Financial stability, competitiveness and banks' innovation capacity

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Financial stability, competitiveness and banks' innovation capacity: Evidence from the Global Financial Crisis

Abstract

This paper provides nuanced evidence on the effect of competitiveness and financial stability on banks' innovation-capacity (technological-change) levels during the Global Financial Crisis (GFC) in 2007-2008. We applied contemporary developments in non-parametric frontier analysis, employing a new index, the Global Financial Centres Index, to measure the business competitiveness of 45 financial centres. Our findings indicated a nonlinear and positive relationship between financial centres' competitiveness, banks' stability and innovation-capacity levels. This suggests that banks' ability to increase stability alongside financial centres' stability in a highly competitive environment acts as a protective measure against the GFC's negative effects.

Keywords; Global Financial Crisis; Financial centres; Innovation capacity; Non-parametric frontier analysis.

JEL Codes: G21, D24, C14, O16

1. Introduction

The Global Financial Crisis (GFC) in 2007-2008 exposed the banking system's fragility and the need to understand further the mechanisms that enhance banks' performance. Monitoring banks' performance concerns policy makers and regulators, but current extant literature is embryonic as far as exploring impacts from financial markets and the general business climate on the banking system. Hausman and Johnston (2014) asserted that banks' innovation capability was diminished during the GFC, which enhanced the GFC's negative effects on the global banking system. Financial centres, (London, New York, Shenzhen, Boston, Dubai, Geneva, Melbourne, Shanghai, Toyko, etc.) with their ability to accumulate resources, are one of the dominant determinants of this ongoing dynamic change between the market and the business ecosystem, impacting productivity levels on both national and regional levels (Degl'Innocenti *et al.*, 2018).

Financial centres are important to banks, as they attract two-thirds of global banking assets, more than three-quarters of the global revenue pool of investment banking services, in excess of 70% of all private and public debt securities, and almost 80% of all interest-rate derivatives (Deutsche Bank Research, 2010). Many of these activities are concentrated in US and EU financial centres. However, the financial crisis has challenged the leading role that Western financial centres have played. East Asian financial centres, particularly Singapore and Hong Kong, have navigated the financial turmoil more effectively than their Western counterparts. Chinese financial centres (e.g., Shenzhen, Shanghai and Beijing) have begun to reduce their dependence on leading financial centres for their development needs by improving and developing their business environments and regulatory systems (Derudder *et al.*, 2011). Starting from the GFC's onset, financial centres have been denounced because of their role in spreading financial instability worldwide, as highlighted by Derudder (2011), French (2009) and Wainwright (2012).

Extant literature before the GFC (e.g., Cassis, 2007; Engelen, 2007; Grote, 2008) widely focused on and acknowledged the importance of financial centres in increasing knowledge and promoting technological spillovers, but the present study focuses on this aspect after the GFC.

We contributed to post-GFC literature by investigating how financial centres' competitiveness has affected innovation capacity (in the form of technological change[1]) in the banking system. We further examined whether the joint effect of business competitiveness and stability improved the banking system's capacity for innovation.

Given the theoretical support among competitiveness and innovation capacity (Hausman and Johnston, 2014; Chen *et al.*, 2017), our study provides empirical evidence of the examined relationships during the GFC period between competitiveness and innovation capacity within the banking system. We contend that risk (or a bank's stability levels) affects and determines the interlinkages between the business climate and a bank's innovation capacity. High standards of efficiency/productivity, financial structures, bank characteristics and stability have become a critical issue concerning banks' viability, especially after the GFC (Mallick and Yang, 2011; Mallick and Sousa, 2013; Benbouzid *et al.*, 2017, 2018).

The present study aimed to explore how financial centres' competitiveness and the banking system's stability can contribute to the innovation capacity measured by technological changes in the banking system. Therefore, we provided new insights for policymakers on how to promote and improve bank performance, as well as prevent banks from taking on too much risk. By doing so, we contributed to extant literature in several ways.

First, we enriched the literature on financial centres, which so far has focused solely on analysing centres in London, Amsterdam and Frankfurt (e.g., Engelen, 2007; Engelen and Grote, 2009; Grote, 2008; Klagge and Martin, 2005). We used the new and unique Global Financial Centres Index (GFCI) to measure competitiveness and development within worldwide financial centres' business environments.

Second, we contributed to the current debate on banking performance, advocating for the need to return to understanding the financial environment's competitiveness. To

[1]Technological change indicates movements of the estimated production frontier (Bădin *et al.*, 2012; Kumbhakar and Lovell, 2000; Mastromarco and Simar, 2015, among others). According to Shao and Lin (2016), technological change is the result of banks' innovation capacity, which enables the frontier to shift.

date, regardless of the theoretical and empirical framework presented in extant business literature that explores the link between competition and innovation (Hausman and Johnston, 2014; Chen *et al.*, 2017), empirical banking studies have focused on the relationships among efficiency, risk, single banking market, integration and financial openness (e.g., Altunbas *et al.*, 2000; Altunbas *et al.*, 2007; Casu and Girardone, 2006; Chortareas *et al.*, 2016; Fiordelisi *et al.*, 2011; Goddard *et al.*, 2007; Lozano-Vivas *et al.*, 2001; Mamatzakis *et al.*, 2008; Maudos and de Guevara, 2007; Pasiouras *et al.*, 2009; Schaeck and Cihák, 2014), but not on how the nexus of financial centres' competitiveness and the banking system's stability can contribute to innovation capacity as measured by technological change in the banking system. To achieve this, we used a global sample of banks and integrated the analysis as a measure of the business environment's competitiveness.

Third, from a methodological perspective, we employed the latest developments in non-parametric frontier analysis to identify, empirically, the joint effect of stability and a business environment's competitiveness on banks' innovation capacity. Through non-parametric frontier analysis, we examined empirically how, and to what extent, banks' technological-change levels are determined by both banking-stability levels and competitiveness within the financial centres where banks are located. We used the probabilistic approach of efficiency measurement (Cazals *et al.*, 2002; Daraio and Simar, 2005) alongside its latest application of this approach (e.g., Bădin *et al.*, 2012), allowing us to explore potential non-linear effects from banks' stability and financial centres' competitiveness on banks' innovation capacity (technological change). Unlike several other data-envelopment analysis (DEA) efficiency studies, we did not employ a second-stage analysis in a regression-type framework to examine determinants of efficiency (censored, OLS, GMM, etc.) due to estimation bias (Simar and Wilson, 2007, 2011). This approach was subject to estimation bias because of the correlation between DEA estimates and the unrealistic assumption of 'separability' among inputs/outputs and the control variable. Consequently, Simar and Wilson (2011, p. 215) have suggested that the 'separability' condition does not hold when the control variables (in our case, financial centres' competitiveness and banking stability) can affect the frontier, as well as the inefficient process. Under these circumstances, an estimator of conditional measures of efficiency must be applied, as shown in this paper (Cazals *et al.*, 2002; Daraio and Simar, 2005; Bădin *et al.*, 2012).

Fourth, we applied a robust quantile frontier measure, namely the *Order-α* frontier. This methodology offered the advantage of providing partial frontiers that were more robust to outliers. Daraio and Simar (2007) note that such frontiers do not envelop all data points, nor do they suffer from the curse of dimensionality. Thus, we were able to compare banks of different sizes, from different countries, without compromising our estimates' reliability.

Fifth, we estimated banking soundness and efficiency among a sample of banks during the GFC. As Tsionas *et al.* (2015) pointed out, few studies have focused on bank performance during the crisis period. Therefore, the period that our analysis covered is an additional contribution from our study.

The rest of the paper proceeds as follows: Section 2 reviews extant literature. Sections 3 and 4 describe the methods and data used. Section 5 presents the empirical results, and Section 6 concludes the study report.

2. Background discussion

A developing body of knowledge on economic geography has highlighted the importance of financial centres in business development, innovation and reduction of asymmetric information and, thus, overall risk to the financial system. Financial centres work as catalysts for labour forces and businesses, including the promotion of technical innovation (Cassis, 2007). Firms can experience economies of scale at the industrial level by sharing the fixed costs of common inputs (e.g., services and infrastructure). All these factors help improve firms' cost efficiency in proximity to financial centres.

One perspective would be that a financial centre with a competitive and dynamic business environment provides important externalities to enhance production technology, thereby increasing banks' innovation-capacity levels. For example, a competitive environment between domestic and foreign financial institutions actually can reduce the cost of financial services for firms and households in less-developed financial systems, thereby expanding local financial markets and promoting diffusion of best practices (Guiso *et al.*, 2004). Furthermore, an increase in competition within a financial market can pressure banks to become more innovative. This might be due to the loss of market power. Banks actually can take on excessive risks (Altunbas *et al.*, 2007; Fiordelisi *et al.*, 2011). A competitive environment also can force banks to improve the variety in their services and products (Bos *et al.*, 2013). On this point, extant research has shown that non-interest income sources tend to be more volatile than traditional interest-income sources, which could affect banks' stability negatively, especially for large banks (Lepetit *et al.*, 2008; Li and Zhang, 2013; Stiroh and Rumble, 2006). The effect of financial centres' competitiveness on banks' ability to increase their innovation capacity is an ambiguous *a priori* risk, representing an important conduit that potentially can harm a bank's future opportunities. This suggests that banks may allocate their resources less efficiently in response to this competitive pressure.

Financial centres can mitigate the effect of risk on innovation capacity in the banking industry. Scholars such as Beunza and Stark (2004), Engelen (2007) and Faulconbridge *et al.* (2007) have contended that geographical proximity to financial centres reduces information asymmetry through a more efficient and effective exchange of information. These studies also advanced several counterarguments to the hypothesis that geographic proximity to financial centres does not matter due to rapid improvements in information and communication technology (ICT). Clark and O'Connor (1997) and Engelen (2007) distinguish financial products in terms of their information properties. They specifically highlight that the information content of financial services leads to the distribution of functions over the international financial system. This means that more-transparent financial products, in which asymmetric information is less severe, are likely to be traded in more-developed financial centres, whereas more opaque and illiquid products are more likely to be traded in secondary financial centres. More liquidity, transparency, better ICT infrastructure, high-quality skilled labour and efficient local norms are all factors that facilitate innovation with a potentially lower negative externality in terms of risk. All these factors can allow banks to allocate their own resources more efficiently, as well as invest in high-quality, innovative activities. This can be reflected in increasing technological change at banks. A more competitive financial centre can better adapt to changes in normative and economic conditions, and to dynamic, competitive mechanisms between financial centres, thereby preserving their profitable financial-service offerings (Lee and Schmidt-Marwede, 1993; Karreman and Van der Knaap, 2009) and their innovative role in the financial context.

However, some limits exist regarding financial centres' beneficial effects on the risk and technological-change nexus. The GFC actually has shown that more developed and international financial centres were more vulnerable to global banking shocks. Well-developed and integrated financial centres played a pivotal role in spreading banking instability to other countries globally (Engelen and Grote, 2009). The presence of global banks in those financial centres negatively affected market functioning, worsening banking stress and instability in other regions worldwide. The reason is that these banks increasingly became integrated, acting as a principal vehicle of instability and stress transmission (Huang *et al.* 2012). In this context, vulnerability in one market easily can be transferred to another market abroad. In addition, during the GFC, banking institutions behaved similarly, and banking systems in advanced economies and emerging markets were more synchronised (Bhimjee *et al.*, 2016).

It is clear that business competitiveness in financial centres can reduce risks and present conditions to boost technological change, yet they have been the vehicles through which banking and financial instability were transmitted among countries during the GFC. This paper's purpose is to provide insights on whether financial centres' competitiveness, along with banks' stability, affected innovation capacity during the GFC, and if so, whether it did so positively. In the next section, we lay out our methodological contributions to banking-efficiency studies, which allowed us to respond to our research hypothesis.

3. Methodological strategy and data description

3.1 The model

In this section, we outline the procedure that we adopted to calculate banks' technological-change (innovation capacity) levels. We started by modelling the bank's production process based on the intermediation approach (Sealey and Lindley, 1977). As posited by Berger and Humphrey (1997), the intermediation approach is best-suited for evaluating bank efficiency. Following several other studies (Assaf *et al.*, 2013, and Matousek and Tzeremes, 2016, among others), banks' production function consists of three inputs (personnel expenses, total customer deposits and total fixed assets) and three outputs (gross loans, other earning assets and securities).[2]

Banks' activities can be characterised by pairs of certain inputs $x \in \Re_+^p$ and outputs $y \in \Re_+^q$, with the production set of those technical, feasible pairs characterised as:

$$\Psi = \left\{ (x, y) \in \Re_+^p \times \Re_+^q \middle| x \text{ can produce } y \right\}. \quad (1)$$

In our scenario, we assumed free disposability of the production set, implying that it is feasible to produce fewer outputs using more inputs, i.e., $(x, y) \in \Psi$ implies that $(x', y') \in \Psi$ for any (x', y') such that $x' \geq x$ and $y \leq y'$. We also assumed convexity of the frontier's shape, assuming that if $(x, y) \in \Psi$ and $(x', y') \in \Psi$, then $(\beta x + (1-\beta)x', \beta y + (1-\beta)y') \in \Psi$ for any $\beta \in [0,1]$. As a result, the boundary of Ψ defines the efficient frontier of banks' production process. A bank's efficiency then can be estimated by measuring the distance from a given level of input and output to the boundary. Given a certain level of bank input and output $(x_0, y_0) \in \Psi$, the efficiency score can be defined in radial terms as:

$$\varepsilon_0 = \varepsilon(x_0, y_0) = \inf \left\{ \varepsilon > 0 \middle| (\varepsilon x_0, y_0) \in \Psi \right\}. \quad (2)$$

In Equation (2), ε_0 indicates the bank's Farrell-Debreu input-efficiency score (Debreu, 1951; Farrell, 1957), representing the proportionate reduction of inputs given the output levels. In this respect, it can be said that the bank at level (x_0, y_0) is input-oriented and efficient.[3] Furthermore, ε_0 is reciprocal to Shephard's input distance function (Shephard, 1970), whereas εx_0 indicates the bank's technical, efficient input of producing y_0[4].

[2]The data have been extracted from Fitch IBCA's Bankscope database. Before estimation, we followed Mastromarco and Simar (2015), and we normalised the inputs and outputs used with respect to the median. This normalisation ensures the homogeneity assumption in inputs and outputs, and accounts directly for any potential scale effects that may affect the estimation.
[3]The choice of the input orientation is logical in our case, since the decision maker at a bank has greater control over the inputs compared with the outputs.
[4]In this paper, we assumed input orientation (rather than output orientation) since a bank's decision maker has more control over the inputs of a bank's production process, compared with outputs.

By following Cazals *et al*. (2002), Daraio and Simar's (2005, 2007) analytical insights help explain the framework of an efficiency measurement's probabilistic approach, suggesting that the production set can be identified from the density support (X,Y) as:

$$\Psi = \left\{(x,y) \in \Re_{+}^{p+q} \middle| H_{XY}(x,y) > 0\right\}, \tag{3}$$

in which the probability function, H_{XY}, can be decomposed as:

$$\begin{aligned} H_{XY}(x,y) &= H_{X|Y}(x|y)S_y(y) \\ &= P(X \le x|Y \ge y)P(Y \ge y). \end{aligned} \tag{4}$$

Therefore, a bank's production set can be characterised as:

$$\Psi = \left\{(x,y) \in \Re_{+}^{p+q} \middle| H_{X|Y}(x|y) > 0\right\}, \tag{5}$$

and, thus, a bank's input-oriented efficiency score at level (x_0, y_0) can be defined as:

$$\varepsilon_0 = \varepsilon(x_0, y_0) = \inf\left\{\varepsilon > 0 \middle| H_{X|Y}(\varepsilon x_0|y_0) \in \Psi\right\}. \tag{6}$$

Furthermore, let $Z \in \Re^r$ denote an environmental factor that influences a bank's production process and is not in direct control of a bank's decision maker[5]. Then, given that $Z = z_0$, the conditional production set Ψ_{z_0} can be represented as:

$$\Psi_{z_0} = \left\{(x,y) \in \Re_{+}^{p+q} \middle| H_{X|Y,Z}(x|y,z_0) > 0\right\}. \tag{7}$$

Following Daouia and Simar (2007) the *Order-α*, quantile-type, input-oriented efficiency measure (also known as a partial measure) can be represented as:

$$\varepsilon_\alpha(x_0, y_0) = \inf\left\{\varepsilon > 0 \middle| H_{X|Y}(\varepsilon x_0|y_0) > 1-\alpha\right\}. \tag{8}$$

an $\alpha \in (0,1]$ indicates the *Order-α* quantile frontier defined as the input level not exceeded by $(1-\alpha)\times 100$ percent of banks producing at least the level y_0 of outputs (Daraio and Simar, 2007). We used an α=0.95 because we were trying to measure

[5]The variable(s)/factor(s) is/are exogenous to the production process. In our case, they represent the influence of risk and the influence of financial centres' competitiveness wherever banks are located. We rejected the 'separability' assumption following the procedure described by Daraio *et al.* (2018).

banks' technological change (innovation capacity). However, if a median value is used (i.e.α=0.5), technological catch-up (efficiency changes) can be measured (Bădin *et al.*, 2012).[6] If a bank has $\varepsilon_\alpha = 1$, it suggests that it operates on the frontier and is regarded as efficient. However, a bank with an efficiency score of $\varepsilon_\alpha < 1$ is regarded as inefficient, while if it has an efficiency score of, $\varepsilon_\alpha > 1$ it is regarded as super-efficient. When $\alpha \to 1$, the *Order-α* efficiency score converges to $\varepsilon(x_0, y_0)$. Then, given that $Z = z_0$, the *Order*-α, input-oriented efficiency score can be presented as:

$$\varepsilon_\alpha\left(x_0, y_0 \middle| z_0\right) = \inf\left\{\varepsilon > 0 \middle| H_{X|Y,Z}\left(\varepsilon x_0 \middle| y_0, z_0\right) > 1 - \alpha\right\}. \tag{9}$$

3.2 Estimation and computational issues

The unconditional, input-oriented efficiency score can be estimated via data-envelopment analysis (DEA) as:

$$\hat{\varepsilon}\left(x_0, y_0\right) = \inf\left\{\varepsilon > 0 \middle| \varepsilon x_0 \geq \sum_{i=1}^{n} \omega_i X_i, y_0 \leq \sum_{i=1}^{n} \omega_i Y_i \text{ for some } \omega_i \geq 0 \quad i = 1, \dots, n\right\}. \tag{10}$$

Moreover, to compute the input-oriented, conditional-efficiency estimates $\varepsilon\left(x_0, y_0 \middle| z_0\right)$, we followed Bădin *et al.* (2012) to estimate the empirical version of $H_{X|Y,Z}\left(\cdot \middle| \cdot, \cdot\right)$ as:

$$\hat{H}_{X|Y,Z}\left(x \middle| y, z\right) = \frac{\sum_{i=1}^{n} I\left(X_i \leq x, Y_i \geq y, \left\|Z_i - z\right\| \leq h/2\right)}{\sum_{i=1}^{n}\left(Y_i \geq y, \left\|Z_i - z\right\| \leq h/2\right)} = \frac{\sum_{i \in I(z_0, h)} I\left(X_i \leq x, Y_i \geq y\right)}{\sum_{i \in I(z_0, h)} I\left(Y_i \geq y\right)}. \tag{11}$$

As can be observed from Equation (11), some smoothing techniques are needed to estimate the above estimator. For that reason, we followed the procedure outlined by Bădin *et al.* (2010) for bandwidth selection[7]. In accordance with Daouia and Simar (2007), the unconditional *Order-α,* quantile-type, input-oriented efficiency score can be obtained as:

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[6] Other robust measures, such as *Order*-m frontiers, also can be applied. However, according to Daraio and Simar (2007), *Order*-α frontiers are more robust to outliers, even though they share the same properties as *Order*-m.

[7]Since we had two external variables, product kernels with compact support have been applied. For more details on smoothing and relevant computational issues, see Daraio and Simar (2005, 2007) and Bădin *et al.* (2010, 2012).

$$\hat{\varepsilon}_{\alpha}\left(x_0, y_0\right) = \begin{cases} \chi^{y}_{((1-\alpha)\Gamma_y)} \text{ if } (1-\alpha)\Gamma_y \in N \\ \chi^{y}_{([(1-\alpha)\Gamma]+1)} \text{ otherwise,} \end{cases} \tag{12}$$

in which $\Gamma_y = n\hat{S}_{Y,n}(y) > 0 = \sum_{i=1}^{n} I(Y_i \geq y)$ and $\chi_i = \max_{k=1,\ldots,p} \frac{X_i^k}{x^k}$, $i = 1,\ldots,n$. Furthermore, N denotes the set of all nonnegative integers (Daraio and Simar, 2007).

Moreover, the conditional *Order-α*, quantile-type, input-oriented efficiency score can be calculated from:

$$\hat{\varepsilon}_{\alpha}\left(x_0, y_0 \middle| z_0\right) = \begin{cases} \chi^{y}_{(1)} \text{ if } 1 \leq 1\text{-}\alpha < l_1 \\ \chi^{y}_{(k+1)} \text{ if } l_k \leq 1\text{-}\alpha < l_{k+1},\ k = 1,\ldots,\Gamma_y - 1. \end{cases} \tag{13}$$

Given that $\Theta_{y,z} = \sum_{i=1}^{n} I(Y_i \geq y) K(Z_i - z/h)$, then $l_k = (1/\Theta_{y,z}) \sum_{j=1}^{k} K\left(\left(Z^{y}_{[j]} - z\right)/h\right)$. In this respect, Equation (13) provides a local robust estimator that is local and obtained only by points in the neighbourhood of $Z = z_0$ (Bădin *et al.*, 2012).

Finally, to analyse the effect of risk and financial centres' competitiveness on banks' innovation capacity, we followed the latest developments by Bădin *et al.* (2012). By using the robust (*Order-α* quantile) estimates, we created, from the partial frontiers, the following ratio:

$$\hat{Q}_{\alpha} = \frac{\hat{\varepsilon}_{\alpha}\left(x_0, y_0 \middle| z_0\right)}{\hat{\varepsilon}_{\alpha}\left(x_0, y_0\right)}. \tag{14}$$

Then, by using a nonparametric regression, we were able to analyse the behaviour of $\hat{Q}_{\alpha}$ as a function of banks' risk measure and the rating of the financial centres where banks are located. Let the nonparametric-regression smoothing be presented as:

$$Q_{\alpha,i} = g(Z_i) + \varepsilon_i, i = 1,\ldots,n, \tag{15}$$

In which ε_i is the error term with $E\left(\varepsilon_i \middle| Z_i\right) = 0$, and g is the mean-regression function, as $E\left(Q_i \middle| Z_i\right) = g(Z_i)$. For the nonparametric regression in Equation (15), we followed Jeong *et al.* (2010) and applied a local linear estimator that is less sensitive to edge effects. Moreover, as explained by Bădin *et al.* (2012), in an input-oriented case, an increasing regression line would indicate a negative effect, whereas a decreasing, nonparametric regression line would indicate a positive effect on banks' technological change (i.e., a shift in the estimated frontier).

3.3 Sample Description

The data on financial centres' competitiveness are provided in the Global Financial Centres Index (GFCI), which is produced by Z/Yen Group in association with the City of London Corporation. Since 2007, the GFCI has provided ratings and rankings for financial centres around the word. It was built on two distinct sources of data: external indices (e.g., cost of property survey and occupancy-cost index; corruption perception index; opacity index; Mercer's Quality of Living Survey, UBS' Wage Comparison Index, and Transparency International's Corruption Perceptions Index, among others) and responses to an online survey. The index encompasses four key indicators: *people* (e.g., availability of good personnel, business education and the flexibility of the labour market), *business environment* (e.g., tax rates, levels of corruption, economic freedom and the ease of doing business), *market access* (e.g., level of securitisation, volume, value of trading in equities and bonds, and the number of firms engaged in the financial-service sector), *infrastructure and general competitiveness* (e.g., cost and availability of buildings and office space, the city's overall competitiveness and quality of life).

The present study used a sample of 782 banks across 45 financial centres during the 2007-2013 period. We specifically considered the unconsolidated balance sheets of banks that have their own headquarters in financial centres. We calculated the banks' risk factor using Z-scores, which have been used widely in extant literature to measure banks' 'soundness' (Laeven and Levine, 2009; Demirguc-Kunt and Huizinga, 2010; Houston *et al.*, 2010; Fu *et al.*, 2014; Fiordelisi and Mare, 2014; Schaeck and Cihák, 2014; Goetz *et al.*, 2016). The Z-score includes banks' buffers (profits and capital) and risk, which is measured through standard deviation of returns on assets. A high Z-score indicates a lower probability of insolvency and, thus, more stability. The Z-score is calculated as follows:

$$Zscore = (\mathrm{ETA} + \mathrm{ROA})/\sigma ROA, \qquad (16)$$

In which ETA is the equity-to-total-assets ratio, ROA is the return on assets and σROA is the standard deviation of the return on assets. To control for a skewed distribution, we used the log transformation of this measure to smooth out higher values of the distribution, as suggested by Danisewicz *et al.* (2015).

3.4 Descriptive Statistics

Table 1 shows the rating of each financial centre in 2007 and 2013. We also calculated the growth rate of the rating for each financial centre between 2007 and 2013. Growth is immediately visible on Table 1, especially in the financial centres in Asia that have managed to grow faster than financial centres in other regions during the GFC. This is reasonable to accept, as it was the US and EU financial systems that the GFC affected the most adversely.

Insert Table 1 and Figure 1 about here

Figure 1 shows the average rating of financial centres for the 2007-2013 period, while Table 1 illustrates growth rate over the same period. Several features are noteworthy. We noted that the ratings for financial centres in Asia and Oceania are higher and grew faster than several financial centres on other continents (20%). Financial centres in North America had the highest average rating in 2013, mainly because of New York City's Wall Street being a financial hub. We observed that most financial centres are located in the EU. Nevertheless, only a few financial centres appear to have a high standard of business environment. The most competitive centres in the EU are London, Frankfurt, Zurich and Geneva, while those located in Southern and Eastern Europe appear to be consistently less advanced. This provided an important warning sign for EU policy makers for two main reasons. First, the financial system appears to be particularly fragmented and displays important structural inequalities concerning business environment. This suggests that previous regulatory changes that aimed to improve the financial integration of European financial systems have not been as effective or purposeful as intended. Furthermore, EU financial centres are losing their competitive position at the expense of emerging financial markets, especially in Asia, which has demonstrated strong growth in recent years and has fully exploited and accelerated its innovation processes. In addition to Figure 1, Figure 2 presents the density plots of financial centres' ratings levels (subfigure 2a), alongside banks' estimated Z-scores (subfigure 2b) for 2007, 2010 and 2013. It is evident that during

2010, the instability of banks increased (lower Z-scores) alongside a reported decrease in financial centres' competitiveness levels.

We also noted that vast regions in the Southern Hemisphere do not have highly rated financial centres. In particular, financial centres in Africa, the Middle East (except Dubai) and South America have low ratings. The descriptive statistics on all variables, in addition to inputs/outputs used for banks' performance measurements, are reported in Table 2.

Insert Table 2 and Figure 2 about here

4. Empirical results

4.1 Efficiency trend: Main results and robustness check

Figure 3 presents, in a diachronic manner, the mean-efficiency scores for the 782 banks included in our sample. Specifically, Subfigure 3a shows the input-oriented efficiency scores derived from the DEA measures (see Equation 10)[8] and the robust *Order-α* (see Equation 12) frontiers, whereas Subfigure 3b displays the efficiency scores' standard deviations.

Our results indicate that the efficiency curve obtained from the partial frontier (solid line) is much higher compared with the efficiency curve derived from the full frontier (dashed, dotted line). It is reasonable to expect such a discrepancy between the two efficiency curves. In this regard, Daraio and Simar (2007) stated that partial frontiers are more robust to outliers because they do not envelop all data points, and they do not suffer from the curse of dimensionality. As for the efficiency trend, we noticed that the *Order-α* efficiency curve slightly decreased during the 2007-2009 period. Such a trend can be attributed to the GFC, which weakened the banking industry. Tsionas *et al.* (2015) also confirmed a drop in technical efficiencies around the time of the crisis

[8]We present here, for comparison reasons, the DEA estimates under the constant returns to scale (CRS) assumption. Banks with efficiency scores equal to 1 are regarded as efficient, whereas banks with efficiency scores less than 1 are regarded as inefficient. According to Zelenyuk and Zelenyuk (2014, p.9), the CRS assumption in the DEA framework has a greater discriminative power compared with the variable returns-to-scale (VRS) model and is more suited for measuring efficiency in highly competitive industries, such as the banking sector.

period. However, we also noticed that banks' efficiency gradually increased after 2009 (mid-2009s to 2013).

By focusing on the full frontier under the assumption of constant return to scale (CRS), we noticed that the decrease in banks' efficiency levels due to the GFC was larger (up to 2010) than in our estimation with the partial frontiers. Our evidence also indicated that banks stabilised their efficiency levels only after 2010. Such a difference between the two efficiency curves can be explained by the fact that we assumed that banks operate under the assumption of constant returns to scale. As depicted earlier, this assumption particularly suits highly competitive industries (such as the banking industry). Since the results of *Order-α* frontier are more robust that those of the CSR frontier, we only made use of the *Order-α* efficiency for conditional efficiency.

Figure 3 outlines the efficiency score' volatility. In particular, Subfigure 3b shows the estimated efficiency scores' standard deviations. Here, we noticed that the results have a low and stable standard-deviation value for the full frontier. In contrast, in the case of the partial frontier, the standard-deviation values are much higher and increased slightly over the examined period. The efficiency scores' volatility also is higher, especially during the GFC (i.e., 2008 and/or 2009). This finding is consistent with Tsionas (2006) and Matousek *et al.* (2015), who contended that evidence existed of a slow adjustment in efficiency levels following shocks to the banking system. The GFC actually has contributed to a strong deterioration in banks' balances and has increased banks' non-performing exposure.

De Haas and Van Horen (2013) showed that the GFC led to reductions in banks' lending activities, including new loans. Matousek *et al.* (2015) stated that despite consistent amounts of state aid and support provided to the banking system, especially in the EU and the US, along with reductions in labour and operation expenses, banks still did not restore their technical efficiency after the GFC.

Insert Figure 3 about here

4.2 How efficient are banks in financial centres? A global analysis

Figure 4 presents a map of the average efficiency score during the 2007-2013 period for the banks located in the same regions as the financial centres. We reported the results for the input-oriented efficiency scores derived from the robust (*Order-α*) and full-frontier (CRS) frontiers. Consistent discrepancies immediately are visible between the two frontiers, especially for some banks located near specific financial centres (e.g., London and Brussels). As shown in Figure 4, this result suggests that the use of a frontier that is more robust to outliers can reduce the problem of biased results and avoid misleading conclusions. For our discussion, we referred to the results relative to the efficiency scores derived from the *Order-α* frontier analysis.

The geography of banks suggests that the most efficient banks in terms of Order-α are located in Western-Central Europe (Frankfurt, Munich, Geneva, Milan and Amsterdam), Northern Europe (Edinburgh and Copenhagen), and especially in Asia and Australia (Melbourne, Sydney). By contrast, the big European cities (Paris and London) demonstrated relatively low efficiency. This finding is attributed to the fact that the GFC hit these financial centres severely, and as a result, this reflects on these banks' efficiency levels. Apart from a few exceptions (Tokyo), the banks located near Asian financial centres in China, Japan (Osaka), Singapore and India (Mumbai) appear to have a relatively high technical-efficiency level (especially Osaka and Hong Kong) compared with banks in other geographical areas. When shifting our focus to the US, we noticed that the most efficient banks are located on the East Coast, with New York and Boston as the leading centres when compared with others (e.g., San Francisco, Chicago). New York and Boston also have a high rating in an international context.

Insert Figure 4 about here

4.3 Financial centres' ratings and risks, and banks' innovation capacity

In this section, we examine how and to what extent banks' innovation capacity (frontier shift) is explained jointly by financial centres' competitiveness and stability. From a methodological perspective, we employed the non-parametric model proposed by Bădin *et al.* (2012). Figure 5 presents the effect of financial centres and risk exposure on banks' innovation capacity (frontier shift). The three-dimensional picture displayed in Figure 5 has 'Qα' ratios as a dependent variable, representing the effect on banks' technological-change levels. This figure was derived from the local, linear, non-parametric regression analysis of the 'Q' ratios against the ratings of financial centres and banks' Z-score values. In particular, it examined the effect of financial centres' ratings and Z-scores on innovation capacity for the entire sample.

Our findings suggest that the proximity of a bank to a financial centre with a high rating matters for banks' technological-change levels. Specifically, it appears that most competitive (i.e., highly rated) financial centres have a positive effect on banks' technological change. The slightly downward, sloping, non-parametric regression line indicates a positive effect. This finding is consistent with previous studies showing that financial centres generate positive externalities for technological spillover (Cassis, 2007; Groote, 2008).

Our findings also show that banks' stability (which was examined with the financial centres' ratings) positively influences the banking system's innovation capacity. Unlike previous studies (Berger and De Young, 1997; Williams, 2004; Fiordelisi *et al.*, 2011; Schaeck and Cihák, 2014)[9], we noted that the relationship between innovation capacity and stability is not linear. In particular, we found that banks exhibit improvements in their technological-change levels only for higher Z-scores (higher than 2). In contrast, banks with low levels of stability (from 0 to 2) appear to experience a decrease in technological change (indicated by an increasing nonparametric line). This would suggest that banks can achieve a higher level of innovation capacity only when they have a high level of stability. During the GFC, banks actually were more vulnerable to pressure from both the funding and lending sides simultaneously. They consistently reduced their lending activities, including new loans (e.g., De Haas and Van Horen, 2013; Ivashina and Scharfstein, 2013), and were under pressure due to the freeze in the European Interbank market and the threat of a drop in the deposit supply side because of 'bank runs' (Iyer *et al.*, 2014).

Looking at the joint effect of financial centres' competitiveness and stability, we noticed that innovation capacity can be promoted in the banking industry when banks are more stable and are based in a more favourable business environment. As depicted

[9] These papers mainly focused on cost efficiency, rather than technical efficiency.

earlier, the business-environment competitiveness of financial centres creates conditions that promote technological advancement (e.g., Cassis, 2007; Groote, 2008) by mitigating asymmetric information problems (e.g., Engelen, 2007).

Our results also support extant literature on 'competition fragility' and 'competition stability' (Beck *et al.*, 2006; Boyd and De Nicolò, 2005; Schaeck and Cihák, 2014; Schaeck *et al.*, 2009), which historically have focused on banking competition as a driver of banking stability, while underplaying the importance of financial centres' business environments.

Insert Figure 5 about here

4.4 Additional robustness check

In this section, we account for the size of banks to investigate whether our results differ significantly for large and small banks. Recent extant research suggests that implicit and explicit guarantees can strengthen the perception and probability that big banks will be bailed out during crisis periods because they are 'too big to fail' (Hakenes & Schnabel, 2010; Völz and Wedow, 2011).

Berger and Roman (2015) recently found that markets power banks, typically the large ones, which take on more risk compared with their smaller counterparts because of capital injections during the TARP programme. Consequently, compared with small banks, large banks could have had a different risk attitude during the GFC. Therefore, we reran our main model by splitting the sample into large and small banks.

Subfigure 6a focuses on large banks[10], while Subfigure 6b describes the joint effect of financial centres' ratings and banks' stability on innovation capacity for small banks. Our results suggest that financial centres with high ratings marginally improve larger banks' innovation capacity, as indicated by the rather straight nonparametric line. Furthermore, large banks' stability appears to boost innovation capacity, but only under high levels of stability. Again, all the observed effects are non-linear. A possible

[10]For a robustness check of our estimates, banks were classified into large and small by separating the overall sample into two sub-samples based on average size. Bank size was measured using the logarithm of banks' total assets, providing us with a homogeneous definition of small and large banks without using the definition that local regulators provided.

explanation for this result might be that large banks typically are more diversified and eventually can cope better with risk and technological change than small banks. Actually, diversification can reduce banks' individual probability of failure (Wagner, 2010), eventually allowing them to achieve innovation capacity at lower levels of stability, even though non-interest-income sources tend to be more volatile than traditional interest-income sources (Lepetit *et al.*, 2008; Stiroh and Rumble, 2006). With respect to small banks, we noticed instead that they can increase their innovation capacity by improving their stability. By comparing Subfigures 6a and 6b, we noted that the effect of stability on their innovation-capacity levels decreased in a more linear fashion in Subfigure 6b, signifying a positive effect. It is evident that financial centres' competitiveness has a more pronounced positive effect on small banks' innovation-capacity levels.

Insert Figure 6 about here

5. Conclusion

This paper investigated the effects of financial centres' competitiveness and risk on banks' innovation capacity (technological change) during the Global Financial Crisis. We used a new index, the Global Financial Centres Index, which measures financial centres' business-environment competitiveness. In particular, we used this new index to gauge 45 financial centres worldwide, eliciting several important contributions to ongoing empirical research on banking performance and risk.

From a theoretical perspective, we presented evidence on the mechanisms underlying technological change (innovation capacity). From a methodological perspective, we calculated the conditional *Order-α*, quantile-type, input-oriented efficiency following Daraio and Simar (2005, 2007). This methodology has the advantage of providing partial frontiers that are more robust than outliers (Daouia and Simar, 2007). Next, we employed the latest advances in nonparametric frontier analysis, proposed by Bădin *et al.* (2012), which allowed us to examine efficiency and technical change as a function of banks' risk and the ratings of the financial centres' geographic proximities.

We found that the most efficient banking systems are located in Western-Central Europe, Northern Europe and Asia. Furthermore, our key findings suggested that business-environment competitiveness plays a pivotal role in stimulating technological change. Our findings supported the view that business-environment competitiveness in financial conditions promotes innovation (Cassis, 2007; Groote, 2008). In contrast to several other studies (Berger and De Young, 1997; Williams, 2004; Fiordelisi *et al.*, 2011; Schaeck and Cihák, 2014), we found that the relationship between innovation capacity and stability is not linear. In particular, we found that banks exhibit improvements in technological-change levels only for a higher Z-score value. Conversely, lower stability appears to hinder improvements in technological change. In particular, we found that large banks can improve their innovation-capacity levels only when they achieve a high level of stability. In contrast, the relationship between stability and innovation capacity follows a more linear pattern in the case of small banks. This finding elicits important implications for policymaking and regulation, as it suggests that banks' innovation capacity can be promoted through policy interventions aimed at enhancing the business environment where banks operate. In particular, by improving the drivers of financial centres' competitiveness, e.g., regulatory systems, infrastructure, labour-market flexibility and market access, banks can improve their innovation-capacity levels. We also contend that EU financial centres lost their competitiveness edge amid emerging financial markets, especially in Asia.

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