy (Ciro, 2012). We therefore feel justified in confining the effect of the global financial crisis on Japan to the period 2007–2009.

The global financial crisis was addressed by the Japanese government and the three regulating bodies. The government adopted the so-called "Measures to Counter Difficulties in People's Daily Lives", which provided extra interest on a part of current deposits held at the (Japanese Bankers Association, 2015). The December 2008 amendment to the Act on "Special Measures for Strengthening Financial Functions" allowed capital injections to banks and reclassification of their rescheduled loans (so-called "condition-changed loans"), thereby sustaining banks' lending opportunities (Yamori et al., 2013). The Act established special examination criteria for the Financial Services Agency to be used in examining applications by each bank, which requested support (Endo, 2013).

Policies to improve liquidity included government guarantees on commercial paper, loosening of the BOJ's capital adequacy ratio, lowering of criteria for credit ranking and reduction of the overnight interest rate from 0.3% to 0.1% (Yamori et al., 2013; Ciro, 2012). Additionally, the Bank of Japan provided capital injections through purchases of stock held by banks and giving subordinated loans to banks, based on their applications for this financial instrument (Bank of Japan, 2016). The Financial Services Agency expanded the guidelines for not classing rescheduled loans to SMEs as non-performing loans – the latter measure was targeted at regional banks in order to maintain their risk-taking abilities (Sato, 2009).

The Deposit Insurance Corporation of Japan applied two types of measures on a case-by-case basis: coverage of deposits through capital injections; and the acquisition of equity positions at some banks in association with crisis management activities (Deposit Insurance Corporation, 2015).

Some of the anti-crisis measures were implemented after examination of the situation at each particular bank, which may be interpreted as regulators' awareness of potential technological heterogeneity. However, the types of heterogeneity have never been pronounced explicitly. Moreover, the criteria for business evaluation were broad and uniform. For instance, capital injections according to the "Special Measures for Strengthening Financial Functions" could be supplied to a bank if the FSA confirmed that the institution had a solid management plan and was taking steps to improve its profitability and efficiency (Endo, 2013).

2.4. The Great East Japan Earthquake

The Great East Japan Earthquake occurred at 14.46 on March 11, 2011 and had a magnitude of 9.0 at its epicenter off Japan's Pacific coast (Japan Meteorological Agency, 2013). The earthquake set off massive tidal waves, which caused widespread destruction in several prefectures on the Pacific coast, particularly Iwate, Miyagi and Fukushima. The waves hit the Fukushima nuclear plant (Tokyo Electric Power Company), causing radiation leakage and loss of electric power.

Tohoku, the region of northern Japan, which was directly exposed to the natural disaster, acounts for only 2.5% of Japanese GDP (Government of Japan, 2011). Nonetheless, the earthquake had a serious negative impact on the whole of Japan's economy. Firstly, supplier plants for a number of manufacturing industries were situated in Tohoku, so domestic and export markets were affected by supply chain disruption (Todo et al., 2015; Carvalho et al., 2014; Umezawa, 2014). Secondly, closure of the Fukushima nuclear plant caused power shortages and blackouts in the areas served by Tokyo Electric Power Company. The earthquake highlighted the vulnerability of nuclear power plants in Japan, forcing subsequent closure of nuclear reactors throughout the country. Japan had to reduce the production and consumption of electricity, and increase of oil and gas imports led to a negative trade balance (Umezawa, 2014). The decline in energy production after the earthquake may have aggravated the supply chain disruptions, slowing down economic recovery (Schnell and Weinstein, 2012). Finally, negative corporate and household sentiment towards particular goods (e.g. agricultural products or fish that were suspected to be contaminated) and general economic shock throughout the economy led to reduction of output (Nakamura, 2011). The number of firm bankruptcies rose sharply in 2011–2013, and the increase of bankruptcy rates was uniform throughout the country (Umezawa, 2014). These developments explain why the post-earthquake period is sometimes referred to in Japan as "the great recession".

Direct impact of the earthquake on banks included a rise in credit-related expenses and securities impairment, increase of loans to SMEs and a fall in deposits (77 Bank, 2011). Immediate policy by the government is reflected in the July 2011 provisions to the Act on "Special Measures for Strengthening Financial Functions", which included sustaining the financial strength of banks in vulnerable areas of their business (Endo, 2013). The measures by the Bank of Japan helped to supply liquidity and ensured stability of the payment and settlement systems (Bank of Japan, 2011). The Bank kept its interest rate at zero level to assist recovery in the post-earthquake period.[8]

3. Methodology

3.1. Quantile regression

Panel data quantile regression (Koenker, 2004) may be specified as:

$$y_{it} = \mathbf{x}'_{it}\boldsymbol{\theta}(u_{it}) \tag{1}$$

$$\tau \mapsto \mathbf{x}'_{it}\boldsymbol{\theta}(\tau) \tag{2}$$

where τ denotes the value of a given quantile for conditional distribution of the continuous dependent variable y for observation i at period t, a vector of covariates $\mathbf{x}$ includes an intercept, $u_{it} \sim U[0, 1]$, i=1, ..., n, t=1, ..., T and $\rho_\tau(\cdot)$ is the (Koenker and Bassett, 1978) loss function $\rho_\tau(u) = u(\tau - I(u < 0))$.

A consistent estimation involves minimizing the weighted quantile regression objective function

$$Q_{NT}(\tau, \boldsymbol{\theta}) = \frac{1}{nT}\sum_{i=1}^{n}\sum_{t=1}^{T}\rho_\tau(y_{it} - \mathbf{x}'_{it}\boldsymbol{\theta}) \tag{3}$$

We exploit the (Canay, 2011) quantile independent fixed effects (i.e. "locational shift") model and a computationally simple two-step estimator, which firstly, consistently estimates fixed effects and then, secondly, applies the above pooled version of the panel data quantile regression to the fitted value of the dependent variable.[9] It should be noted that quantile regressions for panel data exploit asymptotics with large T. However, our data has 13 years available which may cause only a negligible bias of the estimated coefficients (Canay, 2011).

In this paper we use the fixed effects model as follows. Denote $\tilde{y}_{it} = y_{it} - \eta_i$. Canay, 2011 showed the consistency of a two-step estimator for the below system with exogenous $\mathbf{x}_{\text{it}}$:

$$y_{it} = \mathbf{x}'_{it}\boldsymbol{\theta}(u_{it}) + \eta_i \tag{4}$$

$$\tau \mapsto \mathbf{x}'_{it}\boldsymbol{\theta}(\tau) \tag{5}$$

under u_{it} and $(\mathbf{x}_{it}, \eta_i)$ are independent. At the first stage, we consider the mean regression

$$y_{it} = \mathbf{x}'_{it}\boldsymbol{\theta}_\mu + \eta_i + e_{ij},$$

where $\boldsymbol{\theta}_\mu = \mathbf{E}\boldsymbol{\theta}(u_{it})$. The conventional within estimator $\hat{\boldsymbol{\theta}}_\mu$ is used to compute the fixed effects $\hat{\eta}_i \equiv \frac{1}{T}\sum_{t=1}^{T}[y_{it} - \mathbf{x}'_{it}(\hat{\boldsymbol{\theta}}_\mu)]$. The second stage defines $\hat{y}_{it} \equiv y_{it} - \hat{\eta}_i$ by subtracting the individual effects and estimates $\hat{\boldsymbol{\theta}}(\tau)$ as:

$$\hat{\boldsymbol{\theta}}(\tau) = \text{argmin}_{\boldsymbol{\theta}}\frac{1}{nT}\sum_{i=1}^{n}\sum_{t=1}^{T}\rho_\tau(\hat{y}_{it} - \mathbf{x}'_{it}\boldsymbol{\theta}). \tag{6}$$

Following (Canay, 2011), we use the estimators for the asymptotic covariance function

$$\boldsymbol{\Sigma}(\tau, \tau') = \mathbf{A}(\tau)^{-1}\mathbf{B}(\tau, \tau')[\mathbf{A}(\tau')^{-1}]' \tag{7}$$

of the stochastic process $\hat{\boldsymbol{\theta}}(\tau)$:

$$\hat{\mathbf{B}}(\tau, \tau') = \hat{S}(\tau, \tau') + \hat{J}(\tau)\hat{\Omega}_{g\xi}(\tau') + \hat{\Omega}_{g\xi}(\tau)'\hat{J}(\tau')' + \hat{J}(\tau)\hat{\Omega}_{\xi\xi}\hat{J}(\tau')', \tag{8}$$

$$\hat{\mathbf{A}}(\tau) = \frac{1}{2nTh_n(\tau)}\sum_{i=1}^{n}\sum_{t=1}^{T}I(|\hat{\epsilon}_{it}(\tau)| \le h_n(\tau))\mathbf{x}_{it}\mathbf{x}'_{it}, \tag{9}$$

$$\hat{J}(\tau) = \frac{1}{2nTh_n(\tau)}\sum_{i=1}^{n}\sum_{t=1}^{T}I(|\hat{\epsilon}_{it}(\tau)| \le h_n(\tau))\mathbf{x}_{it}, \tag{10}$$

where $\hat{\epsilon}_{it}(\tau) = \hat{y}_{it} - \mathbf{x}'_{it}\hat{\boldsymbol{\theta}}(\tau)$, and $h_n(\tau)$ is an appropriately selected bandwidth (we use $h_n(\tau) = \kappa[\Phi^{-1}(\tau + h_{nT}) - \Phi^{-1}(\tau - h_{nT})]$ with κ

[8] Shifting to a negative interest rate in 2016.

[9] Canay (2011) imposes an independence requirement, so that fixed effects do not change across quantiles (assumption 1(i)) and a conditional mean equation for y_{it}, where fixed effects are canceled out in the first differences.

equal to median absolute deviation of the τ-th quantile regression residuals and h_{nT} defined in Koenker and Machado (1999)). The terms $\widehat{\Omega}_{g\xi}$ and $\widehat{\Omega}_{\xi\xi}$ are estimated through a two-step technique. The first step uses the within estimator, which gives the fitted value of the constant in one step. The regression is

$$y_{it} - \bar{y}_i + \bar{y} = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\mathbf{x}})'\boldsymbol{\theta}_\mu + \bar{\eta} + \varepsilon_{it} - \bar{\varepsilon}_i + \bar{\varepsilon}.$$

The OLS estimates of $\boldsymbol{\theta}_\mu$ are exactly the within estimates and the fitted value of the constant is zero, given the mean individual effect. Next, we follow (Canay, 2011) and define

$$\psi_{it} = \begin{pmatrix} y_{it} - \hat{\mu}_y \\ 0 \\ \vdots \\ 0 \end{pmatrix} + \widehat{\Omega}_{\mathbf{xx}}^{-1}\tilde{\mathbf{x}}_{it}\hat{v}_{it},$$

where the constant is ordered first in the list of covariates, $\tilde{\mathbf{x}}_{it} = \mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\mathbf{x}}$, $\hat{v}_{it} = \hat{y}_{it} - \mathbf{x}'_{it}\hat{\boldsymbol{\theta}}_\mu$, and $\widehat{\Omega}_{\mathbf{xx}} = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \mathbf{x}_{it}\mathbf{x}'_{it}$. Then we define $\hat{\xi}_{it} = \hat{\mu}_{\mathbf{x}}\hat{\psi}_{it} - \hat{v}_{it}$, where $\hat{\mu}_y = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T y_{it}$, $\hat{\mu}_{\mathbf{x}} = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \mathbf{x}_{it}$.

Finally, setting the scores $s_{it}(\tau)$ of the objective function in (3) as a piecewise derivative

$$s_{it}(\tau) = -\frac{\partial\rho_\tau(\epsilon_{it}(\tau))}{\partial\boldsymbol{\beta}'} = \mathbf{x}'_{it}\psi_\tau(\epsilon_{it}(\tau)), \tag{11}$$

where $\psi_\tau(\epsilon_{it}(\tau)) = \tau - I(\epsilon_{it}(\tau) < 0)$, $\epsilon_{it} = \tilde{y}_{it} - \mathbf{x}'_{it}\boldsymbol{\theta}(\tau)$ (and straightforwardly $\hat{s}_{it}(\tau) = \mathbf{x}'_{it}\psi_\tau(\hat{\epsilon}_{it}(\tau))$), we obtain the following second-step estimates:

$$\widehat{\Omega}_{g\xi} = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \sum_{s=1}^T \hat{s}_{it}(\tau)\hat{\xi}_{is}, \quad \text{and} \quad \widehat{\Omega}_{\xi\xi} = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \sum_{s=1}^T \hat{\xi}_{it}\hat{\xi}_{is}.$$

These definitions differ from Canay (2011) and allow for correlation within groups, as we use groupwise clusters. The groups employed in our analysis are the types of bank charter: city banks, regional banks, regional second-tier banks, long-term credit banks and trust banks (See Section 2.1). The approach allows pooling of the data across all banks and takes account of special features of each bank charter.

As for the $\hat{S}(\tau, \tau')$, we relax the (Canay, 2011) assumption on homoscedasticity and independence of the u_{it} within a longitudinal observation, and use the (Parente and Santos Silva, 2016) approach for clustered standard errors in quantile regression.[10] The estimator of $S(\tau, \tau')$ in the expression for $\hat{\mathbf{B}}(\tau, \tau')$ becomes:

$$\hat{S}(\tau, \tau') = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \sum_{s=1}^T \hat{s}_{it}(\tau)'\hat{s}_{is}(\tau') = \frac{1}{nT}\sum_{i=1}^n \sum_{t=1}^T \sum_{s=1}^T \mathbf{x}_{it}\mathbf{x}'_{is}\psi_\tau(\hat{\epsilon}_{it}(\tau))\psi_{\tau'}(\hat{\epsilon}_{is}(\tau')).$$

We apply this estimator for $T \to \infty$ instead of a constant T in Parente and Santos Silva (2016). Therefore, a multiplier T is entered in the denominator, and we assume the existence of a finite positive definite limit in probability of the estimator (the same is done for $\hat{\mathbf{A}}(\tau)$).

It should be noted that the asymptotic test for choosing between the random-effects and fixed-effects specifications cannot be applied to quantile regressions. Although the estimates in (1)–(2) are consistent and asymptotically normal, they are inefficient: efficiency requires knowledge of the unknown density $f_{\epsilon(\tau)}(0|\mathbf{x})$, when it depends on $\mathbf{x}$ (Buchinsky, 1998). Accordingly, we adhere to the fixed effects specification on economic grounds, assuming the presence of cluster-specific effects which would capture, for instance, unobservable managerial practices linked to bank charter in Japan.

We assess the fit using an equivalent of the R^2 statistics computed for pairs of quantile regressions: with a constant term alone and with a full set of covariates and a constant (Koenker and Machado, 1999).

The models are estimated independently for each quantile. This way we avoid multiple testing issue and our estimates for quantiles outside the extreme of the interval $(0, 1)$ are not influenced by potential failure of the standard asymptotic theory to provide an accurate representation of the finite sample distribution. We use several values of τ, starting at $\tau = 0.1$ at the 0.1–step, for a more detailed analysis. As the estimates at the extreme values ($\tau = 0.1$ and $\tau = 0.9$) may be taken only as tentative, we establish potential tendencies across quantiles, considering values of coefficients for quantile points, adjacent to these extremes (i.e. 0.2 and 0.8). Statistical difference between the coefficients for quantiles 0.2 and 0.8, and between coefficients in each quantile and the median estimate is analyzed using the Wald test. The covariance matrix estimator for $(\hat{\boldsymbol{\beta}}(\tau), \hat{\boldsymbol{\beta}}(\tau'))$ in the test is constructed from the estimator of the general asymptotic covariance function (7) with the (Koenker, 2005) methodology.[11]

3.2. Cost function

Although economies of scale may be measured both with both production and cost functions, the use of the former may be

[10] Wooldridge (2007) proposes similar use of scores for correction of $\hat{\mathbf{B}}$ in time-series estimates and Wang and He (2007) derive asymptotic properties of rank scores tests in a multiple quantile model.

[11] See eq. (3.8) in Koenker (2005). It should be noted that the block matrix built using (7) gets close to singular under a small number of groupwise clusters. Therefore, we decrease the cluster size to a single bank, as well as exclude the (Parente and Santos Silva, 2016) correction in the Wald test for the robustness check.

inapplicable in the banking industry as it fails to include risk-taking behavior in the analysis (Hughes et al., 2001). Therefore, following (Hughes and Mester, 2013) this paper concentrates exclusively on cost functions, and adds equity capital as a proxy for the risk variable in the specification. The approach essentially supplements cost equation with capital structure and output quality: equity as a quasi-fixed input and the non-performing loan ratio, which reflects quality of loans (Hughes and Mester, 2014).

We use revenue from loans and revenue from other business activity as outputs, and this specification captures risk in Japanese banking (Drake et al., 2009; Drake and Hall, 2003). It also accounts for intermediary activity of banks, which may be viewed as a general approach in the banking literature (Fethi and Pasiouras, 2010).[12]

To measure economies of scale and scope we use the (Beccalli et al., 2015) and Altunbas et al. (2000) formulation of a translog cost function, which follows (Hughes et al., 1996; Hughes and Mester, 1998) and Hughes and Mester (2013) to include equity as risk variable, interactive with other outputs and output prices.[13] A system of equations in the (Hughes et al., 1996) utility maximization models allows fully incorporate endogeneity of risk in case of conditional mean estimations, but might involve computational complexity in quantile regressions. Therefore, we apply quantile regressions to single-equation models, which nonetheless includes the opportunity cost in the managerial utility through an introduction of equity (Hughes and Mester, 2014). To account for endogeneity in such a framework the analysis exploits the generalized method of moments estimation at the second stage.

Cost function homogeneity of degree one in prices is imposed by division of costs and all prices by a numeraire price. Let

$$\ln\frac{c_{it}}{p_{Kit}} = \theta\ln E_{it} + \phi\ln E_{it}\ln E_{it} + \sum_{m=1}^{M}\alpha_m\ln y_{mit}\ln E_{it} + \sum_{k=1}^{K-1}\alpha_k\ln\frac{p_{kit}}{p_{Kit}}\ln E_{it} + \sum_{m=1}^{M}\beta_m\ln y_{mit} + \sum_{k=1}^{K-1}\beta_k\ln\frac{p_{kit}}{p_{Kit}} + 0.5\sum_{s=1}^{K-1}\sum_{o=1}^{K-1}\beta_{os}\ln\frac{p_{oit}}{p_{Kit}}\ln\frac{p_{sit}}{p_{Kit}}$$
$$+ 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn}\ln y_{mit}\ln y_{nit} + \sum_{k=1}^{K-1}\sum_{m=1}^{M}\beta_{km}\ln\frac{p_{kit}}{p_{Kit}}\ln y_{mit} + \sum_{j=1}^{J}\beta_j z_{jit} + u_{it} \quad (12)$$

where c_{it} is total costs of bank i in year t, $\mathbf{y}_{it} = (y_{1it}, \ldots, y_{Mit})$ is a vector of outputs, $\mathbf{p}_{it} = (p_{1it}, \ldots, p_{Kit})$ is a vector of input prices and p_{Kit} is a numeraire price (we use K=3, so the price of funds p_{3it} is the numeraire in our analysis, further details are given in Table 1 in Section 4), E_{it} is equity (netput), $\mathbf{z}_{it} = (z_{1it}, \ldots, z_{Jit})$ is a vector of environmental variables – variables related to technology but not as directly controlled by the producer as inputs, u_{it} is a stochastic term, and symmetry restrictions require $\beta_{os} = \beta_{so}$ and $\beta_{mn} = \beta_{nm}$. The cost Eq. (12) becomes the specification for the conditional quantile regressions, estimated in the empirical part of the paper with the dependent variable $\ln C_{it} = \ln(c_{it}/p_{Kit})$.

The vector of bank environmental variables $\mathbf{z}_{\mathrm{it}}$ is constructed to account for risk and quality of capital: namely, it includes the logarithm of off-balance sheet items,[14] equity capital and the non-performing loan ratio (Beccalli et al., 2015; Drake and Hall, 2003; Berger and Mester, 2003, 1997; Yoshioka and Nakajima, 1987).[15] Other variables in $\mathbf{z}_{\mathrm{it}}$ reflect size (log of branches) and product diversity (Herfindahl index measured with the major components of the banks operating income), see Simar and Wilson (2007); Mester (1996); Aly et al. (1990). Thereby, the specification incorporates the variables that proxy risk-taking behavior, bank size, and business model in terms of product diversification and quality of capital. Regional environmental variables are: rate of growth of gross regional product (GRP), rate of growth of commercial land price, share of monetary aggregate (M2+negotiable certificates of deposit) in gross regional product, and share of loans in gross regional product (Liu and Tone, 2008). Annual dichotomous variables capture time effects. We analyze the values of coefficients for the years of the global financial crisis and the post-earthquake years.[16] The cost equation accounts for the effects of the two crises through interactions between the non-performing loan ratio and annual dummies. Concerning the 2011 Great East Japan earthquake, the growth of gross regional product includes potential effects linked to economic slowdown at each prefecture. We introduce the interaction terms between Fukushima prefecture and annual dummies to study additional impact of the nuclear plant explosion, which may go beyond the effect on economic growth.[17]

Economies of scale in a multi-output cost function may be defined as (Braeutigam and Daughety, 1983; Baumol et al., 1982; Panzar and Willig, 1977):

$$es_{it} = \sum_{m=1}^{M}\frac{\partial\ln C_{it}}{\partial\ln y_{mit}}, \quad (13)$$

where i denotes bank, t indicates year, m is the index for output, $C_{it} = c_{it}/p_{Kit}$ by definition in Eq. (12), $\partial\ln C_{it}/\partial\ln y_{mit}$ is elasticity of cost with respect to m-th output. Expansion opportunities are observed when $es_{it} < 1$ (the higher the value below unity, the lower are expansion opportunities).

For each bank i in each year t we compute pairwise cost complementaries cc_{it}^{mn} between outputs m and n, and the negative value of $cc^{mn}{}_{it}$ is a sufficient condition for the presence of economies of scope (Baumol et al., 1982):

[12] Although earlier analysis of Japanese banking regards loans and securities as outputs.

[13] A more flexible Fourier cost function did not fit our data, presumably owing to moderate sample size (1400 observations): a direct attempt to estimate the equations showed insignificance of most trigonometric terms.

[14] Off-balance sheet operations are an indicator of non-traditional banking. The use of a revenue approach in our paper does not make it possible to include off-balance sheet items in the list of outputs, so we exploit it as an environmental variable.

[15] It should be noted that the inclusion of the share of loan loss provisions in total loans instead of the non-performing loan ratio (e.g. Altunbas et al. (2000); Drake and Hall (2003); Drake et al. (2009)) does not change the estimates appreciably since correlation between the two variables in Japan is extremely high.

[16] This specification allows for nonlinear relationship, which might not be revealed through the conventional approach with the linear time trend.

[17] Our attempt to expand the geographic region, which had experienced such an impact (i.e. considering the Tohoku geographic zone or adding prefectures that had a certain increase in the soil radiation level) showed insignificance of corresponding interaction terms with post-2011 years.

Table 1
Descriptive statistics for the unbalanced panel in 2001–2013.

Variable	Definition	Mean	St.Dev.	Min.	Max.
Total cost c	Sum of asset costs, stock exchange, operational and other costs	144,700	411,500	4900	4343900
Inputs					
x_1	Capital=premises and real estate+intangibles	38,600	107,300	30	1,222,600
x_2	Labor=total employees	2467	3747	312	31,461
x_3	Funds from customers=total deposits+negotiable certificates of deposits +call mone+bills sold+borrowed money+foreign exchange deposits +other deposits	5,467,700	14,847,900	211,400	157,287,800
Outputs					
y_1	Revenue from loans=interest on loans and discounts+interest on bills bought	71,300	183,700	3600	2,153,800
y_2	Revenue from other business activity=total operating income − other operating income − interest and dividends on securities − y_1	54,100	179,900	660	2,000,700
Input prices					
p_1	Capital price=depreciation/ x_2	1.380	5.670	.018	131.393
p_2	Labor price=(general and administrative expenses − depreciation)/x_1	.017	.008	.006	.086
p_3	Price of funds=fund raising expenditure/ x_3	.003	.003	.0003	.037
Netput E	Equity capital	345,700	1,005,700	5200	11,741,500
Bank environmental variables					
OffBalance	Off-balance sheet items	183,800	863,300	100	10,754,200
ln branches	=ln(branches)	4.543	.582	2.639	6.750
HH index	Herfindahl index of product diversity=$-\ln\sum s_k$, where s_k are major components of operating income: interest income; fees and commissions; trading income; other operating income; other income; commissions on trust accounts	.652	.213	.164	1.584
NPL	Non-performing loan ratio=non-performing loans /total loans, where non-performing loans are: loans to borrowers in legal bankruptcy; past due loans in arrears by 6 months or more; loans in arrears by 3 months or more and less than 6 months; restructured loans	.050	.028	.004	.209
Bank charter					
City	=1 if city bank	.047	.211	0	1
Regional	=1 if regional bank	.550	.498	0	1
Second-tier	=1 if regional second-tier bank	.356	.479	0	1
Trust	=1 if trust bank	.031	.172	0	1
Long-term credit	=1 if long-term credit bank	.017	.129	0	1
Prefectural environmental variables					
GRP growth	Rate of growth for gross regional product, in 2010 real terms	1.007	.035	.912	1.181
M/GRP	Share of monetary aggregate in gross regional product	.547	.282	.257	1.523
loans/GRP	Share of loans in gross regional product	.694	.403	.339	1.952
Land price growth	Rate of growth for price of commercial land, in 2010 real terms	.714	.154	.409	1.107
2nd stage regression variables					
lnTA	=ln(total assets)	14.732	1.164	12.32	19.122
Tier1	Tier 1 regulatory capital ratio	0.085	0.025	0	0.019
LLPL	Loan loss provisions ratio=loan loss provisions/total loans	.019	.011	.003	.098
LIQR	Liquidity ratio=liquid assets/deposits	.054	.042	.011	.502
ROE	Return on equity=net income/equity	.549	.217	.194	2.998
DEPA	Deposits-to-assets ratio=deposits/total assets	.862	.114	.215	.966
EA	Equity-to-assets ratio=equity/total assets	.05	.014	.01	.128
SECTA	Securities-to-assets ratio=securities/total assets	.255	.076	.005	.520
NIM	Net interest margin=net interest income/total loans	.027	.005	.011	.065
Crises dummies					
crisis	=1 in 2007–2009 (period of Japan's exposure to the global financial crisis)	.232	.422	0	1
earthquake	=1 in 2011–2013 (economic slowdown after the Great East Japan Earthquake)	.229	.420	0	1

Note: Financial variables are in million yen. The total number of observations is 1409 (1405 for Tier 1 regulatory capital ratio). M=M2+negotiable certificates of deposit.

$$cc_{it}^{mn} = \frac{\partial^2 \ln C_{it}}{\partial \ln y_{mit} \partial \ln y_{nit}} + \frac{\partial \ln C_{it}}{\partial \ln y_{mit}} \cdot \frac{\partial \ln C_{it}}{\partial \ln y_{nit}}, \tag{14}$$

where m and n are indices for different outputs. Cost inefficiency ce_{it} for each bank i in each year t is defined as:

$$ce_{it}(\tau) = \ln C_{it} - Q_\tau(\ln \widetilde{C}_{it} | \mathbf{y}_{it}, \mathbf{p}_{it}, \mathbf{z}_{it}), \tag{15}$$

where $Q_\tau(\ln \widetilde{C}_{it} | \mathbf{y}_{it}, \mathbf{p}_{it}, \mathbf{z}_{it})$ is the conditional τ-th quantile of the cost distribution (after deducting fixed effects).

Our analysis uses the estimate of cost inefficiency. Namely, the τ-th quantile of the cost distribution conditional on covariates is approximated with its fitted value:

$$\widehat{ce}_{it}(\tau) = \ln C_{it} - \widehat{Q}_\tau(\ln \widetilde{C}_{it} | \mathbf{y}_{it}, \mathbf{p}_{it}, \mathbf{z}_{it}), \tag{16}$$

where $\widehat{Q}_\tau(\ln \widetilde{C}_{it} | \mathbf{y}_{it}, \mathbf{p}_{it}, \mathbf{z}_{it})$ is the fitted value of the log of total cost, normalized by the price of funds as a numeraire price and estimated according to Eqs. (3) and (12), with subtracted fixed effects. Higher values of $\widehat{ce}_{it}$ reflect higher inefficiency. It should be noted that point estimates of cost inefficiency for each observation increase with smaller values of τ, since $\widehat{ce}_{it}$ is the distance between the actual cost and cost, measured using the chosen τ-th quantile of the cost distribution. We use point estimates with $\tau = 0.1$ and $\tau = 0.2$, as these values are commonly chosen as benchmarks for computing efficiency residuals in quantile regressions.

3.3. Second-stage analysis

The second-stage analysis[18] is applied to the estimates of scale economies $\widehat{es}_{it}(\tau)$, where $\tau \in [0.1, 0.9]$, and to the values of cost inefficiencies $\widehat{ce}_{it}(\tau)$ at $\tau \in [0.1, 0.2]$. The lists of covariates capture the effect of major variables related to bank risk, quality, capital structure and profitability.[19] We use generalized method of moments models to address endogeneity of risk and variables related to the business model (Hughes et al., 2001; Berger and Mester, 1997; Mester, 1996).

The regressions with the dependent variable $\widehat{es}_{it}(\tau)$ exploit the following explanatory variables: quality of capital (Tier 1 regulatory capital ratio *Tier* 1); credit risk (loan loss provisions-to-loans ratio *LLPL*, liquidity ratio *LIQR* and its square *LIQR*2); bank business model (securities-to-assets ratio *SECTA*); profitability (net interest margin *NIM* and return-on-equity *ROE*). See the justification for correlates of scale economies in Beccalli et al. (2015); Bertay et al. (2013); Rogers (1998), and Berger and Mester (1997).

The regressions with the dependent variable $\widehat{ce}_{it}(\tau)$ use covariates which proxy quality of capital (*Tier* 1 and equity-to-assets ratio *EA*), credit risk (*LLPL*, *LIQR*),[20] profitability (*NIM* and *ROE*), bank business model (deposits-to-assets ratio *DEPA*), and size (logarithm of total assets *lnTA*). Further details on correlates of cost inefficiency may be found in Koutsomanoli-Filippaki and Mamatzakis (2011); Altunbas et al. (2000); Mester (1996).

Each regression explaining $\widehat{es}_{it}(\tau)$ or $\widehat{ce}_{it}(\tau)$ has a dichotomous right-hand side variable which equals unity in 2007, 2008 and 2009. The variable accounts for the impact of the global financial crisis. We interact this variable with each of the covariates. Similarly, the variable with unity values for 2011, 2012 and 2013, and its interactions with the second-stage explanatory variables capture the impact of the economic recession due to the earthquake.

Concerning the expected signs of coefficients, we note that higher liquidity and net interest margin, along with reliance on investment banking are associated with potential expansion for European banks, while capital strength reduces the bank's growth prospects (Beccalli et al., 2015; Bertay et al., 2013). Risk, quality of capital and deposits are inversely related to efficiency of banks in the EU and the U.S. (Koutsomanoli-Filippaki and Mamatzakis, 2011; Berger and Mester, 1997). In Japan cost inefficiency of banks in the 1990s had a negative association with financial performance and was positively linked to business mix (Altunbas et al., 2000).

The following Wald test is used to establish the statistical differences between the coefficients for covariates in the regressions with scale economies. For each τ the regressions have the same point values of the explanatory variables and differ only in values of the dependent variable $\widehat{es}_{it}(\tau)$. So the Wald statistics for the auxiliary regression with the dependent variable $\widehat{es}_{it}(\tau) - \widehat{es}_{it}(0.5)$ may be used to analyze the difference between the estimates in the second-stage regressions at τ and at the median.

4. Data

We exploit the data for Japanese city, regional, regional second-tier, long-term credit and trust banks in the fiscal years 2001–2013. The main data source is the Japanese Bankers Association, which provides financial variables from consolidated financial statements and statements of cash flow, along with variables on the number of employees, bank branches and bank charter from interim financial statements. The Bankscope data (Bureau van Djik) are used for Tier 1 regulatory capital ratio and equity capital. Regional (prefectural) variables come from: the Bank of Japan (deposits, cash in vaults, loans and bills discounted); the Economic and Social Research Institute, and Cabinet Office (gross domestic product and gross domestic product deflator for each region); the

[18] It should be noted that in terms of obtaining the fitted value of the cost variable, relevant bank variables may need to be explicitly introduced in the first-stage equation. However, a second-stage analysis is a helpful sensitivity tool for establishing an association between the estimated variables in the model and their correlates.

[19] As well as to guarantee that the pairwise correlation coefficients and the variance-inflation factors are low, so multicollinearity problem is unlikely.

[20] Banks may exploit loan loss provisions to “smooth out” their profits, setting aside more when profits are high. Nonetheless, we follow the general agreement in the literature to use *LLPL* as a proxy for risk. Employing the non-performing loan ratio as an alternative second-stage covariate would not solve the issue, as *NPL* and *LLLP* are highly correlated in the sample of Japanese banks (correlation coefficient is 0.9357).

Table 2
Estimated coefficients for environmental variables in the cost function.

	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
ln(OffBalance)	0.021	0.014	0.013	0.006	0.013	0.011	0.009	0.013	0.036*
	(0.018)	(0.017)	(0.016)	(0.015)	(0.015)	(0.019)	(0.022)	(0.025)	(0.021)
ln(branches)	0.349***	0.354***	0.356***	0.357***	0.353***	0.343***	0.326***	0.368***	0.29**
	(0.047)	(0.039)	(0.041)	(0.055)	(0.054)	(0.057)	(0.046)	(0.059)	(0.12)
HH index	0.664***	0.612***	0.611***	0.631***	0.679***	0.666***	0.666***	0.708***	0.737***
	(0.082)	(0.077)	(0.08)	(0.093)	(0.082)	(0.085)	(0.099)	(0.105)	(0.109)
GRP growth	−0.399*	−0.085	−0.062	−0.09	−0.107	−0.074	−0.018	−0.126	0.133
	(0.215)	(0.228)	(0.185)	(0.177)	(0.174)	(0.226)	(0.227)	(0.256)	(0.212)
M/GRP	0.3*	0.235	0.263*	0.274*	0.271	0.249	0.262	0.222	0.339*
	(0.18)	(0.143)	(0.135)	(0.16)	(0.199)	(0.258)	(0.229)	(0.19)	(0.197)
loan/GRP	−0.221*	−0.221**	−0.25***	−0.257**	−0.24*	−0.204	−0.208	−0.198	−0.265**
	(0.13)	(0.097)	(0.088)	(0.102)	(0.13)	(0.174)	(0.164)	(0.121)	(0.124)
Land price growth	−0.013	−0.089	−0.05	−0.043	−0.004	0.02	0.029	0.088	0.036
	(0.098)	(0.111)	(0.114)	(0.115)	(0.112)	(0.124)	(0.138)	(0.17)	(0.195)
NPL2001	3.419***	3.11***	2.859***	2.724**	4.015***	3.603***	3.896***	2.45***	3.332
	(1.118)	(0.865)	(0.884)	(1.219)	(0.606)	(0.731)	(1.392)	(0.618)	(2.76)
NPL2002	3.336***	3.27***	2.05**	2.6***	2.629*	2.837**	3.806***	3.435***	3.239***
	(0.95)	(0.885)	(0.922)	(0.893)	(1.361)	(1.342)	(1.034)	(1.022)	(1.158)
NPL2003	3.236***	1.996**	1.576**	1.876**	1.547	2.058**	2.245	1.636	4.329**
	(0.822)	(1.008)	(0.734)	(0.762)	(1.424)	(1.04)	(1.505)	(1.214)	(2.04)
NPL2004	5.519***	4.909***	4.07***	3.977***	3.548***	3.805***	3.047***	3.501***	4.614***
	(0.818)	(0.631)	(0.512)	(0.646)	(0.892)	(0.839)	(1.058)	(1.32)	(1.638)
NPL2005	5.442***	3.504***	3.284***	3.768***	4.794***	4.936***	4.597**	5.427***	7.193***
	(1.194)	(0.912)	(1.054)	(1.458)	(1.455)	(1.456)	(1.843)	(1.38)	(2.367)
NPL2006	6.149***	6.165***	5.626***	5.006***	6.02*	6.002***	5.791***	5.085***	4.194***
	(0.901)	(1.092)	(1.412)	(1.863)	(3.237)	(0.71)	(0.676)	(0.637)	(0.809)
NPL2007	3.207***	2.44**	2.663	3.587	4.028	5.651**	5.393**	8.057***	7.699***
	(0.787)	(0.968)	(4.358)	(3.248)	(2.626)	(2.718)	(2.492)	(0.646)	(0.572)
NPL2008	2.147	2.189	1.831	2.876***	2.194**	3.462	5.364*	3.566	5.355
	(1.893)	(2.696)	(2.624)	(1.075)	(1.106)	(5.612)	(2.963)	(2.879)	(4.486)
NPL2009	2.17*	0.501	0.77	0.456	1.437	1.147	0.796	1.877	3.953***
	(1.285)	(1.221)	(1.644)	(3.047)	(1.327)	(1.313)	(1.45)	(2.54)	(1.298)
NPL2010	1.328*	0.789	0.725	0.537	−0.136	0.312	−0.284	−1.148	0.969
	(0.753)	(0.987)	(1.143)	(1.608)	(2.412)	(1.054)	(1.12)	(1.574)	(1.787)
NPL2011	2.169***	1.244	0.496	1.127	1.665	1.287	1.511	0.811	1.16
	(0.747)	(1.015)	(0.97)	(1.288)	(1.727)	(3.357)	(1.775)	(1.949)	(5.243)
NPL2012	-0.615	1.006	2.247	3.137*	2.152	2.315	2.322	2.408	2.184
	(1.2)	(1.927)	(1.534)	(1.872)	(1.392)	(2.066)	(2.153)	(2.268)	(2.798)
NPL2013	2.265	1.077	2.673	2.328	2.315	2.119	2.855	2.484	2.692
	(1.43)	(1.405)	(1.802)	(1.789)	(1.733)	(4.452)	(2.428)	(2.861)	(3.085)
Koenker (2005) χ^2 with the Parente and Santos Silva (2016) approach (p-value)									
Sub-vector of environmental variables									
H_0: $\widehat{\beta}(\tau) = \widehat{\beta}(0.5)$	0.6563	0.530	0.678	0.446	–	0.997	0.840	0.431	0.345
H_0: $\widehat{\beta}(0.1) = \widehat{\beta}(0.9)$	4.0e-07	–	–	–	–	–	–	–	4.0e-07
H_0: $\widehat{\beta}(0.2) = \widehat{\beta}(0.8)$	–	5.4e-07	–	–	–	–	–	5.4e-07	–
H_0: $\widehat{\beta}(0.3) = \widehat{\beta}(0.7)$	–	–	0.875	–	–	–	0.875	–	–

Notes: The Table reports the estimated coefficients for the sub-vector of environmental variables, listed in Section 3.2, in the conditional quantile regression according to Eq. (12) with the dependent variable $\ln C_{it} = \ln(c_{it}/p_{3it})$, where c_{it} is the total accounting costs of bank i in year t and p_{3it} is the price of funds. Robust standard errors are in parentheses. H_0 is rejected at level α if p-value $\leq \alpha$. *, ** and *** show significance at the 0.1, 0.05 and 0.01 level, respectively.

Ministry of Land, Infrastructure and Transport, and the Japan Statistical Yearbook (price of commercial land site). All regional variables are computed in 2010 real terms.

Descriptive statistics for our sample are presented in Table 1. The sample consists of 1409 longitudinal observations with 130 banks.[21] Dichotomous variables by bank charter show the prevalence of each type of banks. The variables are used for groupwise fixed effects and for descriptive analysis of scale economies, cost complementarities, and cost inefficiencies.

It should be noted that the numbers of bank employees and bank branches are reported in the accounting statistics only from 2001, which justifies the first year in our panel. Gross regional product – the key variable for economic performance of each prefecture – is available till 2013,[22] which becomes the last year in our panel. The fiscal year in Japan runs from April to March, so

[21] Annual samples of 105–111 banks with non-missing data (2–6 city banks, 59–60 regional banks, 37–40 regional second-tier banks, 3–4 long-term credit banks and 1–2 trust banks a year), the number of banks decreases over years due to consolidation.

[22] As of April 2016.

Table 3
Estimated coefficients for annual effects in the cost function.

	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
Fukushima2002	−0.171	−0.243*	−0.21	−0.01	−0.05	−0.097	0.175*	0.035	0.025
	(0.112)	(0.125)	(0.141)	(0.075)	(0.082)	(0.081)	(0.106)	(0.096)	(0.064)
Fukushima2003	−0.101	−0.092	−0.114	0.184**	0.128	0.085	0.104	0.039	−0.07
	(0.073)	(0.114)	(0.113)	(0.073)	(0.081)	(0.077)	(0.139)	(0.047)	(0.081)
Fukushima2004	−0.187***	−0.237***	−0.262***	−0.237***	−0.22*	−0.279**	−0.053	−0.083	−0.206***
	(0.039)	(0.054)	(0.069)	(0.065)	(0.119)	(0.115)	(0.077)	(0.084)	(0.071)
Fukushima2005	−0.118**	−0.122	−0.175*	−0.017	−0.072	−0.113	−0.071	−0.117	−0.178***
	(0.052)	(0.083)	(0.092)	(0.113)	(0.111)	(0.129)	(0.08)	(0.087)	(0.046)
Fukushima2006	−0.106**	−0.153*	−0.21**	−0.021	−0.063	−0.134	0.016	−0.018	−0.09*
	(0.051)	(0.086)	(0.083)	(0.102)	(0.121)	(0.106)	(0.089)	(0.094)	(0.05)
Fukushima2007	0.029	0.011	−0.061	−0.055	−0.083	−0.181	−0.067	−0.07	−0.08
	(0.048)	(0.087)	(0.186)	(0.095)	(0.1)	(0.122)	(0.082)	(0.101)	(0.067)
Fukushima2008	0.153***	0.049	−0.01	−0.012	−0.057	−0.101	−0.163***	−0.202*	−0.232***
	(0.03)	(0.039)	(0.079)	(0.037)	(0.041)	(0.098)	(0.055)	(0.105)	(0.065)
Fukushima2009	0.053	−0.003	−0.023	−0.029	−0.092*	−0.103*	−0.081	−0.108	−0.128***
	(0.049)	(0.054)	(0.054)	(0.042)	(0.052)	(0.058)	(0.079)	(0.093)	(0.047)
Fukushima2010	−0.046	−0.106	−0.12	−0.002	−0.033	−0.069	−0.021	−0.065	−0.091*
	(0.054)	(0.09)	(0.094)	(0.083)	(0.107)	(0.089)	(0.077)	(0.09)	(0.047)
Fukushima2011	−0.078	−0.133	−0.174*	−0.142*	−0.181**	−0.194	−0.008	−0.055	−0.112
	(0.051)	(0.1)	(0.101)	(0.086)	(0.075)	(0.124)	(0.093)	(0.093)	(0.099)
Fukushima2012	−0.064	−0.174**	−0.215***	−0.251***	−0.25***	−0.265***	−0.073	−0.124	−0.198
	(0.05)	(0.07)	(0.06)	(0.074)	(0.077)	(0.098)	(0.093)	(0.102)	(0.127)
Fukushima2013	−0.118*	−0.214**	−0.267**	−0.242***	−0.257**	−0.277**	−0.162	-0.24*	−0.316*
	(0.065)	(0.1)	(0.104)	(0.091)	(0.104)	(0.121)	(0.117)	(0.127)	(0.177)
y2002	0.005	−0.005	0.114	0.059	0.15	0.095	0.033	0.017	0.054
	(0.097)	(0.108)	(0.091)	(0.104)	(0.103)	(0.117)	(0.113)	(0.12)	(0.258)
y2003	−0.06	0.038	0.047	−0.003	0.128	0.049	0.005	−0.069	−0.24
	(0.132)	(0.151)	(0.094)	(0.104)	(0.088)	(0.105)	(0.135)	(0.116)	(0.305)
y2004	−0.173	−0.137	−0.107	−0.132	−0.019	−0.092	−0.102	−0.23**	−0.253
	(0.128)	(0.126)	(0.084)	(0.106)	(0.073)	(0.1)	(0.116)	(0.113)	(0.315)
y2005	−0.21	−0.095	−0.095	−0.16	−0.123	−0.188*	−0.196	−0.326***	−0.423
	(0.131)	(0.113)	(0.092)	(0.117)	(0.081)	(0.111)	(0.133)	(0.109)	(0.316)
y2006	−0.556***	−0.582***	−0.539***	−0.521***	−0.48***	−0.532***	−0.54***	−0.594***	−0.53*
	(0.135)	(0.139)	(0.108)	(0.141)	(0.149)	(0.114)	(0.124)	(0.119)	(0.32)
y2007	−0.44***	−0.446***	−0.425**	−0.49***	−0.431***	−0.568***	−0.579***	−0.794***	−0.799***
	(0.133)	(0.127)	(0.165)	(0.176)	(0.124)	(0.161)	(0.145)	(0.1)	(0.298)
y2008	−0.264*	−0.257	−0.233*	−0.314***	−0.175*	−0.284	−0.345**	−0.359**	−0.409
	(0.148)	(0.175)	(0.128)	(0.118)	(0.095)	(0.187)	(0.164)	(0.169)	(0.332)
y2009	−0.335**	−0.275*	−0.299***	−0.326**	−0.259***	−0.327***	−0.339***	−0.45***	−0.51
	(0.133)	(0.142)	(0.105)	(0.157)	(0.086)	(0.114)	(0.123)	(0.16)	(0.314)
y2010	−0.215	−0.233*	−0.261**	−0.302**	−0.176	−0.263**	−0.286**	−0.327**	−0.391
	(0.131)	(0.138)	(0.102)	(0.131)	(0.113)	(0.125)	(0.136)	(0.161)	(0.338)
y2011	−0.324**	−0.293**	−0.278***	−0.341***	−0.266***	−0.323**	−0.372***	−0.44***	−0.443
	(0.13)	(0.146)	(0.101)	(0.114)	(0.094)	(0.157)	(0.138)	(0.158)	(0.353)
y2012	−0.251**	−0.273*	−0.321***	−0.385***	−0.259***	−0.342***	−0.388***	−0.483***	−0.497
	(0.128)	(0.148)	(0.111)	(0.125)	(0.09)	(0.128)	(0.142)	(0.168)	(0.33)
y2013	−0.373***	−0.341**	−0.39***	−0.426***	−0.321***	−0.39**	−0.437***	−0.523***	−0.553*
	(0.142)	(0.142)	(0.108)	(0.119)	(0.09)	(0.157)	(0.143)	(0.164)	(0.324)
Koenker (2005) χ^2 with the Parente and Santos Silva (2016) approach (p-value)									
Sub-vector of annual effects									
H_0: $\widehat{\beta}(\tau) = \widehat{\beta}(0.5)$	0.0005	0.026	0.069	0.185	–	0.902	0.0002	0.0003	1.7e-07
H_0: $\widehat{\beta}(0.1) = \widehat{\beta}(0.9)$	0.000	–	–	–	–	–	–	–	0.000
H_0: $\widehat{\beta}(0.2) = \widehat{\beta}(0.8)$	–	0.000	–	–	–	–	–	0.000	–
H_0: $\widehat{\beta}(0.3) = \widehat{\beta}(0.7)$	–	–	2.6e-07	–	–	–	2.6e-07	–	–

Notes: The Table reports the estimated coefficients for annual dichotomous variables, and dichotomous interactions for Fukushima prefecture and year in the conditional quantile regression according to Eq. (12) with the dependent variable $\ln C_{it} = \ln(c_{it}/p_{3it})$, where c_{it} is the total accounting costs of bank i in year t and p_{3it} is the price of funds. Robust standard errors are in parentheses. Fukushima2001 and year2001 are reference categories. H_0 is rejected at level α if p-value $\leq \alpha$. *, ** and *** show significance at the 0.1, 0.05 and 0.01 level, respectively.

the global financial crisis years 2007–2009 encompass the period from April 2007 until March 2010. The Great East Japan Earthquake happened on March 11, 2011. This paper uses data on an annual basis, so we consider fiscal years 2011–2013 to capture the post-earthquake effects.

We use a three input – two output model, where outputs are revenue from loans and revenue from other business activities (Kasuya, 1986; Fukuyama, 1993, 1995; Takahashi, 2000; Fukuyama and Weber, 2010). The choice of the outputs is justified by the

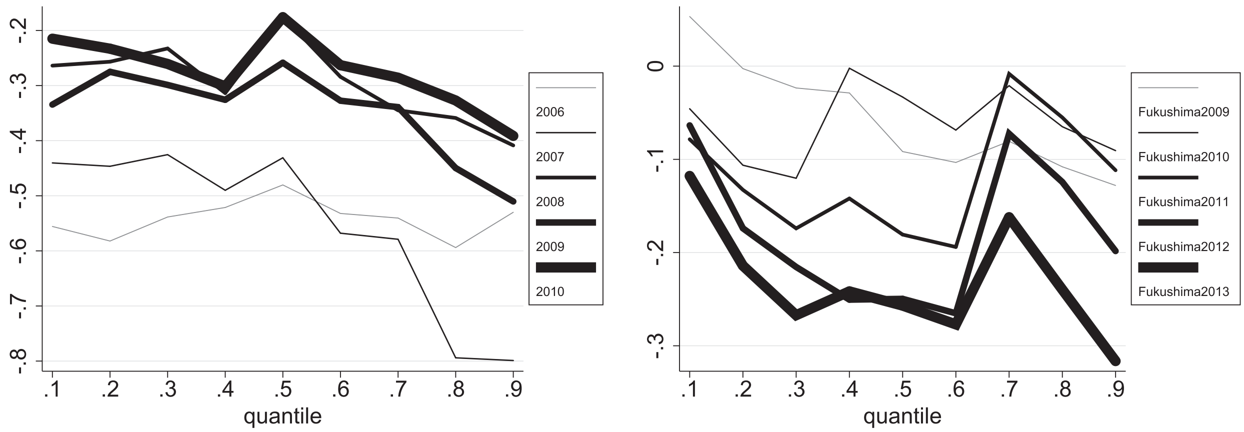

Fig. 1. The results of the conditional quantile regression with the cost function: the estimated coefficients for annual dichotomous variables (left, years close to the global financial crisis) and dichotomous interactions for Fukushima prefecture and year (right, years close to the earthquake).

desire to control for risk in the Japanese banking sector (Drake et al., 2009; Drake and Hall, 2003). The inputs are labor (total employees), capital (premises, real estate and intangibles) and funds from customers (Kasuya, 1986, 1989; Fukuyama, 1993, 1995; Hori and Yoshida, 1996; McKillop et al., 1996; Glass et al., 1998; Fukuyama and Weber, 2002; Miyakoshi and Tsukuda, 2004; Fukuyama and Weber, 2008; Barros et al., 2012). The proxies for input prices are, respectively, personnel expenditure/total employees, capital expenditure/capital, fund-raising expenditure/funds from customers (Kasuya, 1986, 1989; McKillop et al., 1996; Fukuyama and Weber, 2002).

Following common approaches to efficiency analysis in banking (Hughes and Mester, 2014), the cost is measured as total accounting costs, which is the sum of asset costs, stock exchange, operational and other costs (as reported in the financial statements). Concerning Japanese banking, Harimaya (2008) and Altunbas et al. (2000) explicitly take the accounting value of total costs, combining operational and financial cost. Tadesse (2006) regards costs as the sum of personnel expenditures, fees and communication, capital related expenses and interest expenses. This relates to the earliest studies by Kasuya (1986) and Kasuya (1989), who defines costs as the sum of expenses for raising capital, non-personnel expenses and personnel expenses, where non-personnel expenses comprise production and production factor costs. Similarly, Hori and Yoshida (1996) view costs as the sum of personnel expenses, equipment expenses and deposit interest.

5. Results

The results of quantile regressions, shown for the environmental variables, annual effects and Fukushima-year interactions in Tables 2–3, and for outputs and prices in Table B.1 in the Appendix, suggest a good fit: the values of the Machado R^2 statistics vary from 0.83 to 0.86 at different quantiles. As regards technological heterogeneity, our analysis focuses on the whole vector of covariates in the cost equation and sub-vectors: outputs and prices, environmental variables, annual effects and Fukushima-year interactions. According to the (Koenker, 2005) χ^2 test, we may reject the null hypothesis of equality of the estimated coefficients for the whole vector and the sub-vectors at $\tau = 0.2$ and $\tau = 0.8$. The result holds both with the (Parente and Santos Silva, 2016) approach applied in the computation of the test statistics and without the approach. We additionally establish that the estimates for the vector of coefficients and the sub-vectors are statistically different in at least one other pair of the bottom and top quantiles: 0.1 and 0.9, and 0.3 and 0.7. (See p-values in Tables 2–3 and B1). So the fitted values of the coefficients for the low-cost and high-cost quantiles may be taken as statistically different. Secondly, we compare the coefficients in each quantile to the median estimates. Statistical difference from the median under the (Parente and Santos Silva, 2016) approach is found in quantiles 0.2, 0.3, 0.7–0.9 for the whole vector of covariates, and in quantiles 0.1–0.3, 0.7–0.9 for the sub-vector of annual effects and Fukushima-year interactions. In absence of the (Parente and Santos Silva, 2016) correction, the statistical difference from the median is found in all quantiles for the whole vector of covariates; in quantiles 0.1 and 0.9 for the sub-vector of outputs and prices; in quantiles 0.1, 0.2 and 0.7 for the sub-vector of annual effects and Fukushima-year interactions. Concerning the second-stage analysis with scale economies, the Wald test shows that the estimates in each quantile differ from the median.

A cautious interpretation of the results might regard technological heterogeneity of banks in Japan as discrete: there is a more efficient production path (low-cost quantiles) and a less efficient production path (higher-cost quantiles). Despite the potentially discrete typology of banking technology in Japan, the findings are similar to the results for European banks in terms of insufficiency of only median or mean estimates (Koutsomanoli-Filippaki and Mamatzakis, 2011). Overall, the statistical difference of the coefficients of environmental variables and annual effects at the tails of the cost distribution points to differential effect of the banking variables and crises, given the technological heterogeneity of Japanese banks.

Table 4
Mean estimates of cost inefficiencies by year and bank charter.

	Bank charter	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
$\tau = 0.1$	City	0.678	0.555	0.218	0.312	0.292	0.256	0.189	0.279	0.317	0.177	0.194	0.124	0.112
		(0.17)	(0.105)	(0.107)	(0.125)	(0.05)	(0.152)	(0.124)	(0.071)	(0.06)	(0.052)	(0.053)	(0.05)	(0.059)
	Regional/second-tier	0.239	0.259	0.203	0.16	0.192	0.207	0.194	0.234	0.161	0.121	0.137	0.166	0.141
		(0.022)	(0.022)	(0.018)	(0.017)	(0.017)	(0.018)	(0.018)	(0.021)	(0.016)	(0.011)	(0.012)	(0.014)	(0.012)
	Long-term credit/trust	0.442	0.389	0.301	0.408	0.354	0.604	0.59	0.679	0.362	0.255	0.305	0.287	0.318
		(0.109)	(0.146)	(0.13)	(0.097)	(0.088)	(0.291)	(0.203)	(0.137)	(0.065)	(0.091)	(0.104)	(0.103)	(0.127)
	All banks	0.257	0.279	0.21	0.181	0.202	0.228	0.212	0.257	0.178	0.13	0.148	0.169	0.148
		(0.023)	(0.022)	(0.019)	(0.018)	(0.016)	(0.023)	(0.02)	(0.022)	(0.016)	(0.012)	(0.013)	(0.014)	(0.013)
$\tau = 0.2$	City	0.467	0.442	0.116	0.159	0.035	0.176	0.116	0.229	0.262	0.164	0.156	0.09	0.088
		(0.234)	(0.104)	(0.133)	(0.114)	(0.064)	(0.139)	(0.105)	(0.076)	(0.074)	(0.069)	(0.065)	(0.059)	(0.056)
	Regional/second-tier	0.173	0.199	0.129	0.096	0.106	0.159	0.144	0.145	0.099	0.075	0.085	0.086	0.1
		(0.021)	(0.021)	(0.018)	(0.016)	(0.017)	(0.019)	(0.018)	(0.02)	(0.016)	(0.011)	(0.012)	(0.013)	(0.012)
	Long-term credit/trust	0.376	0.317	0.193	0.298	0.158	0.515	0.495	0.593	0.303	0.214	0.228	0.185	0.224
		(0.102)	(0.133)	(0.119)	(0.095)	(0.091)	(0.295)	(0.194)	(0.132)	(0.052)	(0.072)	(0.072)	(0.089)	(0.091)
	All banks	0.189	0.216	0.132	0.11	0.105	0.177	0.159	0.17	0.117	0.086	0.095	0.091	0.105
		(0.021)	(0.021)	(0.018)	(0.016)	(0.017)	(0.023)	(0.02)	(0.021)	(0.016)	(0.012)	(0.012)	(0.013)	(0.012)

Notes: The Table uses the point estimates of cost inefficiencies $\widehat{ce}_{it}(\tau)$, measured according to Eq. (16) for bank i in year t at $\tau = 0.1$ and $\tau = 0.2$. For each τ mean values are taken across each year and each bank charter. Standard errors of the mean are in parentheses.

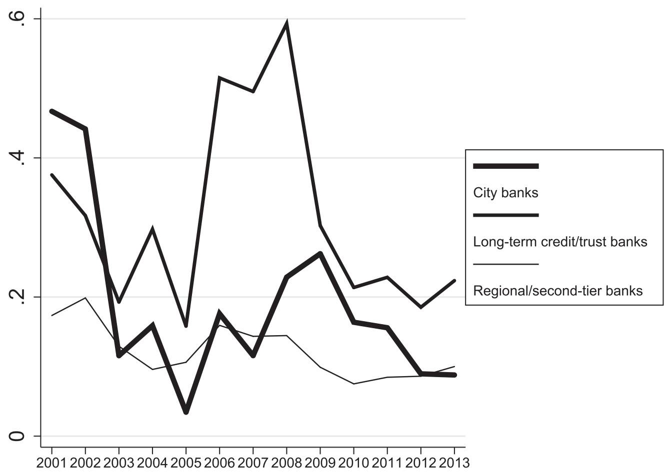

Fig. 2. Mean cost inefficiencies by year and bank charter, measured at $\tau = 0.2$. Note: Mean values of $\widehat{ce}_{it}(0.2)$ for bank i in year t are taken across each year and each bank charter.

The logarithm of bank branches and the index of product diversity are positive correlates of costs, with an increasing relationship over the cost quantiles. This indicates heterogeneous impact of diversification and size on banking costs, and may explain the absence of consensus in the literature with conditional mean estimates (Stiroh, 2014; DeYoung, 2014). Our median result with the positive value of the estimated coefficient for the index of product diversity is similar to findings for U.S. banks, where diversity increases cost inefficiency (Aly et al., 1990). The cost function estimates for outputs and prices, given in Table B1, reveal that elasticity of cost with respect to equity capital is positive at all quantiles, with an increasing value over the cost quantiles. In other words, equity capital may be regarded as a common cushion against bank risk (DeYoung, 2014), which is greater for high-cost banks. The logarithm of off-balance sheet items is a significant correlate of costs only in the highest-cost quantile.

The growth of gross regional product has a negative estimated coefficient but it is only significant in the lowest-cost quantile. The share of monetary aggregate in gross regional product is a positive correlate of costs, while the share of loans in gross regional product has negative estimated coefficients.

The coefficients for the NPL-year interactions are positive and increase over years to reach the highest values in 2006. The first year of the global financial crisis demonstrates a decline in the values of coefficients in the low-cost quantiles, while the effect of NPL on costs increases in the high-cost quantiles. The fact shows an inverse relation between non-performing loans and cost efficiency during the pre-crisis year and at the onset of the global financial crisis. Indeed, along with putting more emphasis on off-balance sheet operations, low-cost banks may have been better at assessing credit risk (Altunbas et al., 2000; Berger and DeYoung, 1997). The coefficients are the highest in absolute terms in 2006–2007 in each quantile, and remain high and significant in 2008–2009 in the highest-cost quantile. A certain decrease after 2008 may be related to faster disposal of non-performing loans during the crisis and effectiveness of capital injections by the (Financial Services Agency, 2015b).

Concerning the effects of economic and financial crises, Fig. 1 and Table 3 show that the values of the time dichotomous variables are generally insignificant in 2004–2005 but become negatively significant in each quantile in 2006. Further decrease of costs is marked in the first year of the global financial crisis and persists throughout 2008–2009. It should be noted that cost reduction in 2007–2009 is less noticeable for the low-cost banks. Arguably, the most technologically advanced banks did not have to change their cost structure radically during the crisis.

Absolute values of the time effects become smaller in 2010. However, the economic recession brought on by the earthquake gives a steady increase of the absolute values and statistical significance of the coefficients for annual dummies in 2011–2013. The post-earthquake effect is also revealed in the coefficients for Fukushima-year interactions in most quantiles. The values are negative and increase in absolute terms in 2011–2013 if compared to the pre-earthquake period.

5.1. Cost inefficiency, economies of scale/scope and bank charter

Table 4 and Fig. 2 show the values of cost inefficiencies. There is a certain rise in mean annual cost inefficiencies during the financial crisis for each bank charter: in 2006–2009 for city banks and long-term credit/trust banks, and in 2006–2008 for regional/second-tier banks.

As can be inferred from Table 5, expansion opportunities exists for each type of bank as scale economies are significantly smaller than unity.[23] However, the values come closer to unity in 2007–2008, showing limited potential for expansion in the crisis years. The estimates by bank charter at $\tau = 0.5$ confirm earlier results in the Japanese banking literature on smaller expansion opportunities at large banks and/or city banks compared with those achieved by regional banks (Hori and Yoshida, 1996; Kasuya, 1986). Our analysis shows substantial heterogeneity: the values of scale economies are smaller at banks in lower conditional quantiles of the cost distribution. This fact may be interpreted in terms of benefits from increasing output at low-cost banks, which would further reduce their costs. Alternatively, the result may be explained by scale effects of improvements in information processing and credit scoring, linked to cost efficiencies of larger banks (Berger and Mester, 1997). With the exception of 2007–2008, scale economies at each bank charter decrease over time, suggesting that bank expansion would have been particularly useful for cost reduction.

Our analysis reveals that cost complementarities between revenue from loans and revenue from other business activity in the 2000s are positive or insignificant in medium and high-cost quantiles of city banks, and in most quantiles of long-term credit/trust banks, indicating absence of economies of scope.[24] However, cost complementarities are negative and significant in low and medium-cost quantiles for regional banks, and in low-cost quantiles for city banks and long-term credit/trust banks. This shows potential for product diversification by low and medium-cost banks.

5.2. Second-stage analysis and effects of crises

We fit panel data GMM models, where the dependent variable is cost inefficiency residual (at $\tau = 0.1$ or $\tau = 0.2$) or economies of scale, estimated in quantile regressions with $\tau \in [0.1, 0.9]$. The GMM model assumes endogeneity of the explanatory variables and considers lags/lagged differences as instruments. The values of the (Hansen, 1982) *J*-test statistics indicate the validity of the instruments. The results of the Granger causality test[25] may be assessed as a tentative indication that the causality is coming from a set of bank-risk and business model variables towards economies of scale (similarly to the (Beccalli et al., 2015) finding with European banks) or cost inefficiency. However, the interpretation of time precedence as causality should not be regarded as a hard and fast rule (Angrist and Pischke, 2009). So we adhere to a cautious understanding of our covariates as correlates of both scale economies and cost inefficiency (Fujii and Kawai, 2010; Mester, 1996).

The findings of the second-stage analysis, outlined for scale economies in Table 6, show statistical difference between the estimated coefficients in each quantile and at the median. The negative correlates of economies of scale in most quantiles are: Tier 1 regulatory capital ratio, interaction of the loan loss provisions ratio with the global financial crisis, and interaction of net interest margin with the global financial crisis/post-earthquake dummies. Positive correlates of economies of scale are: return-on-equity, liquidity and net interest margin. Liquidity has a negative estimated coefficient in similar estimates with the EU data (Beccalli et al., 2015). The finding is different from what is observed in Japan, pointing to importance of bank-firm relationships for development of banking business rather than using liquidity resources.

The global financial crisis was insignificant for scale economies, while the post-earthquake period was negatively significant. Higher return-on-equity increases the value of scale economies, but has no additional effect during the global financial crisis. Interaction of net interest margin with the global financial crisis is negative in most quantiles, but is significant only at $\tau = 0.7$.

[23] The exception is $\tau = 0.9$ for city banks in 2001–2002.

[24] Earlier evidence on mean cost complementarities between different outputs at Japanese banks are limited and controversial. For instance, cost complementarities for revenue from loans and revenue from other business activity at city and regional banks were negative in the early 1980s and positive in the 1990s (Harimaya, 2008; Glass et al., 1998; McKillop et al., 1996; Tachibanaki et al., 1991; Kasuya, 1986).

[25] Following Beccalli et al. (2015), the Granger causality test is introduced with a set of regressions, which keep the first and second lags of each of the explanatory variables and include the first and second lags of the dependent variable as covariates. The results of the GMM estimates indicate that the hypothesis of the absence of joint significance of the first and second lags of the explanatory variables may be rejected in most models with scale economies or cost inefficiency. Additionally, we take each covariate as a dependent variable and regress it on its first and second lags, as well as the first and second lags of scale economies or cost inefficiency. The hypothesis of the absence of joint significance of the first and second lags of scale economies may be rejected in most models.

Table 5
Mean estimates of scale economies and cost complementarities by year and bank charter.

		Scale economies									Cost complementarities								
	Year	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
City banks	2001	**0.929**	**0.897**	**0.901**	**0.92**	**0.82**	**0.852**	**0.768**	**0.938**	1	**0.065**	**−0.037**	0.02	0.016	**0.038**	**0.116**	**0.073**	**0.167**	**0.103**
	2002	**0.914**	**0.826**	**0.85**	**0.863**	**0.775**	**0.818**	**0.71**	**0.894**	0.956	**0.067**	**−0.033**	0.03	0.029	**0.049**	**0.127**	**0.078**	**0.176**	**0.116**
	2003	**0.862**	**0.743**	**0.799**	**0.809**	**0.738**	**0.777**	**0.67**	**0.829**	**0.876**	**0.071**	−0.019	**0.043**	**0.044**	**0.061**	**0.13**	**0.082**	**0.173**	**0.118**
	2004	**0.803**	**0.708**	**0.762**	**0.777**	**0.714**	**0.736**	**0.655**	**0.784**	**0.827**	**0.042**	**−0.039**	**0.02**	**0.025**	**0.045**	**0.109**	**0.071**	**0.151**	**0.095**
	2005	**0.771**	**0.69**	**0.734**	**0.761**	**0.695**	**0.702**	**0.637**	**0.739**	**0.789**	**0.029**	**−0.049**	0.002	0.011	**0.034**	**0.095**	**0.062**	**0.133**	**0.081**
	2006	**0.831**	**0.701**	**0.723**	**0.766**	**0.679**	**0.706**	**0.596**	**0.721**	**0.805**	**0.069**	**−0.028**	0.013	0.022	**0.04**	**0.107**	**0.064**	**0.14**	**0.108**
	2007	**0.922**	**0.789**	**0.801**	**0.841**	**0.736**	**0.78**	**0.646**	**0.81**	**0.903**	**0.104**	−0.004	**0.039**	**0.046**	**0.057**	**0.133**	**0.078**	**0.169**	**0.134**
	2008	**0.868**	**0.745**	**0.749**	**0.782**	**0.693**	**0.737**	**0.614**	**0.782**	**0.872**	**0.059**	**−0.045**	0.002	0.008	**0.031**	**0.109**	**0.063**	**0.15**	**0.112**
	2009	**0.707**	**0.576**	**0.613**	**0.644**	**0.593**	**0.612**	**0.525**	**0.63**	**0.699**	0.008	**−0.073**	**−0.028**	−0.019	0.012	**0.075**	**0.044**	**0.109**	**0.076**
	2010	**0.646**	**0.507**	**0.56**	**0.59**	**0.554**	**0.566**	**0.489**	**0.571**	**0.629**	−0.003	**−0.078**	**−0.035**	**−0.028**	0.006	**0.065**	**0.039**	**0.096**	**0.067**
	2011	**0.626**	**0.483**	**0.541**	**0.571**	**0.54**	**0.55**	**0.476**	**0.551**	**0.606**	−0.007	**−0.079**	**−0.037**	**−0.031**	0.004	**0.062**	**0.037**	**0.091**	**0.064**
	2012	**0.606**	**0.461**	**0.523**	**0.554**	**0.528**	**0.533**	**0.464**	**0.527**	**0.579**	−0.009	**−0.079**	**−0.039**	**−0.033**	0.002	**0.059**	**0.035**	**0.086**	**0.061**
	2013	**0.632**	**0.472**	**0.54**	**0.565**	**0.539**	**0.555**	**0.471**	**0.552**	**0.603**	0.002	**−0.073**	**−0.031**	**−0.027**	0.007	**0.066**	**0.039**	**0.094**	**0.069**
Regional and second-tier banks	2001	**0.536**	**0.672**	**0.654**	**0.671**	**0.651**	**0.655**	**0.697**	**0.717**	**0.722**	**−0.059**	**−0.151**	**−0.142**	**−0.159**	**−0.109**	**−0.041**	**−0.038**	−0.004	**−0.012**
	2002	**0.486**	**0.59**	**0.59**	**0.6**	**0.599**	**0.604**	**0.642**	**0.661**	**0.659**	**−0.071**	**−0.154**	**−0.135**	**−0.141**	**−0.094**	**−0.03**	**−0.028**	0.007	−0.008
	2003	**0.464**	**0.551**	**0.571**	**0.576**	**0.585**	**0.591**	**0.627**	**0.638**	**0.626**	**−0.064**	**−0.134**	**−0.11**	**−0.112**	**−0.071**	**−0.012**	**−0.013**	**0.021**	0.0003
	2004	**0.443**	**0.528**	**0.551**	**0.557**	**0.571**	**0.573**	**0.613**	**0.615**	**0.601**	**−0.066**	**−0.133**	**−0.109**	**−0.11**	**−0.069**	**−0.012**	**−0.013**	**0.021**	−0.001
	2005	**0.454**	**0.544**	**0.572**	**0.579**	**0.59**	**0.592**	**0.634**	**0.628**	**0.609**	**−0.052**	**−0.115**	**−0.091**	**−0.094**	**−0.057**	−0.003	−0.005	**0.028**	0.005
	2006	**0.456**	**0.48**	**0.485**	**0.518**	**0.518**	**0.539**	**0.533**	**0.523**	**0.544**	**−0.025**	**−0.091**	**−0.075**	**−0.078**	**−0.039**	**0.025**	**0.015**	**0.047**	**0.033**
	2007	**0.525**	**0.572**	**0.555**	**0.593**	**0.571**	**0.597**	**0.586**	**0.595**	**0.627**	**−0.014**	**−0.086**	**−0.078**	**−0.087**	**−0.047**	**0.024**	**0.012**	**0.046**	**0.036**
	2008	**0.525**	**0.586**	**0.565**	**0.596**	**0.577**	**0.602**	**0.598**	**0.618**	**0.648**	**−0.028**	**−0.105**	**−0.096**	**−0.109**	**−0.064**	0.008	0.001	**0.035**	**0.026**
	2009	**0.437**	**0.495**	**0.482**	**0.516**	**0.514**	**0.525**	**0.539**	**0.528**	**0.553**	**−0.05**	**−0.12**	**−0.113**	**−0.119**	**−0.072**	−0.006	**−0.009**	**0.023**	**0.013**
	2010	**0.403**	**0.443**	**0.441**	**0.472**	**0.482**	**0.491**	**0.506**	**0.491**	**0.511**	**−0.055**	**−0.122**	**−0.111**	**−0.113**	**−0.068**	−0.003	**−0.006**	**0.026**	**0.013**
	2011	**0.376**	**0.402**	**0.417**	**0.444**	**0.464**	**0.473**	**0.488**	**0.464**	**0.475**	**−0.053**	**−0.115**	**−0.1**	**−0.1**	**−0.057**	0.003	−0.001	**0.03**	**0.015**
	2012	**0.332**	**0.359**	**0.382**	**0.409**	**0.439**	**0.439**	**0.466**	**0.423**	**0.428**	**−0.058**	**−0.118**	**−0.103**	**−0.102**	**−0.059**	−0.002	−0.004	**0.026**	**0.011**
	2013	**0.325**	**0.345**	**0.382**	**0.405**	**0.441**	**0.442**	**0.469**	**0.421**	**0.416**	**−0.052**	**−0.111**	**−0.093**	**−0.093**	**−0.05**	0.005	0.002	**0.031**	**0.015**
Long-term credit and trust banks	2001	**0.685**	**0.794**	**0.824**	**0.848**	**0.796**	**0.794**	**0.816**	**0.82**	**0.808**	0.037	−0.022	0.002	−0.008	0.013	0.068	0.048	**0.093**	0.053
	2002	**0.69**	**0.781**	**0.817**	**0.835**	**0.788**	**0.797**	**0.806**	**0.824**	**0.81**	0.046	−0.011	0.018	0.008	0.027	**0.085**	0.06	**0.108**	**0.065**
	2003	**0.569**	**0.666**	**0.728**	**0.748**	**0.727**	**0.712**	**0.756**	**0.714**	**0.679**	0.012	−0.04	−0.009	−0.01	0.016	0.061	0.047	**0.082**	0.042
	2004	**0.549**	**0.648**	**0.725**	**0.741**	**0.727**	**0.709**	**0.76**	**0.706**	**0.659**	0.01	−0.039	−0.003	−0.004	0.022	0.063	0.051	**0.081**	0.039
	2005	**0.546**	**0.625**	**0.696**	**0.724**	**0.705**	**0.688**	**0.728**	**0.661**	**0.627**	0.018	−0.035	−0.003	−0.001	0.026	0.069	0.056	**0.084**	0.047
	2006	**0.576**	**0.624**	**0.658**	**0.707**	**0.668**	**0.659**	**0.67**	**0.62**	**0.628**	0.02	−0.048	−0.029	−0.029	0.005	0.062	0.047	**0.079**	**0.052**
	2007	**0.655**	**0.708**	**0.716**	**0.764**	**0.705**	**0.705**	**0.7**	**0.695**	**0.722**	0.031	−0.04	−0.026	−0.03	0.002	0.065	0.046	**0.087**	**0.058**
	2008	**0.7**	**0.734**	**0.754**	**0.782**	**0.728**	**0.742**	**0.721**	**0.765**	**0.784**	0.027	−0.046	−0.016	−0.019	0.011	**0.076**	**0.053**	**0.104**	**0.064**
	2009	**0.609**	**0.636**	**0.669**	**0.699**	**0.664**	**0.666**	**0.662**	**0.672**	**0.684**	0.002	**−0.065**	−0.034	−0.034	0.001	**0.06**	**0.043**	**0.087**	**0.049**
	2010	**0.543**	**0.567**	**0.613**	**0.643**	**0.624**	**0.62**	**0.627**	**0.609**	**0.611**	−0.006	**−0.071**	−0.041	−0.039	−0.002	**0.054**	0.04	**0.078**	**0.043**
	2011	**0.517**	**0.537**	**0.601**	**0.629**	**0.619**	**0.613**	**0.626**	**0.587**	**0.575**	0.0002	**−0.063**	−0.029	−0.028	0.01	**0.061**	**0.049**	**0.081**	**0.046**
	2012	**0.489**	**0.491**	**0.568**	**0.596**	**0.594**	**0.582**	**0.596**	**0.548**	**0.533**	−0.005	**−0.072**	−0.036	−0.035	0.007	**0.059**	**0.048**	**0.078**	**0.044**
	2013	**0.491**	**0.489**	**0.584**	**0.606**	**0.609**	**0.6**	**0.613**	**0.559**	**0.531**	−0.001	**−0.07**	−0.027	**−0.028**	0.018	**0.069**	**0.058**	**0.085**	**0.049**
All banks	All years	**0.466**	**0.519**	**0.528**	**0.551**	**0.551**	**0.561**	**0.576**	**0.576**	**0.585**	**−0.043**	**−0.113**	**−0.096**	**−0.1**	**−0.058**	**0.004**	−0.001	**0.034**	**0.017**

Notes: The Table uses the estimates of scale economies $\widehat{es}_{it}$ and cost complementarities $\widehat{cc}_{it}^{mn}$ measured according to Eqs. (13) and (14) respectively. Mean values are taken across each year and each bank charter. $\widehat{es}_{it}$ ($\widehat{cc}_{it}^{mn}$) different from unity (zero) at the 0.05 level according to the two-tailed t-test in bold. Higher $\widehat{es}_{it}$ imply lower economies of scale; negative $\widehat{cc}_{it}^{mn}$ show economies of scope.

Table 6
Estimated coefficients for correlates of scale economies.

	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
LLPL	-0.781	0.651	0.073	0.100	0.092	-0.387	0.431	0.247	0.290
	(0.559)	(0.604)	(0.641)	(0.645)	(0.494)	(0.535)	(0.520)	(0.598)	(0.563)
LIQR	1.367***	1.004***	1.353***	1.315***	1.029***	0.961**	0.681*	1.066***	1.040***
	(0.480)	(0.387)	(0.402)	(0.420)	(0.336)	(0.374)	(0.364)	(0.357)	(0.371)
LIQR2	−1.707	−0.701	−1.355	−1.201	−0.872	−0.639	−0.088	−1.180	−1.132
	(1.580)	(1.446)	(1.497)	(1.558)	(1.300)	(1.433)	(1.420)	(1.322)	(1.291)
SECTA	0.308**	−0.103	0.083	0.146	0.061	0.067	−0.153	−0.148	−0.092
	(0.156)	(0.113)	(0.128)	(0.128)	(0.102)	(0.115)	(0.105)	(0.120)	(0.117)
NIM	1.260	6.469***	4.246**	4.622**	3.461***	2.434	4.810***	4.358***	4.607***
	(2.588)	(1.456)	(1.742)	(1.813)	(1.265)	(1.634)	(1.381)	(1.395)	(1.691)
ROE	0.232***	0.201***	0.212***	0.185***	0.160***	0.232***	0.152***	0.251***	0.240***
	(0.072)	(0.068)	(0.072)	(0.070)	(0.056)	(0.067)	(0.053)	(0.068)	(0.068)
Tier1	−2.117***	−1.680***	−1.899***	−1.673***	−1.404***	−1.709***	−1.207**	−2.072***	−2.069***
	(0.607)	(0.648)	(0.668)	(0.649)	(0.522)	(0.551)	(0.539)	(0.579)	(0.597)
Crisis	0.004	0.055	−0.035	0.013	−0.029	−0.064	−0.035	−0.050	0.009
	(0.105)	(0.106)	(0.111)	(0.102)	(0.088)	(0.102)	(0.095)	(0.105)	(0.105)
Earthquake	−0.413**	−0.315*	−0.304*	−0.273*	−0.217*	−0.255*	−0.140	−0.331**	−0.378**
	(0.170)	(0.162)	(0.159)	(0.154)	(0.126)	(0.130)	(0.135)	(0.143)	(0.148)
CrisisLLPL	−2.351**	−1.856**	−1.834**	−1.841**	−1.287*	−1.193	−0.878	−1.692**	−1.948**
	(1.018)	(0.748)	(0.838)	(0.814)	(0.668)	(0.755)	(0.584)	(0.807)	(0.819)
CrisisLIQR	0.367	0.234	0.138	0.158	0.072	0.102	0.029	0.119	0.265
	(0.519)	(0.433)	(0.458)	(0.443)	(0.380)	(0.435)	(0.395)	(0.450)	(0.401)
CrisisLIQR2	−3.381	−2.207	−1.839	−2.121	−1.248	−1.434	−0.582	−1.303	−2.228
	(2.777)	(2.341)	(2.381)	(2.358)	(1.928)	(2.219)	(1.901)	(2.279)	(2.165)
CrisisSECTA	−0.198*	−0.071	−0.035	−0.109	−0.018	−0.015	0.088	0.063	−0.046
	(0.106)	(0.099)	(0.106)	(0.112)	(0.089)	(0.098)	(0.098)	(0.109)	(0.095)
CrisisNIM	3.493**	−1.354	−0.438	−0.103	−0.828	−0.043	−3.110**	−1.378	0.025
	(1.505)	(1.235)	(1.344)	(1.307)	(1.057)	(1.104)	(1.260)	(1.339)	(1.232)
CrisisROE	−0.034	0.023	0.038	0.019	0.040	0.058	0.078	0.054	0.006
	(0.074)	(0.077)	(0.083)	(0.077)	(0.068)	(0.078)	(0.073)	(0.083)	(0.075)
CrisisTier1	0.630	0.514	0.816	0.685	0.662	0.777	0.604	0.729	0.582
	(0.559)	(0.569)	(0.591)	(0.546)	(0.476)	(0.523)	(0.490)	(0.544)	(0.553)
EarthquakeLLPL	−1.085	−1.360	−0.818	−0.656	−0.499	−0.280	−0.032	−1.117	−1.692
	(1.560)	(1.697)	(1.703)	(1.672)	(1.379)	(1.332)	(2.148)	(1.542)	(1.498)
EarthquakeLIQR	−0.177	−0.411	−0.525	−0.520	−0.451	−0.336	−0.483	−0.402	−0.260
	(0.459)	(0.391)	(0.375)	(0.399)	(0.308)	(0.355)	(0.340)	(0.353)	(0.362)
EarthquakeLIQR2	−0.503	−0.081	0.487	0.328	0.448	0.072	0.489	0.356	−0.244
	(1.583)	(1.411)	(1.435)	(1.483)	(1.220)	(1.366)	(1.301)	(1.311)	(1.288)
EarthquakeSECTA	−0.419**	−0.129	−0.187	−0.249*	−0.122	−0.132	0.045	−0.054	−0.157
	(0.167)	(0.145)	(0.142)	(0.148)	(0.113)	(0.121)	(0.135)	(0.133)	(0.129)
EarthquakeNIM	−5.924	−6.835**	−7.818**	−8.465***	−6.894***	−7.313**	−8.907**	−7.425**	−5.588*
	(3.817)	(3.478)	(3.236)	(2.697)	(2.549)	(2.876)	(3.470)	(3.309)	(3.241)
EarthquakeROE	0.612***	0.564***	0.541***	0.548***	0.426***	0.491***	0.399***	0.554***	0.572***
	(0.145)	(0.144)	(0.154)	(0.129)	(0.123)	(0.131)	(0.118)	(0.143)	(0.132)
EarthquakeTier1	3.772***	2.355***	2.693***	2.669***	1.983***	2.165***	1.276**	2.470***	2.800***
	(0.828)	(0.758)	(0.785)	(0.686)	(0.629)	(0.656)	(0.608)	(0.689)	(0.745)
Constant	0.361***	0.355***	0.388***	0.377***	0.437***	0.467***	0.480***	0.498***	0.485***
	(0.132)	(0.111)	(0.118)	(0.113)	(0.093)	(0.110)	(0.099)	(0.107)	(0.115)
Observations	1405	1405	1405	1405	1405	1405	1405	1405	1405
Number of banks	130	130	130	130	130	130	130	130	130
Wald test (p-value) H_0: $\beta(\tau) = \beta(0.5)$	0.000	0.000	0.000	0.000	–	0.000	1.1e-32	0.000	0.000
Hansen's J (p-value)	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999

Notes: The Table presents the results of the second-stage GMM regressions with the dependent variable $\widehat{es}_{it}(\tau)$, i.e. scale economies at bank i in year t at each $\tau \in [0.1, 0.9]$, estimated in Eq. (13). The list of explanatory variables is given in Section 3.3. Robust standard errors are in parentheses. *, ** and *** show significance at the 0.1, 0.05 and 0.01 level, respectively.

Interactions of the liquidity ratio with the global financial crisis/post-earthquake dummy are insignificant for scale economies at Japanese banks. Arguably, the first-stage regressors for NPL-year effects capture an association between liquidity and expansion of banking size.

The quality of capital, measured by Tier 1 regulatory capital ratio, has negative estimated coefficients. The coefficients are highest in absolute terms at the tails of the conditional cost function distribution. With reference to low-cost quantiles, this fact reveals a link

Table 7
Estimated coefficients for correlates of cost inefficiency.

	$\tau = 0.1$	$\tau = 0.2$
LLPL	1.045***	0.932***
	(0.393)	(0.301)
ROE	0.171***	0.191***
	(0.012)	(0.011)
NIM	2.328**	0.271
	(1.053)	(0.926)
LIQR	0.023	0.224***
	(0.134)	(0.078)
logTA	0.020***	0.003
	(0.005)	(0.006)
DEPA	−0.238***	−0.103**
	(0.056)	(0.052)
EA	3.064***	2.450***
	(0.462)	(0.460)
Tier1	−2.444***	−1.464***
	(0.225)	(0.128)
Crisis	0.964***	1.154***
	(0.154)	(0.213)
Earthquake	0.677***	0.334**
	(0.178)	(0.146)
CrisisLLPL	3.600***	4.036***
	(0.730)	(0.578)
CrisisROE	−0.126***	−0.190***
	(0.046)	(0.042)
CrisisNIM	−0.322	0.038
	(1.581)	(1.009)
CrisisLIQR	0.043	−0.204
	(0.158)	(0.195)
CrisislogTA	−0.029***	−0.025***
	(0.005)	(0.007)
CrisisDEPA	−0.475***	−0.655***
	(0.059)	(0.078)
CrisisEA	−3.312***	−2.470***
	(0.865)	(0.675)
CrisisTier1	1.027**	−0.248
	(0.443)	(0.348)
EarthquakeLLPL	−2.453	−0.072
	(1.632)	(1.590)
EarthquakeROE	−0.012	−0.098**
	(0.042)	(0.041)
EarthquakeNIM	−5.332**	−2.749
	(2.680)	(1.722)
EarthquakeLIQR	−0.218*	−0.292***
	(0.131)	(0.068)
EarthquakelogTA	−0.023***	−0.001
	(0.007)	(0.006)
EarthquakeDEPA	−0.124*	−0.072
	(0.075)	(0.056)
EarthquakeEA	−2.969***	−2.836***
	(0.571)	(0.477)
EarthquakeTier1	1.151***	0.278
	(0.341)	(0.317)
Constant	−0.020	0.034
	(0.127)	(0.139)
Observations	1405	1405
Number of banks	130	130
Hansen's J (p-value)	0.999	0.999

Notes: The Table presents the results of the second-stage GMM regressions with the dependent variable $\widehat{ce}_{it}(\tau)$, i.e. cost inefficiency residual at bank i in year t at $\tau = 0.1$ or $\tau = 0.2$, estimated in Eq. (16). The list of explanatory variables is given in Section 3.3. Robust standard errors in parentheses. *, ** and *** show significance at the 0.1, 0.05 and 0.01 level, respectively.

between managerial opportunities for cost-efficient production and quality of capital (Beccalli et al., 2015; Hosono and Miyakawa, 2014). The interaction of Tier 1 with the global financial crisis is insignificant in all quantiles, which may be explained by the anti-crisis policies of the Bank of Japan: it relaxed the capital adequacy requirement, so that banks could stop deduct valuation losses from securities (Yamori et al., 2013). The coefficient for the post-earthquake period and Tier 1 interaction term is positive.

Japanese banks differ from banks in the EU, as profitability of traditional lending in Japan (net interest margin) is linked to economies of scale and this association evolves in years of both crises. The insignificance of the securities-to-assets ratio and of its interaction with the crisis dummies in most quantiles shows the limited role of investment banking in Japan. Arguably, Japanese banks have a more conservative business model and rely on traditional activities rather than investment.

The results of the second-stage regressions for cost inefficiency, presented in Table 7, show that, controlling for all other covariates, the global financial crisis and the earthquake increased cost inefficiency. There is a positive relation of cost inefficiency with the log of total assets, return-on-equity and the equity-to-assets ratio. The share of loan loss provisions and its interaction term with the global financial crisis are positive correlates of inefficiency. This fact may be linked to the "skimming hypothesis", when cost efficiency is achieved through less stringent loan monitoring and fewer resources spent on credit underwriting (Koutsomanoli-Filippaki and Mamatzakis, 2011). The phenomenon was observed during the global financial crisis in Japan, when banks had to grant loans to SMEs. But the relation is inverted during the post-earthquake slowdown of the economy, proving the importance of good management in achieving cost efficiency.

At the same time, there is an inverse relation between each of the crises and the coefficient for the deposits-to-assets ratio, as well as the post-earthquake recession and the coefficient for the liquidity ratio. These facts may be linked to deposit insurance measures taken by the regulator in the crises.

Our estimates prove the hypothesis that the 2007–2009 financial crisis impacted Japanese banks through size of their equity portfolios. The interaction between the equity-to-assets ratio and the crisis has a negative coefficient in explaining cost inefficiencies.

6. Conclusions

Similarly to the U.S., Japan exhibits a "dichotomous structural equilibrium" (DeYoung, 2014) with activities segmented between national and regional banks, and economies of scale at regional banks. At the largest Japanese banks (city banks), our estimates reveal economies of scale, which are also observed in the U.S. and Europe (Beccalli et al., 2015; DeYoung, 2014). U.S. banks have expansion opportunities due to population growth and European banks enjoy prospects of business growth due to EU integration (Goddard and Molyneux, 2014), while economies of scale at Japanese city banks may be attributed to slow adoption of new technologies, which are prerequisites for increase of output at large banks (DeYoung, 2014). The Japanese banking industry proves the general rule of an inverse relation between such a risk factor as the share of loan loss provisions in total loans, on the one hand, and economies of scale/cost efficiencies, on the other hand. Unlike banks in the EU, profitability of traditional lending by banks in Japan is linked to economies of scale and this association evolves during the two crises. At the same time, the role of investment banking in Japan is rather limited.

The novelty of our empirical results is a demonstration of technological heterogeneity at Japanese banks. Low-cost and high-cost banks show different associations between costs and risk-taking behavior (as regards equity capital), bank business model (proxied by log branches or an index of product diversity) and their regional macroeconomic environment.

The effects of exogenous shocks, such as the global financial crisis and the Great East Japan Earthquake, and their time profiles are heterogeneous. For instance, the positive relationship between the non-performing loan ratio and costs at the onset of the global financial crisis is greater at high-cost banks compared with the median and with low-cost banks. A justification for such differences may be linked to better credit risk evaluations at low-cost banks (Altunbas et al., 2000; Berger and DeYoung, 1997). Our findings on heterogeneous effects of bank profitability, liquidity, non-traditional activities and non-performing loans demonstrate similarity between the global financial crisis and the economic slowdown following to the Great East Japan Earthquake. In particular, net interest margin is more important for expanding opportunities at high-cost banks in crisis.

The heterogeneity is connected with unusual features of bank profitability in Japan. Higher return-on-equity has no effect on economies of scale at Japanese banks during the global financial crisis. This may be attributed to the social role of banks in Japan in supporting small and medium-sized enterprises (Uchida et al., April 2007, Hoshi and Kashyap, 2004). Indeed, both implicit government regulation and empirical evidence on the long-term bank-firm relationship suggest that the social responsibility of Japanese banks extends to offering credit support during financial crises (Yamori et al., 2013, Ogawa and Tanaka, 2012).

To sum up, the empirical results in this paper highlight the role of banking technology and underline the importance of diversified regulation. Study of production and cost patterns at banks may be helpful in ensuring the best use of anti-crisis measures, such as writing-off non-performing loans or injecting capital. Japan's Financial Services Agency is already taking steps towards quantifying technological heterogeneity. The FSA's "Strategic Directions and Priorities for 2015–2016" include examination of governance practices and large-scale market surveys on the intermediary functions of financial institutions (Financial Services Agency, 2015a), which might help to take account of technology patterns in future policy decisions.

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Appendix A. Technological heterogeneity of Japanese banks

Table A1
Effects of banking variables on costs and scale economies at low-cost and high-cost banks.

	Low-cost bank	High-cost bank
Correlates of cost		
1.*Business model*		
Logarithm of branches (ln*branches*)	Median	Higher
Index of product diversity (*HH index*)	Lower	Higher
2. *Risk-taking behavior*		
Equity capital (*E*)	Insignificant	Median
3. *Regional economy*		
Share of loans in the gross regional product ($loan/GRP$)	Smaller	Insignificant
4. *Non-performing loans at the onset of the global financial crisis*		
$NPL\cdot year2007$	Lower	Higher
5. *Post-earthquake recession*		
$Fukushima\cdot year2013$	Lower	Higher
Correlates of scale economies		
1. *Profitability*		
Net interest margin (*NIM*)	Higher	Lower
3. *Liquidity (credit risk)*		
Ratio of liquidity assets in deposits (*LIQR*)	Lower	Higher

Notes: The Table shows a qualitative assessment of the coefficients for selected covariates (and elasticity of cost with respect to equity capital), which differ across low-cost and high-cost banks. The correlates of costs are explanatory variables from the conditional quantile regressions (the dependent variable is $\ln C_{it} = \ln(c_{it}/p_{3it})$, where c_{it} is the total accounting costs of bank i in year t and p_{3it} is its price of funds.). The correlates of scale economies are covariates in the second-stage GMM regressions, listed in Section 3.3. "Low-cost banks" and "high-cost banks" denote respectively banks in quantiles 0.2 and 0.8 of the conditional cost function $\ln C_{it}$. "Higher", "median" and "lower" implies that the absolute value of the corresponding coefficient is higher, close or lower to the estimate at the median ($\tau = 0.5$).

Appendix B. Results of quantile regressions

Table B1
Estimated coefficients for outputs and prices in the cost function.

	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
$\ln y_1$	0.045	1.165	1.314**	1.66***	1.723***	1.83***	2.081*	2.018*	1.364
	(0.981)	(0.77)	(0.548)	(0.638)	(0.639)	(0.672)	(1.063)	(1.146)	(0.996)
$\ln y_2$	0.469	0.416	0.095	−0.235	−0.34	−0.387	−0.293	−0.547	−0.141
	(0.352)	(0.357)	(0.441)	(0.389)	(0.453)	(0.527)	(0.538)	(0.497)	(0.742)
$(\ln y_1)^2$	0.123	0.127*	0.089	0.093	0.048	0.037	0.003	0.055	0.093
	(0.097)	(0.065)	(0.071)	(0.059)	(0.074)	(0.066)	(0.082)	(0.108)	(0.101)
$(\ln y_2)^2$	0.091***	0.104***	0.125**	0.118**	0.094**	0.085**	0.064*	0.063	0.048
	(0.032)	(0.029)	(0.049)	(0.046)	(0.042)	(0.041)	(0.038)	(0.047)	(0.061)
$\ln y_1 \ln y_2$	−0.044	−0.114	−0.099	−0.107	−0.064	−0.01	−0.015	0.019	0.012
	(0.09)	(0.07)	(0.083)	(0.081)	(0.068)	(0.07)	(0.071)	(0.057)	(0.115)
$\ln y_1 \ln (p_1/p_3)$	−0.027	−0.064***	−0.065***	−0.061**	−0.06***	−0.057**	−0.07**	−0.069***	−0.055
	(0.023)	(0.019)	(0.022)	(0.025)	(0.021)	(0.027)	(0.029)	(0.026)	(0.058)
$\ln y_2 \ln(p_1/p_3)$	0.02	0.024*	0.023	0.026	0.025**	0.031**	0.024*	0.024*	0.021
	(0.013)	(0.013)	(0.02)	(0.018)	(0.012)	(0.015)	(0.013)	(0.014)	(0.023)
$\ln y_1 \ln(p_2/p_3)$	−0.009	−0.057	−0.05	−0.088**	−0.056	−0.045	−0.041	−0.037	−0.04
	(0.069)	(0.054)	(0.044)	(0.039)	(0.047)	(0.058)	(0.086)	(0.07)	(0.078)
$\ln y_2 \ln (p_2/p_3)$	−0.038	−0.018	0.012	0.03	0.024	0.011	0.011	0.014	−0.006
	(0.029)	(0.027)	(0.036)	(0.028)	(0.036)	(0.031)	(0.037)	(0.036)	(0.059)
$\ln y_1 \ln E$	−0.127	−0.116	−0.078	−0.081	−0.065	−0.109	−0.06	−0.178	−0.187
	(0.133)	(0.08)	(0.097)	(0.098)	(0.114)	(0.1)	(0.144)	(0.14)	(0.144)
$\ln y_2 \ln E$	−0.128	−0.098	−0.14	−0.108	−0.093	−0.114	−0.082	−0.091	−0.082
	(0.079)	(0.064)	(0.102)	(0.082)	(0.086)	(0.075)	(0.079)	(0.089)	(0.082)
$\ln(p_1/p_3)$	0.165	0.387***	0.331**	0.319**	0.344***	0.346**	0.47***	0.299*	0.318*

	(0.116)	(0.132)	(0.131)	(0.146)	(0.133)	(0.176)	(0.167)	(0.166)	(0.192)
$\ln(p_2/p_3)$	−0.021	0.18	0.425	0.31	0.031	−0.224	−0.268	−0.877	−1.202
	(0.343)	(0.387)	(0.403)	(0.369)	(0.474)	(0.517)	(0.592)	(0.758)	(1.102)
$\ln E$	0.298	−0.27	−0.055	0.028	0.2	0.163	−0.109	0.055	0.126
	(0.709)	(0.532)	(0.395)	(0.44)	(0.531)	(0.674)	(0.921)	(0.911)	(0.929)
$(\ln(p_1/p_3))^2$	−0.018***	−0.019***	−0.021***	−0.019***	−0.02***	−0.021***	−0.021***	−0.02***	−0.016**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.007)
$(\ln(p_2/p_3))^2$	0.052***	0.05***	0.036**	0.044**	0.064**	0.079***	0.089***	0.114***	0.124*
	(0.017)	(0.016)	(0.018)	(0.018)	(0.027)	(0.026)	(0.028)	(0.042)	(0.075)
$(\ln E)^2$	0.091**	0.091***	0.093	0.073	0.064	0.097*	0.073	0.121***	0.109*
	(0.043)	(0.033)	(0.06)	(0.056)	(0.049)	(0.05)	(0.063)	(0.037)	(0.064)
$\ln(p_1/p_3)\ln(p_2/p_3)$	0.011	0.009	0.015	0.016	0.014	0.018	0.007	0.02	0.02
	(0.01)	(0.011)	(0.011)	(0.01)	(0.011)	(0.015)	(0.015)	(0.018)	(0.016)
$\ln E\ln(p_1/p_3)$	0.012	0.024*	0.027	0.021	0.02	0.012	0.025	0.027	0.012
	(0.016)	(0.013)	(0.022)	(0.027)	(0.018)	(0.022)	(0.023)	(0.02)	(0.052)
$\ln E\ln(p_2/p_3)$	0.018	0.029	−0.002	0.013	−0.018	−0.021	−0.028	−0.029	0.003
	(0.036)	(0.034)	(0.031)	(0.033)	(0.049)	(0.049)	(0.058)	(0.047)	(0.078)
ϵ_{equity}	0.072*	0.014	0.117***	0.049	0.152***	0.158***	0.185***	0.154***	0.046
	(0.041)	(0.029)	(0.032)	(0.032)	(0.031)	(0.038)	(0.037)	(0.035)	(0.042)
Machado R2	0.856	0.849	0.843	0.840	0.837	0.834	0.830	0.830	0.843
Koenker (2005) χ^2 with the Parente and Santos Silva (2016) approach (p-value)									
Vector of outputs, prices, environmental variables and annual effects									
H_0: $\hat{\beta}(\tau) = \hat{\beta}(0.5)$	0.999	0.000	0.000	0.999	–	0.999	0.000	0.000	0.000
H_0: $\hat{\beta}(0.1) = \hat{\beta}(0.9)$	0.000	–	–	–	–	–	–	–	0.000
H_0: $\hat{\beta}(0.2) = \hat{\beta}(0.8)$	–	0.000	–	–	–	–	–	0.000	–
H_0: $\hat{\beta}(0.3) = \hat{\beta}(0.7)$	–	–	0.000	–	–	–	0.000	–	–
Sub-vector of outputs and prices									
H_0: $\hat{\beta}(\tau) = \hat{\beta}(0.5)$	0.235	0.869	0.903	0.962	–	0.806	0.246	0.447	0.152
H_0: $\hat{\beta}(0.1) = \hat{\beta}(0.9)$	0.879	–	–	–	–	–	–	–	0.879
H_0: $\hat{\beta}(0.2) = \hat{\beta}(0.8)$	–	0.011	–	–	–	–	–	0.011	–
H_0: $\hat{\beta}(0.3) = \hat{\beta}(0.7)$	–	–	0.008	–	–	–	0.008	–	–

Notes: The Table reports the estimated coefficients for the sub-vector of outputs and prices, and the goodness of fit statistics in the conditional quantile regression according to Eq. (12) with the dependent variable $\ln C_{it} = \ln(c_{it}/p_{3it})$, where c_{it} is the total accounting costs of bank i in year t and p_{3it} is its price of funds. Elasticity of cost with respect to equity is $\epsilon_{equity} = \partial \ln C/\partial \ln E$. Robust standard errors, calculated for ϵ_{equity} using delta method, are in parentheses.*, ** and *** show significance at the 0.1, 0.05 and 0.01 level, respectively.

Appendix C. Analyses of costs in Japanese banking

Table C1
Review of specifications.

Study	Method	Data	Inputs	Outputs	Prices
Kasuya (1986)	OLS cross-section regressions with translog cost function	Annual data for city and regional banks in 1974–1984	Collected funds, real capital, labor	Revenue from lending activity (interest on loans and discount on bills), revenue from other business activities (including securities investment)	Price of funds=fund-raising expenses/ average outstanding balance of raised fund, price of non-personnel expenses=non-personnel expenses/ average outstanding balance of movables and immovables, price of labor=personnel expenses/average number of employees

Kasuya (1989)	Stochastic frontier panel data model with translog cost function	Semi-annual data (Japanese Bankers Association) for city, regional, regional second-tier banks in 1975–1986	Collected funds, real capital, labor	Operating revenue	Price of funds=fund-raising expenses/ average outstanding balance of raised fund, price of non-personnel expenses=non-personnel expenses/ average outstanding balance of movables and immovables, price of labor=personnel expenses/average number of employees
Tachibanaki et al. (1991)	OLS cross-section regressions with translog cost function	Annual data for listed corporate regional and city banks in 1985–1987 (Nikkei financial quests)	Capital, labor	Revenue from lending activity, revenue from other business activities (securities, capital commission)	Price of capital=(non-personnel expenses less fringe benefits)/total area of a bank, price of labor=personnel expenses/average number of employees
McKillop et al. (1996)	OLS cross-section regressions with translog and composite cost function	Annual data for 5 city banks in 1978-1991	Funds from customers, capital, labor	Loans and bills discounted, cash and due from banks plus call loans, securities plus trading account securities	Price of funds=fund-raising expenses/ average outstanding balance of raised fund, price of non-personnel expenses=non-personnel expenses/ average outstanding balance of movables and immovables, price of labor=personnel expenses/average number of employees
Glass et al. (1998)	OLS pooled data model with quadratic cost function	Annual data for 5 city banks in 1977–93	Deposits, capital, labor	Intermediation approach: loans and bills discounted, cash and call loans, trading account securities; value-added approach: loans and bills discounted, time deposits, sight deposits; integrated model: total deposits, loans and bills discounted, trading account securities	Uses the approach by Kasuya (1986)
Altunbas et al. (2000)	Stochastic frontier cross-section models with Fourier cost function	Annual data for 139 Japanese banks in 1993-1996	Capital, total funds, labor	Loans, securities, off-balance sheet items	Price of labor=personnel expenses/assets, price of capital=depreciation and other capital expenses/ fixed assets, price of funds=interest expenses/funds
Tadesse (2006)	OLS pooled data model translog cost function	Annual data for Japanese banks in 1974–1991 from Nihon Keizai Shimbun America, Inc. (2034 banks in the pooled	Deposits, employees, area of building occupied by bank's facilities (proxy for capital), funds borrowed from	Loans=personal loans +industrial loans +investments in cash dues and securities	Price of labor=personnel expenditure/ employees, price of capital=capital costs (depreciation, rentals

		sample)	intermediary sources		et.)/area of the building, price of deposits=interest on deposits/deposits, price of borrowing=interest costs of funds/ borrowing
Harimaya (2008)	OLS pooled data model with translog cost function	Financial statements of all banks in 1994–2003 (63–64 annual observations)	Deposits, capital, labor	Loans and bills discounted, investment securities and trading account securities, total liabilities in trust accounts	Price of labor=personnel expenses/number of employees, price of funds=interest expenses on deposits/ amount of deposits, price of capital=non-personnel expenses/ value of movable and immovable capital

Note: In this Table the term "funds from customers" is used synonymously with "collected funds", "raised funds" and "procured funds".

Table C2
Selected estimates of scale economies and cost complementarities.

Study	Economies of scale	Economies of scope
Kasuya (1986)	City banks: [0.92,0.97], regional banks: [0.94,0.96]	Negative cost complementarities between revenue from loans and revenue from other business activity
Tachibanaki et al. (1991)	City and regional banks: [0.806,0.863], all banks: [0.724,0.787]	Negative cost complementarities between loans and securities in 1987, absence of cost complementarities in 1985-1986
Hori and Yoshida (1996)	City banks: [0.90,0.95], regional banks: [0.89,0.90], second-tier banks: [0.82,0.89]	
McKillop et al. (1996)	City banks: [0.78, 0.93]	Absence of economies of scope between loans, liquid assets and securities
Glass et al. (1998)	City banks: [1.51, 1.89]	Negative cost complementarities for loans and bills discounted, positive cost complementarities for both cash and call loans and current deposits, absence of economies of scope for cash and call loans and either current deposits, time deposits or total deposits
Harimaya (2008)	0.7717, decreases from 0.9195 in 1994 to 0.7925 in 2003	Positive cost complementarity between loans and securities, and loan and trusts, negative cost complementarity between securities and trusts

Note: Economies of scale in this Table are calculated as $\sum \partial \ln C/\partial \ln y$. Economies of scale for Hori and Yoshida (1996) are inferred from Fig.3 on p.58.

Appendix D. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jempfin.2017.02.002.

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