INSTITUTE OF FOOD AND RESOURCE ECONOMICS
UNIVERSITY OF COPENHAGEN

MSAP Working Paper Series

No. 03/2012

Bank efficiency and risk during the financial crisis: Evidence from weight restricted DEA models

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July 6, 2012

Abstract

The recent financial crisis highlighted how banks' funding and investment portfolios are associated with their risk taking. In a "normal" DEA banking efficiency model this risk element, embedded in banks' business models, is indicated by possibly inappropriate mixes of funding portfolio and/or investment portfolio which, in turn, is revealed by the weights assigned by each bank to the inputs and outputs in the model. Using the crisis as a natural experiment, we define weight restrictions to be imposed on all banks by using the banks that were not bailed out during the crisis, or with relatively higher external rating, and which are efficient in the normal DEA model, as our model banks. Thus, banks seemingly taking excessive risks by using inappropriate weights to make themselves look efficient, are restricted to only applying weights also used by efficient non-bailed-out banks.

Analysing data collected from audited financial statements of around 70 of the largest EU banks from 2006 to 2009, we find a clear pattern indicating that non-bailed-out banks with relatively high external rating become significantly more efficient than the other banks once weight restrictions are applied to control for risk, even if this pattern was not clear from the models without weight restrictions. In models already incorporating some risk elements, the non-bailed-out banks are significantly more efficient even before weight restrictions are included, but the imposition of weight restrictions makes the pattern even stronger.

Keywords: Data Envelopment Analysis (DEA), weight restrictions, banking, efficiency, risk, financial crisis.

1 Introduction

The recent financial crisis revealed the relationship between banks' risks and their funding and portfolio structures. On the funding side, over-reliance on wholesale funding may expose banks to excessive risk if there is a sudden withdrawal of funding in the wholesale funding market as was the case during the crisis. On the asset side, a bank's investment portfolio is associated with exposure to market risks such as volatility in interest rates, exchange rates, commodity prices, share prices and bubbles in the real estate market and credit risk.

In this paper we use Data Envelopment Analysis (DEA) models (c.f. Charnes et al., 1978) to analyse the efficiency of a representative sample of over 70 of the largest European banks. The set of banks is divided into two groups, of those banks that were required to undergo far-reaching restructuring to return to viability and those that were not required to undergo restructuring. It is evident that the funding structures, loan portfolios and relative amounts of trading assets are different between these two groups of banks. Besides explicit risk factors such as loan quality, other risk elements originating from a bank's input and/or output mixes are implicitly embedded in their business models. In the analysis in this paper we incorporate these risk elements directly into efficiency measurement models. As well as controlling for loan quality and loan loss provision, we account for the implicit risk element arising from the input and/or output mixes. This is done by restricting the weights attached to inputs and outputs during the optimisation process, thereby restricting the possibilities of excessive risk taking arising from inappropriate reliance on certain inputs and/or output. The weight restrictions are defined from the efficient non-bailed-out banks serving as model banks. This way, only the weights used by these model banks can be applied by any bank during the efficiency measurement.

In a DEA model that directly incorporates risks arising from impaired loans, as well as indirectly captures the risk of the output mix through the prices, the group of non-bailed-out banks have significantly higher efficiency scores than the bailed-out banks. However, in a DEA model considering the input mix, there is no significant difference in efficiency scores between bailed-out and non-bailed-out banks before any weight restrictions are applied. But once weight restrictions are included to control for risk taking, a clear pattern emerges that bailed-out banks are significantly less efficient than non-bailed-out banks. We also find evidence that bailed-out banks' efficiency scores are more affected by the imposition of the weight restrictions than those of the non-bailed-out banks. These patterns are also found in an alternative classification where external rating information is also considered when classifying the banks into sounds and unsound, which shows the robustness of the results.

The rest of this paper is structured as follows: In section 2 we briefly describe the EU supported aid to the banks and section 3 provides a brief review of some of the relevant literature. In section 4 the DEA models, both without and with weight restrictions, used to assess the efficiencies of the banks are defined. Section 5 provides a description of the data, models and variables used for the analysis and section 6 comprises the results. Finally section 7 concludes the paper.

2 Background: EU sanctioned state aid to banks

The large European banks considered in this study have in our empirical analysis been divided into two groups according to the state aid they received during the crisis: The banks that received substantial government support during the crisis and were required to undergo far-reaching restructuring to return to viability (bailed-out banks), and banks that may have had access to government support through national-level general schemes (such as a central bank liquidity facility or state guarantee) but were not required to undergo restructuring (non-bailed-out banks).

To better understand the difference between bailed-out and non-bailed-out banks, we here provide a brief background of the interventions by the EU competition authority during the recent financial crisis, regarding the grant of aid by each member state to the financial sector. During the crisis, the EU Member States intervened on a large scale to rescue failing financial institutions. In order to ensure that the rescue measures in each member state could attain the objectives of financial stability and maintenance of credit flows, whilst still ensuring a level playing field between banks located in different member states as well as between banks which received public support and those which did not, avoiding harmful subsidy races, limiting moral hazard and ensuring the competitiveness and efficiency of European banks, the European Commission intervened to control the aid granted by each of the member states. Five successive communications providing guidance on the design and implementation of state aid in favour of banks were issued between October 2008 and July 2009. The guidance relates to two types of aid: 1) General schemes to aid all banks, and 2) Ad hoc interventions in support of a particular bank. Detailed information on the general guidance and on specific cases are available from the European Commission's website and the European Commission's state aid register.

The above distinction is made to enable us choosing model banks used to provide appropriate weight restrictions (see section 4.2 for details). However, recognising that some non-bailed-out banks may have been lucky to get away with only receiving general rather than individual aid, but may still be intrinsically unsound, we also consider external credit rating information in an alternative classification of model banks. The external rating by Moody was used because they, besides rating the banks' debts and deposit as other rating agencies (like S&P and Fitch) do, also have a rating related to banks' intrinsic financial strength, Bank Financial Strength Ratings (BFSRs) which represent Moody's opinion of a bank's intrinsic safety and soundness. Unlike deposit ratings, BFSRs do not address the probability of timely payment. Instead BFSRs are a measure of the likelihood that a bank will require assistance from third parties, such as its owners, its industry group, or official institutions. Factors considered in the assignment of BFSRs include bank-specific elements such as financial fundamentals, franchise value, and business and asset diversification. BFSRs do not take into account the probability that the bank will receive external support mentioned above, nor do they address risks arising from sovereign actions that may interfere with a bank's ability to honour its domestic or foreign currency obligations. However, they do take into account other risk factors in the bank's operating environment, including the strength and prospective performance of the economy, as well as the structure and relative fragility of the financial system, and the quality of banking regulation and supervision. Further information on the rating is provided on Moody's website and is publicly available. Based on the rating information, we also choose as model banks the non-bailed banks with BFSRs of C or above, with long term deposit rating of A or above and with short term deposit rating of Prime-1. We call these banks "sound" banks. See the Appendix for the rating scales of BFSRs and deposit ratings.

3 Selective literature review

The research presented in this paper is related to the strand of literature separating risk from performance when measuring bank efficiency. Laeven (1990) is among the earliest to consider a risk measure in the analysis of bank efficiency. Laeven (1990) uses excessive loan growth, defined as the growth above the level of loans that a bank would have provided if it would have put its inputs to use as efficiently as in a defined base year, as their measure of risk. Hughes et al. (2001) use a best-practice risk-return frontier to measure inefficiency, where expected return is obtained from a managerial utility maximising profit function. Therefore, in their framework, instead of the common considerations of profit maximisation or cost minimisation, a bank is considered efficient if the trade-off between risk and expected return is made with minimum agency cost. More recently, Settlage et al. (2009) propose a DEA model in which banks are assumed to behave as mean-variance utility maximisers. More specifically, their model determines the maximum level of profits given the additional constraint that the observed level of variance of a bank's portfolio (an indicator of risk) cannot be exceeded. This maximum level of expected profit is then compared to the observed level of profits, with equality implying risk-adjusted efficiency. Other studies include risk measures in the model to control for risk. For instance, Berg et al. (1992) and Hughes and Mester (1993) included non-performing loan as an input. Altunbas et al. (2001) use equity capital and Pastor and Serrano (2005) incorporate loan loss provisions in their efficiency estimations to control for risk. There are also studies treating risk as an external factor and analysing the effect of risk on efficiency in two-stage DEA or SFA models, see for instance Chang (1999), Carvallo and Kasman (2005), Yildirim and Philippatos (2007) and Koutsomanoli-Filippaki and Mamatzakis (2011).

The present work differs from the above studies by proposing a way to incorporate a risk element into the efficiency measurement model without explicitly quantifying bank risk beforehand. Based on the lessons learned during the recent financial crisis, we suggest that, besides explicit risk measures such as loan quality (along the lines of what is used in some of the above studies), another risk element is implicitly embedded in banks' business models through their reliance on certain inputs and/or outputs. Therefore we, as well as controlling for loan quality and loan loss provision (as shown in section 5), account for this implicit risk element by restricting the weights that are allowed for inputs and outputs during the optimisation process. This way, the efficiency model penalises excessive risk taking arising from inappropriate mixes of inputs and/or outputs.

The research is also related to another strand of literature discussing the relationship between risk and efficiency. As argued by Berger et al. (1997), the relationship between efficiency and risk can be in different directions. If bank managers are bad at managing the banks efficiently, the poor management may lead to both low efficiency as well as high levels of problem loans, i.e. higher risk (bad management hypothesis). Alternatively, short-run "inefficiency" of banks devoting resources to loan underwriting and monitoring may lead to less problem loans in the long run, indicating a risk-efficiency trade off (skimping hypothesis). Or the other way around, a bank may take higher risk to pursue short-run efficiency. Similarly, a bank which is currently inefficient may be expected to take higher risk in the near future (also known as the moral hazard hypothesis). Using U.S. evidence, Berger et al. (1997) and Kwan and Eisenbeis (1997) show that poorly performing banks in the U.S. are more vulnerable to risk-taking and increases in problem loans (bad management). However, Altunbas et al. (2007) do not find a positive relationship between inefficiency and bank risk-taking in Europe. Instead, inefficient banks appear to be less risky (skimping). By contrast, using a slightly different sample in Europe, Williams (2004) finds that poorly managed banks tend to make more poor quality loans, consistent with the U.S. evidence. More recently, Fiordelisi et al. (2011) suggest that banks lagging behind in their efficiency levels might expect higher risk in the near future (moral hazard).

This research contributes to the above literature by investigating the relationship between efficiency and risk during the financial crisis. We find that, in models controlling for risk, non-bailed-out banks are more efficient than bailed-out banks, also when using credit rating information to select model banks. We also find evidence that bailed-out banks are more affected by the imposition of weight restrictions controlling for risk than non-bailed-out banks. Thus we find evidence of a risk-efficiency trade-off, where reducing the ability to take certain risks reduces the efficiencies, especially for the banks that proved to be exhibiting high-risk behaviour as indicated by their need for government bail-outs. In the next section we formally define the DEA models used to analyse efficiency with and without weight restrictions.

4 Methodology

Let N be the set of n observed banks, $j = 1, \ldots, n$ described in section 5 below. The banks are observed in four different years, t=2006, ...,2009, and within each DEA model considered a bank is viewed as using $k = 1, \ldots, r$ inputs to produce $l = 1, \ldots, s$ outputs. The variables considered in the models are defined in section 5. Let $(x^k_{j.t})$ denote bank j's consumption of the k'th input in year t and $(y^l_{j.t})$ its production of the l'th output in year t. Thus bank j in year t is described as $(x_{j.t}, y_{j.t}) \in \mathbf{R}^{r+s}_{+}$. Further let the set of observed banks N be divided into two mutually exclusive and exhaustive subsets $N^{Problem}$ and N^{Model}, where $N^{Problem}$ contains the banks that were bailed out by their respective governments during the financial crisis (or have low ratings in the alternative classification), and N^{Model} comprises the non-bailed-out (highly rated) banks used as model banks.

4.1 Unrestricted DEA models

The unrestricted DEA efficiency score $E_{i.t}$ under constant returns to scale (c.f. Charnes et al., 1978) for bank i within a given year t, $(x_{i.t}, y_{i.t}) \in \mathbf{R}^{r+s}_{+}$, but compared to a pooled frontier defined by all banks in all years of the study period, is in the envelopment form given by

$$
\begin{aligned}
E_{i.t} = \quad & 1/\max \phi_{i.t} \\
\text{s.t.} \quad & \sum_{t=2006}^{2009} \sum_{j=1}^{n} \lambda_{j.t} x^k_{j.t} \leq x^k_{i.t}, k = 1, \ldots, r \\
& \sum_{t=2006}^{2009} \sum_{j=1}^{n} \lambda_{j.t} y^l_{j.t} \geq \phi_{i.t} y^l_{i.t}, l = 1, \ldots, s \\
& \lambda_{j.t} \geq 0, j = 1, \ldots, n.
\end{aligned}
\qquad (1)
$$

The model above is formulated as being output oriented, and in the following we consider both input- and output oriented model. But since we are assuming constant returns to scale, the efficiency scores from input- and output oriented models will be identical, and therefore we do not here formally define input oriented versions of the models.

The dual formulation of the LP model (1) above is given by

$$
\begin{aligned}
E_{i.t} = \quad & 1/\min \sum_{k=1}^{r} v^k_{i.t} x^k_{i.t} \\
\text{s.t.} \quad & \sum_{l=1}^{s} u^l_{i.t} y^l_{i.t} \geq 1,
\end{aligned}
\qquad (2)
$$

$$\sum_{t=2006}^{2009}\sum_{k=1}^{r} v_{i.t}^{k} x_{j.t}^{k} - \sum_{t=2006}^{2009}\sum_{l=1}^{s} u_{i.t}^{l} y_{j.t}^{l} \geq 0, j = 1, \ldots, n$$
$$v_{i.t}^{k}, u_{i.t}^{l} \geq 0, k = 1, \ldots, r, l = 1, \ldots, s,$$

where the dual variables $v_{i.t} \in \mathbf{R}_{+}^{r}$ and $u_{i.t} \in \mathbf{R}_{+}^{s}$ are the weights, or multipliers, assigned to the inputs and outputs by the bank under analysis (bank i) in the specific year t.

The normal unrestricted DEA multiplier model (2) above allows each bank to choose the weights that make themselves appear as efficient as possible, subject only to the constraints that all weights are non-negative and that no bank $j \in N$ in year t can have an efficiency score $\frac{v_{i.t} x_{j.t}}{u_{i.t} y_{j.t}} \geq 1$ with that set of weights.

To prevent banks from choosing what is deemed inappropriate weights, including for instance assigning weights of zero to inputs and/or outputs that the bank performs relatively poorly on, various forms of weight restrictions have been proposed in the literature. Allen et al. (1997) provide a survey of studies on weight restrictions and value judgments in DEA. Of particular relevance to this paper is Charnes et al. (1990)'s cone ratio approach where cones are selected either to emphasize inputs and/or outputs, or to favour individual observations based on external expert opinions, thus tightening the efficiency criteria. Similar to that approach we in this study use relative weight restrictions, i.e. imposing restrictions on ratios of the weights such that banks are restricted to using only weights within a certain range on one input or output relative to the weight on another input or output. For instance, a bank will only be allowed to use a certain range of weights assigned to wholesale funding relative to the weight on retail funding. The following subsection illustrates how relative weight restrictions, defined from the set of model banks, are applied in this study.

4.2 DEA models with weight restrictions

For each year we consider the non-bailed-out and efficient (or alternatively high rated) banks as the 'model' banks (N^{ME}) that is, the banks from the set N^{Model} that are fully efficient in the unrestricted DEA models above, i.e. with $\phi_{i.t}^{*} = 1$ in models (1) and (2). Thus let $N^{ME} = \{(x_{i.t}, y_{i.t}) \in N^{Model} | \phi_{i.t}^{*} = 1\}$.

Following Charnes et al. (1990), we consider using the ranges of weights from the non-bailed-out efficient model banks, N^{ME}, to provide relative weight restrictions to be used for all banks. This way, a relative restriction (or range of allowable weights) between, for instance, two inputs, k' and k'', defined from the set of non-bailed-out and efficient model banks, N^{ME}, would be given as:

$$\frac{\min_{j \in N^{ME}} v_{j.t}^{k'}}{\max_{j \in N^{ME}} v_{j.t}^{k''}} \leq \frac{v_{i.t}^{k'}}{v_{i.t}^{k''}} \leq \frac{\max_{j \in N^{ME}} v_{j.t}^{k'}}{\min_{j \in N^{ME}} v_{j.t}^{k''}}, \tag{3}$$

and similarly for restrictions between two outputs or between an input and an output.

This approach does, however, suffer from two practical problems I) Minimum values of zero, and II) Non-unique weights.

I) For all the variables considered for the relative weight restrictions included into the empirical models, the minimum value across the model banks is zero. This means that the lower value for the ranges of allowable weights in all cases is zero and, more problematically, that the upper value is undefined. As a practical, but unsatisfactory, measure one could consider using the minimum non-zero value amongst the model banks to define the restrictions.

II) When estimating the weights from the linear programming model (2), most efficient observations will tend to have non-unique optimal weights. This means that there, for each model bank, will be a range of optimal weights that have to be considered when estimating the weight restrictions - and those ranges are generally burdensome to identify in practice.

For these reasons we have chosen a slightly different approach to using the model banks to provide weight restrictions to be used for all banks. Specifically we consider all fully-dimensional facets of the efficient frontier (see e.g. Olesen and Petersen, 2003) that are spanned only by (efficient) model banks. These facets will each have a unique set of non-zero weights that are optimal for all of the model banks spanning that facet. In practice, the facets of the efficient frontier can be identified using the QHull software, which also provides information about which observations span each facet. We can then use the ranges of weights across those facets to provide weight restrictions. Denote the set of fully-dimensional facets spanned only by model banks by F and let ν_h^k and μ_h^k denote the input- and output weights respectively, on the h'th facet. A relative restriction (or range of allowable weights) between two inputs, k' and k'', defined from the set of fully-dimensional facets F (which again are determined from the (efficient) model banks, N^{ME}), would now be given as:

$$\min_{h \in F} \frac{\nu_h^{k'}}{\nu_h^{k''}} \leq \frac{\nu_{i.t}^{k'}}{\nu_{i.t}^{k''}} \leq \max_{h \in F} \frac{\nu_h^{k'}}{\nu_h^{k''}}. \tag{4}$$

Similarly the general restriction between two outputs, l' and l'', is given by:

$$\min_{h \in F} \frac{\mu_h^{l'}}{\mu_h^{l''}} \leq \frac{\mu_{i.t}^{l'}}{\mu_{i.t}^{l''}} \leq \max_{h \in F} \frac{\mu_h^{l'}}{\mu_h^{l''}}, \tag{5}$$

and the restriction between an input k' and an output l' is:

$$\min_{h \in F} \frac{\nu_h^{k'}}{\mu_h^{l'}} \leq \frac{\nu_{i.t}^{k'}}{\mu_{i.t}^{l'}} \leq \max_{h \in F} \frac{\nu_h^{k'}}{\mu_h^{l'}}. \tag{6}$$

For the pairs of inputs and/or outputs for which relative restrictions are desired, the corresponding ranges of allowable weights are defined from equation (4), (5) or (6) above as appropriate, linearised, and simply added as constraints to the DEA multiplier model (2).

5 Data

The data used to analyse the risk and efficiency of the European banking system includes annual observations (2006, . . . ,2009) from 71 European banks headquartered in 20 different member states. This sample of banks, with total assets of EUR 27,021 billion at the end of 2009, represents approximately 63% of the total assets of the EU-27 banking system. All data are collected directly from banks' audited financial reports.

5.1 Sample selection

The selection of the sample follows the principle used by the 2010 EU-wide stress test exercise conducted by the Committee for European Banking Supervisors (CEBS)[1] for its selection of the sample banks. The CEBS sample is designed to be representative enough to provide a good proxy of the overall resilience of the EU banking sector. The scope includes the major EU cross-border banking groups and a group of additional, mostly large, credit institutions in Europe. In each EU member state, the sample has been built by including banks, in descending order of size, so as to cover at least 50% of the national banking sector, expressed in terms of total assets. Once the market share, in terms of total assets, reached 50% no other bank was included from that member state, unless it voluntarily wished to include additional banks. Two special cases are Germany and Spain. In Germany, the public banking sector dominated by 7 Landesbankens faced severe financial difficulties during the financial crisis. Consequently 14 banks, including both the largest commercial banks and the public owned Landesbankens, have been included, representing more than 50% of the market share in German banking system in terms of total assets. In Spain 27 banks were included, representing around 95% of the Spanish banking system in terms of total assets, amongst which 25 were domestic savings banks (CAJAs) representing around 40% of the assets in the Spanish banking system. These savings banks also faced severe financial difficulties during the crisis. As a result the EU-wide stress test includes 91 banks in total.

In this study, for the sake of consistency and comparability, banks are included in descending order of size to cover at least 50% of the national banking sector in terms of total assets. As mentioned previously, we divide all banks into two groups, i.e. bailed-out banks and non-bailed-out banks (alternatively unsound and sound c.f. the alternative classification described in Section 2) and use the efficient non-bailed-out (sound) banks to design weight restrictions imposed on all banks. In our sample, there are 23 banks

[1]Detailed information about the EU-wide stress test is available at http://www.c-ebs.org/EuWideStressTesting.aspx

that received significant amounts of aid (in the form of capital injections, toxic asset relief measures and state guarantees) approved by the European Commission on an individual basis. These banks are considered by the national authorities and/or the European Commission as financially distressed banks which require far-reaching restructuring over the next few years to restore viability. Some of these banks were not included in the EU-wide stress test but are included in our study. Moreover, our sample includes 5 Spanish savings banks (which now belong to 3 savings bank groups following mergers and restructuring of the Spanish savings banking industry) which failed the EU wide stress test in 2010. Detailed data for the other 2 savings groups that also failed the stress test were not available. Finally, the Greek bank ATE is included since it also failed the EU wide stress test in 2010. The rest of the banks are considered by the national authorities and/or the European Commission to be internally efficient and sound, but adversely affected by the extreme market conditions during the crisis. They still had access to government support through general schemes open to all banks, but these banks were expected to be able to return to viability with the general-scheme support and without far-reaching restructuring. The total number of banks included in our sample is 71, of which 29 are classified as bailed-out, having received significant amounts of aid and/or failed the EU stress test whereas the remaining 42 banks are classified as non-bailed-out, c.f. the fifth column in Table 1 below.

As a robustness check we also use an alternative classification based also on external rating information, c.f. section 2, where 34 and 37 banks are classified as sound (S) and unsound (US) respectively, as shown in the last column in Table 1.

It is worth noting that the EU banks have been selected on a group-wide basis. This means that subsidiaries and branches of a cross-border operating bank are included as part of its consolidated group in the sample. As such, all EU Member States are covered indeed and the data of an EU subsidiary of a foreign EU banking group are covered as part of a consolidated group. As a result, the banks in the sample are headquartered in 20 EU Member States. For the remaining 7 EU Member States, where more than 50% of the local market was already covered, no further bank was added to the sample. The list of banks included in this study with their market shares (in terms of total assets) in the EU-27 banking system is reported in Table 1 below.

Table 1: List of banks included in the sample

Bank	Member State	Total Assets by end of 2009 (EUR bn)	Market share (total assets) in EU-27 (%)	Far-reaching restructuring	BFSR rating	LT deposit rating	ST deposit rating	Sound bank
ERSTE	Austria	201.7	0.5	N	C	Aa3	P-1	Y
RZB	Austria	147.9	0.3	N	D+	A	P-1	N
BAWAG	Austria	41.2	0.1	Y	D	Baa1	P-2	N
Hypo Tirol	Austria	12.2	0.0	Y	C	Aa1	P-1	N
HGAA	Austria	41.0	0.1	Y	D	Baa1	P-2	N

Table 1: List of banks included in the sample

Bank	Member State	Total Assets by end of 2009 (EUR bn)	Market share (total assets) in EU-27 (%)	Far-reaching restructuring	BFSR rating	LT deposit rating	ST deposit rating	Sound bank
KBC	Belgium	281.6	0.7	Y	C+	Aa3	P-1	N
Dexia	Belgium	577.6	1.3	Y	D+	A	P-1	N
Fortis	Belgium	435.0	1.0	Y	C	A1	P-1	N
Marfin Popular	Cyprus	41.8	0.1	N	C-	A3	P-1	Y
Bank of Cyprus	Cyprus	39.4	0.1	N	C	A2	P-1	Y
DANSKE	Denmark	416.3	1.0	N	C+	Aa3	P-1	Y
JYSKE	Denmark	30.2	0.1	N	C+	A1	P-1	Y
SYDBANK	Denmark	21.2	0.0	N	C+	A1	P-1	Y
OP-Pohjola	Finland	80.4	0.2	N	B-	Aa2	P-1	Y
BNP Paribas	France	2057.7	4.8	N	B-	Aa2	P-1	Y
BPCE	France	1028.8	2.4	Y	C-	Aa3	P-1	N
Credit Agricole	France	1694	3.9	N	B-	Aa1	P-1	Y
Societe Generale	France	1023.7	2.4	N	C+	Aa2	P-1	Y
Deutsche	Germany	1501	3.5	N	B	Aa1	P-1	Y
Commerzbank	Germany	844.1	2.0	Y	C-	Aa3	P-1	N
Hypo Real Estate	Germany	359.7	0.8	Y	E+	A3	P-1	N
LBBW	Germany	411.7	1.0	Y	C-	Aa2	P-1	N
NordLB	Germany	238.7	0.6	Y	C-	Aa2	P-1	N
WestLB	Germany	242.3	0.6	Y	E+	A2	P-1	N
HSH Nordbank	Germany	174.5	0.4	Y	D+	Aa2	P-1	N
NBoG	Greece	113.4	0.3	N	C	A1	P-1	Y
EFGEurobank	Greece	84.3	0.2	N	C-	A2	P-1	Y
Alpha	Greece	69.6	0.2	N	C-	A2	P-1	Y
Piraues	Greece	54.3	0.1	N	C-	A2	P-1	Y
ATE	Greece	32.8	0.1	Y	C-	A1	P-2	N
TT Hellenic Postbanks	Greece	18.0	0.0	N	-	-	-	Y
OTP	Hungary	36.1	0.1	N	D+	Baa1	P-2	N
FHB	Hungary	3.0	0.0	N	D+	Baa3	P-3	N
BoI	Ireland	194.1	0.5	Y	D	A1	P-1	N
Allied Irish Bank	Ireland	174.3	0.4	Y	D	A1	P-1	N
Anglo Irish Bank	Ireland	85.2	0.2	Y	E	A3	P-1	N
UniCredit	Italy	928.8	2.2	N	C+	Aa3	P-1	Y
Intesa Sanpaolo	Italy	624.8	1.5	N	B-	Aa2	P-1	Y
Monte dei Pasche di Siena	Italy	224.8	0.5	N	C-	Aa3	P-1	Y
BPSC	Italy	135.7	0.3	N	C-	A2	P-1	Y
UBI	Italy	122.3	0.3	N	C	Baa1	P-1	N
BCEE	Luxembourg	37.6	0.1	N	C+	Aaa	P-1	Y
ING	Netherlands	882.1	2.1	Y	C+	Aa3	P-1	N
RABO	Netherlands	607.7	1.4	N	B+	Aaa	P-1	Y
ABN AMRO	Netherlands	676.3	1.6	Y	D	A2	P-1	N
FBN	Netherlands	189.8	0.4	Y	C	A1	P-1	N

Table 1: List of banks included in the sample

Bank	Member State	Total Assets by end of 2009 (EUR bn)	Market share (total assets) in EU-27 (%)	Far-reaching restructuring	BFSR rating	LT deposit rating	ST deposit rating	Sound bank
SNS	Netherlands	80.3	0.2	Y	C	A2	P-1	N
BoV	Malta	6.2	0.0	N	D+	Baa2	P-1	N
PKO	Poland	38.1	0.1	N	C-	A2	P-1	Y
CGD	Portugal	105.8	0.2	N	C-	Aa2	P-1	Y
BCP	Portugal	95.6	0.2	N	D+	A1	P-1	N
Espirlto Santo	Portugal	78.1	0.2	N	C-	A3	P-2	N
BPI	Portugal	47.4	0.1	N	C-	A1	P-1	Y
NLB	Slovenia	15.5	0.0	N	C-	A1	P-1	Y
Santander	Spain	1110.5	2.6	N	B-	Aa2	P-1	Y
BBVA	Spain	535.1	1.2	N	B-	Aa2	P-1	Y
LA Caixa	Spain	271.9	0.6	N	B-	Aa2	P-1	Y
Caixa Catlunya	Spain	63.7	0.1	Y	D-	A2	P-2	N
Caixa Tarragona	Spain	10.8	0.0	Y	C-	Baa1	P-2	N
Caixa Manresa	Spain	6.5	0.0	Y	D+	Baa1	P-2	N
Caixa Navarra	Spain	19.5	0.0	Y	C	A2	P-1	N
CajaSur	Spain	19.0	0.0	Y	-	-	-	N
Nordea	Sweden	507.5	1.2	N	C+	Aa2	P-1	Y
SEB	Sweden	225.1	0.5	N	C-	A1	P-1	Y
SB	Sweden	207.1	0.5	N	C+	Aa2	P-1	Y
Swedbank	Sweden	175.1	0.4	N	D+	A2	P-1	N
RBS	UK	1714.3	4.0	Y	C-	A1	P-1	N
HSBC	UK	1641.3	3.8	N	C+	Aa2	P-1	Y
Barclays	UK	1552.7	3.6	N	C	Aa3	P-1	N
Lloyds banking group	UK	1156.7	2.7	Y	C-	A1	P-1	N
Northern Rock	UK	98.5	0.2	Y	E	A2	P-1	N
Total	EU-27	27021.2						
Accumulative market share (%)	EU-27		63.0					

a. Total assets include total loans, financial assets and fixed assets.

b. Market shares are calculated based on data from banks' audited financial reports.

c. Total assets of the EU banking system is from ECB.

d. Data including rating information shown in the table are as at the end of 2009.

5.2 Differences between bailed-out and non-bailed-out (unsound and sound) banks

Table 2 below shows the differences in funding structure and asset portfolios between bailed-out and non-bailed-out banks. Table 3 shows the differences when we instead classify the banks as unsound and sound banks as mentioned in section 2.

In Table 2 and 3, wholesale funding includes inter-bank lending, debt securities issued and subordinated debt; total funding includes retail funding (deposit from individuals and firms) and

Table 2: Mean comparisons of funding structure, and loan and financial asset portfolio between bailed-out (B) and non-bailed-out (NB) banks

	Year 2006		Year 2007		Year 2008		Year 2009	
	B	NB	B	NB	B	NB	B	NB
No. of Obs.	29	42	30	42	29	43	29	42
Wholesale funding/Total Funding (%)	52.9	42.2	53.4	42.9	49.7	41.1	49.0	40.9
T-test (HA: Difference> 0)	10.6** (0.0151)		10.6** (0.0138)		8.7** (0.0283)		8.1** (0.0330)	
Property loans/Total loans to non-bank customers (%)	16.9	9.6	18.1	10.1	16.6	10.5	16.2	10.2
T-test (HA: Difference> 0)	7.3** (0.0118)		8.0*** (0.0059)		6.1*** (0.0042)		6.0*** (0.0057)	
Trading financial assets/Total financial assets (%)	32.5	44.8	31.2	44.1	34.0	46.6	29.0	40.8
T-test (HA: Difference< 0)	-12.3** (0.0439)		-12.9** (0.0308)		-12.6** (0.0461)		-11.8** (0.0453)	

a. Sources: banks' audited financial statements.

b. The sample differs slightly from year to year due to data constraints and restructuring of some banks.

wholesale funding. Property loans include loans to the real estate sector not including residential mortgages. Trading financial assets are assets traded on banks' own accounts; total financial assets include trading and non-trading assets (available-for-sale assets, held-to-maturity assets and other financial assets). See subsection 5.3 below for further details on the variable definitions.

Table 2 shows the mean values of different types of funding, loans and financial assets of each group. In terms of funding structure (measured by wholesale funding/wholesale and retail funding), the bailed-out banks (B) rely significantly more on wholesale funding than banks that were not bailed out (NB). In terms of loan portfolio (measured by property loans/property and non-property loans to non-bank customers), group B has a significantly higher proportion of property loans than group NB. In terms of trading assets (measured by the ratio of trading financial assets/trading and non-trading financial assets), the size of the trading portfolio of group B is, on average, significantly smaller than that of group NB. It is possible that banks in group B are less able to diversify risk with their relatively smaller trading portfolios. The same pattern is also present, and is even more distinctive, in Table 3 where the classification of banks into sound (S) and unsound (US) is not only based on state aid information but also considering external rating information.

The pattern seen in Table 2 and 3 suggests that banks with different funding structures and asset portfolios may exhibit different levels of risk. To put the above observations in the context of bank efficiency measurement, inappropriate usage of banks' inputs (e.g. funding) and production of outputs (e.g. loans and financial assets) may expose banks to higher risk. Such inappropriate mixes are in turn revealed by the weights the banks put on the inputs and outputs, where a bank would put low weight on e.g. an input they use a lot of, thereby implicitly underestimating its cost - including risk. Inspired by the above observations, we incorporate this risk element into the measurement of bank efficiency. We use a normal (unrestricted) DEA model to identify the model (non-bailed-out/sound) banks and the weights they put on the inputs and outputs. We then use the ranges of these weights to design weight restrictions to be imposed on all the banks included in our sample. Thus, banks seemingly taking excessive risks by using inappropriate weights to make themselves look efficient, are restricted to using weights also used by the model banks.

Table 3: Mean comparisons of funding structure, and loan and financial asset portfolio between unsound banks (US) and sound (S) banks

	Year 2006		Year 2007		Year 2008		Year 2009	
	US	S	US	S	US	S	US	S
No. of Obs.	37	34	38	34	37	35	37	34
Wholesale funding/Total Funding (%)	53.1	39.6	53.7	40.2	50.0	38.7	49.4	38.4
T-test (HA: Difference> 0)	13.5***	(0.0023)	13.5***	(0.0020)	11.3***	(0.0053)	11.0***	(0.0054)
Property loans/Total loans to non-bank customers (%)	16.3	8.4	17.3	9.1	16.1	9.7	15.7	9.4
T-test (HA: Difference> 0)	7.9***	(0.0058)	8.2***	(0.0043)	6.5***	(0.0023)	6.3***	(0.0032)
Trading financial assets/Total financial assets (%)	32.8	47.4	31.8	46.5	34.1	49.5	29.1	43.5
T-test (HA: Difference< 0)	-14.7**	(0.0182)	-14.7**	(0.0151)	-15.4**	(0.0174)	-14.4**	(0.0177)

a. Sources: banks' audited financial statements.

b. The sample differs slightly from year to year due to data constraints and restructuring of some banks.

By revealing the risk and performance of the banks in our sample, which are representative of the EU-27 banking system, the results are intended to tease out the risk element embedded in banks' business models from the efficiency measurement, and to give some indication about the relationship between bank risk and efficiency through a comparison of the weight-restricted and unrestricted efficiency scores.

5.3 Model specifications and variables

In the empirical analysis we consider the input mix and output mix separately in two different DEA models. The aim is to better understand risks arising from inappropriate input mixes vis-a-vis output mixes. To investigate the risk and efficiency related to input mixes, we adopt an intermediation approach where banks are perceived as entities that transform deposit and funding into loans and financial assets. Under this specification, the input variables include retail funding expenses, wholesale funding expenses, physical capital expenses and personnel expenses. On the output side, we include loans and financial assets. We also include impaired loan on the input side as discussed below.

To understand the risk and efficiency related to output mixes (i.e. different types of loans and financial assets), we specify a model where banks transform various loans (including property and non property loans) and financial assets (trading and non-trading financial assets) into income. We also include impaired loans on the asset side and provision for impaired loan loss on the income side, also discussed below, as a way of directly controlling for certain risks. Under this specification, prices are assumed to be endogenous. In particular, we assume that the pricing of certain loans and assets are, or should be, related to their underlying risks. Therefore higher risk taking should be compensated for by a higher income, in order for a bank to be deemed efficient.

The definition of each of the variables included in the models is as follows: Retail funding refers to deposits received from retail funding market, i.e. deposits from individuals and firms. Wholesale funding refers to funding obtained from the wholesale funding market, including inter-bank market funding, debt securities issued by the bank, and subordinated debt of the bank. We differentiate retail funding from wholesale funding to explicitly consider the variant reliance on wholesale funding market of the studied banks evident from Table 2 and 3.

All loans are net loans after banks' provision for impairment losses. Property loans are distinguished from other loans since the decline of the property market during the crisis led to significant losses from bad loans in this part of many banks' loan portfolios. Trading financial assets are debt securities and equity securities acquired principally for the purpose of trading in the near term as well as positive fair values of trading derivatives. These assets are held by the banks for trading on their own account (the so-called proprietary trading). On the one hand, excessive holding of trading assets by banks may expose them to market volatilities, especially under extreme market conditions. On the other hand, the trading portfolio may have to be of a relatively significant size to be able to achieve the effect of risk diversification. During the recent crisis, some distressed banks suffered from high trading losses. Therefore we, in this study, distinguish trading assets from other types of financial assets. Other financial assets, used as one of the asset measures, include available-for-sale financial assets, held-to-maturity financial assets and other financial assets. Available-for-sale financial assets include equity and debt securities which are not held for trading in the near term. They are held for an indefinite period of time and may be sold in response to needs for liquidity or in response to changes in market conditions. Held-to-maturity financial assets are non-derivative assets with fixed or determinable payments and fixed maturities and the bank has the intention and ability to hold them until maturity.

The income variable is generated as the sum of net interest income, net commission income, net trading income and all other operating income.

As mentioned before, to ensure that the risk elements embedded in the banks' funding and investment portfolio model are taken into account while measuring banks' efficiency, we make the above distinctions regarding a bank's funding, loans and financial assets. In addition to the inappropriate mixes of funding or/and assets, another important aspect that reflects a bank's risk strategy is the quality of the assets. In the literature, there are different approaches for introducing the quality of loans as an element of risk into a DEA model. For instance, Hughes and Mester (1993) add non-performing loans as a quality measure for total outputs taking account of risk. Charnes et al. (1990) instead considers loan loss provision as an additional input together with accumulated loan losses.

In this study, we include impaired loan as an input and provision for impaired loan loss as an output in our asset-income model, and use the impaired loans as an input in our input mix model. There are several advantages of adopting this approach: Firstly, by introducing impaired loans on the input side, banks with bad management of problem loans or who would otherwise achieve higher short term efficiency by accumulating problem loans are appropriately penalised. Secondly, by introducing provision for impaired loan loss on the output side, banks with a prudent perception in terms of the loss involved in the amount of impaired loans are appropriately rewarded. It is worth noting that the provision for impaired loan loss indicates banks' risk perception, not only based on past loss experience but also based on predictions of future risk conditions. This point is particularly important in the context of current global crisis. The relevant issue is whether banks are allowing adequate losses arising from the impaired loans. As shown in Table 4 (and 5), in spite of the sharp increase in both impaired loans and provision for loan impairment loss during the crisis, the ratio of loan loss provision over total impaired loans is decreasing for both bailed-out and non-bailed-out banks (unsound and sound). This suggests that the increase in impaired loans is greater than the increase in loan loss provision. While we can not conclude from Table 4 or 5 whether banks are making adequate provision for impairment losses corresponding to the increasing impaired loans, the mean comparison tests in Table 4 show that non-bailed-out banks have significantly higher loan loss provisions than bailed-out banks given the amount of impaired loans. This pattern is even more obvious in Table 5 with the unsound banks and sound banks. For the above reasons, we believe it is important to introduce both impaired loans and provision for loan impairment losses into our DEA models. Considering that provision for impaired loan loss directly affects banks' income or profit, and to avoid double counting, we adopt this approach of impaired loans as input and provision for impaired loan loss on the output side in our asset-income model. In the input mix model, we only include impaired loans on the input side to control for loan quality. The detailed definition of impaired loans and provision for impaired loan loss is given below.

Impaired loans are defined under the International Accounting Standard (IAS 39). A financial asset or a group of financial assets is impaired and impairment losses are incurred if, and only if, there is objective evidence of impairment as a result of one or more loss events. Thus, unlike non-performing loans whose definition is subjective and can be different from bank to bank, the above defined impaired loan gives objective indication of loan quality. According to the IAS, if there is objective evidence that an impairment loss on financial assets has occurred, the amount of loss is measured as the difference between the asset's carrying amount and the present value of estimated future cash flows. The carrying amount of the asset is then reduced by the amount of loss (either directly or through use of an allowance account[2]). Although the IAS sets certain standards for the estimation of future cash flows to measure impairment loss, this estimation involved in impairment loss allowance/provision of a bank inevitably reflects a bank's value judgment and risk perception regarding how much impairment loss to set aside out of the impaired assets. Although the methodology and assumptions used for estimating future cash flows may be reviewed, there might be a lag in the adjustment in the difference between loss estimates and actual loss experience. Therefore the provision for loan impairment loss can be perceived as a measurement of how much loss a bank sets aside as risk insurance. In other words, given the amount of impaired loan, the provision for the impairment loss should reflect a bank's perception of the cost of risk involved in the impaired assets.

The above procedure of including impaired loans and loan loss provision resembles the approach applied in Brockett et al. (1997). They also used the provisional loan loss as an output regarding it as "provision for risk insurance", but treated the amount of impairment loss charged for the concerned accounting year as an input. Since the amount of impairment loss charged for the concerned accounting year is based on the provisional loan loss (as at the balance sheet date) on the output side, it also reflects banks' risk perception. It runs the risk of penalising banks of charing high impairment loss each year due to prudential perception of risk. However using impaired loan on the input side addresses this problem since, as mentioned above, it is the objective evidence of loan losses without reflecting banks' risk perception.

In addition, considering that impaired loans and provision for impaired loan loss are not real input and output in a bank's intermediation production plan and that the incorporation of these two variables is primarily to control for loan quality and loan risk perception of banks, we also relax the weight restrictions on them. By doing so, the weight restrictions are primarily used to

[2]Meanwhile, the amount of loss incurred for the concerned accounting year is reflected in profit or loss.

Table 4: Mean comparisons of impaired loans, provision for loan impairment loss and provision for loan impairment loss/impaired loan between bailed-out (B) and non-bailed-out banks (NB)

	Bailed-out (B)				Non-bailed-out (NB)			
	Year 2006	Year 2007	Year 2008	Year 2009	Year 2006	Year 2007	Year 2008	Year 2009
No. of Obs.	29	30	29	29	42	42	43	42
Impaired loans (Euro m)	3196.4	3196.6	5538.7	10266.6	3463.9	4043.9	5270.0	8241.6
Overall	5529.5				5248.2			
T-test (HA: Difference $\neq 0$)	281.2 (0.7619)							
Provision for loan impairment loss (Euro m)	1711.1	1664.3	2597.6	4596.5	2643.5	3124.4	3915.4	5455.4
Overall	2634.0				3785.5			
T-test (HA: Difference < 0)	-1151.4** (0.0289)							
Provision for loan impairment loss/impaired loans(%)	75.7	74.4	57.5	49.4	95.5	81.4	66.1	60.6
Overall	64.4				75.9			
T-test (HA: Difference < 0)	-11.5** (0.0357)							

adjust bank risk arising from inappropriate mixes of inputs and outputs instead of the quality of outputs.

Table 5: Mean comparisons of impaired loans, provision for loan impairment loss and provision for loan impairment loss/impaired loan between unsound (US) and sound (S) banks

	Unsound banks (US)				Sound banks (S)			
	Year 2006	Year 2007	Year 2008	Year 2009	Year 2006	Year 2007	Year 2008	Year 2009
No. of Obs.	37	38	37	37	34	34	35	34
Impaired loans (Euro m)	2736.4	2821.8	4856.1	8952.6	4027.5	4662.2	5920.7	9161.8
Overall	4830.4				5942.9			
T-test (HA: Difference $\neq 0$)	1112.5 (0.2227)							
Provision for loan impairment loss (Euro m)	1475.4	1475.7	2242.3	3988.5	3119.5	3678.7	4592.2	6319.2
Overall	2290.0				4428.6			
T-test (HA: Difference < 0)	-2138.7*** (0.0002)							
Provision for loan impairment loss/impaired loans(%)	81.2	74.8	56.1	48.9	94.3	82.7	63.8	77.5
Overall	65.3				77.5			
T-test (HA: Difference < 0)	-12.2** (0.0257)							

6 Efficiency results

6.1 Output mix: Asset-income model

The results from the asset-income DEA model aimed at investigating the impact of the banks' output mix are shown in Table 6 and show that, as expected, the sound banks are significantly more efficient than the unsound banks. This is because certain risk elements are directly included in this model by the inclusion of both impaired loans and loan loss provisions, and because the fact that the banks' income is used as an output variable in the model means that some of the risk originating from the banks' output mixes is likely to already be captured by the prices (at least by banks with a realistic perception of the risk) and thus is, or should be, reflected in the income. Therefore it is not surprising that the problem banks (here the unsound) show lower mean efficiencies than the sound banks in a model that does not allow excessive risk taking, even before the imposition of weight restrictions. Including either a selected set of weight restrictions (property loans/non-property loans, trading assets/non-trading assets, property loans/income, trading assets/income) c.f. the 3'rd row in Table 6, or weight restrictions on all pairs of variables except those relating to impaired loans and loan loss provisions (5'th row in Table 6), has the effect that it reduces the efficiency scores more for the unsound banks than for the sound banks (though the difference in the decreases is generally not significant) thus making the pattern in terms of the significantly lower efficiency score for unsound banks even stronger.

The pattern in Table 6 in terms of the average unrestricted efficiency scores over time, which are comparable because the efficiencies are all measured relative to a common pooled frontier, shows that the average efficiencies for both the sound and the unsound banks dropped by approximately 20% between 2007 and 2008, coinciding with the peak of the financial crisis around September 2008. This highlights the importance of understanding the trade-off between risk and efficiency, i.e. the understanding of the degree to which banks might take risks to pursue short-run efficiency, since excessive risk taking contributed to the financial crisis, even amongst banks that might have appeared efficient before the crisis. So it is important to understand the risk-efficiency trade-off so that the performance of risky banks, which may have contributed to financial crisis, is not overstated. We do this here by including both variables and weight restrictions that limit the banks' abilities to take excessive risk without being penalised for that in the efficiency assessments.

Please note that since DEA scores are neither independent, nor normal-distributed, we for all tests of differences of mean efficiency scores use the non-parametric Mann-Whitney test rather than the t-tests from the previous tables. While we in the tables in this section show the absolute values of the differences between the average efficiency scores in the different groups, we emphasise that the test probabilities from the Mann-Whitney tests shown in brackets are the probabilities of the mean rank in the two groups being identical, and are thus not tests on the mean efficiencies.

Table 6: Unrestricted and weight restricted efficiency scores (%): Asset-income model

	Year 2006		Year 2007		Year 2008		Year 2009	
	US	S	US	S	US	S	US	S
No. of Obs.	37	34	38	34	37	35	37	34
Unrestricted scores	55.9	76.2	51.9	71.6	33.2	55.7	35.8	52.3
MW test	-20.3*** (0.0050)		-19.7*** (0.0012)		-22.5*** (0.0000)		-16.5*** (0.0000)	
WR scores I	50.0	71.6	44.5	69.1	26.3	51.8	31.7	50.3
MW test	-21.6*** (0.0009)		-24.6*** (0.0000)		-24.5*** (0.0000)		-18.6*** (0.0000)	
Decrease in scores I	5.9	4.6	7.4	2.6	6.9	3.9	4.2	2.0
MW test	1.3 (0.3250)		4.8 (0.0163)		3.0 (0.2720)		2.2 (0.4271)	
WR scores II	49.3	72.5	43.7	68.1	25.9	51.2	31.2	50.1
MW test	-23.2*** (0.0003)		-24.4*** (0.0000)		-25.3*** (0.0000)		-18.9*** (0.0000)	
Decrease in scores II	6.6	3.7	8.3	3.6	7.4	4.5	4.6	2.2
MW test	2.9* (0.1021)		4.7** (0.0220)		2.9 (0.4140)		2.4 (0.4474)	

a. WR scores I with selective set of weight restrictions: property loans/non-property loans, trading assets/non-trading assets, property loans/income, trading assets/income
b. WR scores II with all weight restrictions except for impaired loans and loan loss provision
c. Decrease in scores: the difference between unrestricted and WR scores
d. Mann-Whitney tests for differences between group US and group S
e. The mean differences between US and S are shown only for reference as the Mann-Whitney test p values are based on mean ranks

6.2 Input mix model: Risk-efficiency trade off

The comparisons of unrestricted and weight restricted efficiency scores in Table 7 and Table 8 show a clear trade-off between risk and efficiency across all banks and over the years. The trade-off between risk and efficiency is indicated by the decreases in the efficiencies when the weights are restricted, which are evident for both bailed-out and non-bailed-out banks and for unsound banks and sound banks, and no matter whether weight restrictions on impaired loans are included or not. The decreases in the efficiency scores from the introduction of weight restrictions can be interpreted as an indicator of risk, in the sense that it reflects the degree of risks banks are taking to pursue short-run efficiency. It should, however, be noted that efficiency scores can only decrease with the introduction of weight restrictions, thus the important factor becomes whether the imposition of weight restrictions affects the bailed-out (unsound) banks more than the non-bailed-out (sound) banks.

Before weight restrictions are imposed, the results (2'nd row in Table 7 and 8) show that there is no clear pattern regarding which banks are more efficient. However, after weight restrictions are imposed, the results (3'rd row and 5'th row in Table 7 and 8) show that bailed-out (unsound) banks are significantly less efficient than non-bailed-out (sound) banks, especially before the crisis (i.e. year 2006) and just after the peak of the crisis (i.e. year 2009). We also find that the decreases in efficiency scores (i.e. the risk-efficiency trade-off shown in the 4'th row and the 6'th row in Table 7 and 8) are in general more evident (but not necessarily significant) for bailed-out (unsound) banks than for non-bailed-out (sound banks), especially in 2009. This might indicate that the bailed-out (unsound) banks were slower than the non-bailed-out (sound) banks at adjusting the risks arising from their input mixes after the peak of the crisis. Overall, from the pattern shown in terms of the effect of the imposition of weight restrictions on our model and problem banks, it appears that model banks in general showed less risk-efficiency trade-off than the rest before the crisis took place. After the crisis took place, model banks seemed to be able to adjust risk quicker than the rest, reflected again by a lower risk-efficiency trade-off.

Table 7: Unrestricted and weight restricted efficiency scores (%): Input mix model

	Year 2006		Year 2007		Year 2008		Year 2009	
	B	NB	B	NB	B	NB	B	NB
No. of Obs.	29	42	30	42	29	43	29	42
Unrestricted scores	68.2	70.1	63.6	61.6	59.2	58.3	71.2	72.7
MW test	-1.9 (0.6737)		2.0 (0.6153)		0.9 (0.2988)		-1.5 (0.9440)	
WR scores I	46.9	57.7	41.9	47.4	38.6	44.3	53.1	66.2
MW test	-10.8*** (0.0050)		-5.5** (0.0398)		-5.6* (0.0948)		-13.1**(0.0536)	
Decrease in scores I	22.1	14.5	22.3	16.0	21.2	15.2	19.6	7.5
MW test	7.6*** (0.0077)		6.3** (0.0234)		6.0** (0.0201)		12.1*** (0.0000)	
WR scores II	53.1	61.9	47.2	51.9	41.6	46.6	55.4	66.5
MW test	-8.8** (0.0296)		-4.7 (0.2110)		-5.1 (0.2729)		-11.2 (0.1405)	
Decrease in scores II	15.9	10.3	17.0	11.6	18.3	12.8	17.4	7.1
MW test	5.6*** (0.0019)		5.4*** (0.0013)		5.5*** (0.0103)		10.3*** (0.0000)	

a. WR scores I with all weight restrictions
b. WR scores II with all weight restrictions except those relating to impaired loans
c. Decrease in scores: the difference between unrestricted and WR scores
d. Mann-Whitney tests for differences between group B and group NB
e. The mean differences between B and NB are shown only for reference
as the Mann-Whitney test p values are based on mean ranks

Table 8: Unrestricted and weight restricted efficiency scores (%): Input mix model

	Year 2006		Year 2007		Year 2008		Year 2009	
	US	S	US	S	US	S	US	S
No. of Obs.	37	34	38	34	37	35	37	34
Unrestricted scores	68.2	73.9	63.2	64.3	57.6	61.8	69.7	77.2
MW test	-5.7 (0.1934)		-1.1 (0.8479)		-4.2 (0.8261)		-7.5 (0.1924)	
WR scores I	46.9	56.9	41.4	46.9	38.3	43.9	52.1	68.6
MW test	-10.0*** (0.0031)		-5.5** (0.0299)		-5.6** (0.0293)		-16.5*** (0.0052)	
Decrease in scores I	21.4	17.0	21.8	17.4	19.3	18.0	17.6	8.6
MW test	4.4 (0.1287)		4.4 (0.1602)		1.3 (0.2921)		9.0*** (0.0003)	
WR scores II	50.8	61.0	45.1	51.4	39.6	46.3	52.2	68.8
MW test	-10.2*** (0.0030)		-6.3** (0.0471)		-6.7** (0.0268)		-16.6*** (0.0053)	
Decrease in scores II	17.4	12.8	18.1	12.9	18.0	15.5	17.5	8.4
MW test	4.6** (0.0234)		5.2** (0.0208)		2.5 (0.1326)		9.1*** (0.0002)	

a. WR scores I with all weight restrictions
b. WR scores II with all weight restrictions except those relating to impaired loans
c. Decrease in scores: the difference between unrestricted and WR scores
d. Mann-Whitney tests for differences between group US and group S
e. The mean differences between US and S are shown only for reference
as the Mann-Whitney test p values are based on mean ranks

7 Conclusion

The recent financial crisis highlighted how inappropriate mixes of funding (e.g. wholesale funding vs. retail funding) and assets (e.g. property loans vs. non-property loans) are associated with banks' risk exposure. Motivated by these observations, this study applied weight-restricted DEA models intended to be able to tease out the implicit risk element embedded in banks' business models, especially related to their funding and investment portfolios. The restrictions on the ratios of weights assigned to inputs and outputs were constructed by using those efficient banks that did not go through far-reaching restructuring during the crisis and were relatively highly rated by external rating agency as model banks. In addition, we control for loan quality and banks' perception of risk arising from bad loans by including impaired loans and provision for impaired loan loss in our model(s). The decrease in the efficiency scores resulting from the imposition of weight restrictions, which limit the banks' abilities to benefit from inappropriate mixes of inputs and/or output in the efficiency assessments, give us some indication to the degree of risk banks take to appear more efficient (in the short-term), i.e. a trade-off between risk and efficiency.

To be able to understand the nature and causes of the risk taking of the bailed-out (unsound) and non-bailed-out (sound) banks, we analysed potential risks arising specifically from inappropriate input (such as funding) mixes and from output (loans and assets) mixes in an input mix model (input-asset model) and an asset-income (output mix) model. The asset-income model indicated some risk in the loan and asset mixes reflected in prices, and therefore captured by income, without any weight restrictions. The results from this model confirm that non-bailed-out banks with relatively higher ratings are more efficient than the rest in a model that directly controls for some risk elements. The imposition of weight restrictions in this model only makes the pattern stronger.

In the input mix model there was no clear pattern in the scores for the non-bailed-out (sound) banks vis-a-vis the bailed-out (unsound) banks before the use of weight restrictions to control for risk. But by applying weight restrictions to our input mix model we were able to investigate whether there is a trade-off between risk and efficiency. The results show decreases in the efficiency scores after the imposition of weight restrictions across all banks, indicating a risk-efficiency trade-off. This evidence suggests that, without taking into account that banks' risk taking may be traded for short-term efficiency, the interpretation of bank efficiency scores can be misleading. More importantly, we find a clear pattern emerging to indicate higher efficiency of non-bailed-out and relatively highly rated banks than bailed-out and relatively lower rated banks after using weight restrictions, especially before and after the crisis took place. Moreover, we also find some evidence that bailed-out banks are more affected by the imposition of weight restrictions than non-bailed-out banks.

We are therefore able to conclude that banks seemed to be pursuing short-run efficiency in generating loans, assets or income at the cost of higher risk. More importantly we quantify the degree of banks trading risk for short-run efficiency by analysing the impact of weight restrictions in our DEA models. All our results point at the importance of understanding banks' funding structure and investment portfolios when evaluating banks' operating efficiency.

Appendices

I: Bank Financial Strength Rating Definitions

A: Banks rated A possess superior intrinsic financial strength. Typically, they will be institutions with highly valuable and defensible business franchises, strong financial fundamentals, and a very predictable and stable operating environment.
B: Banks rated B possess strong intrinsic financial strength. Typically, they will be institutions with valuable and defensible business franchises, good financial fundamentals, and a predictable and stable operating environment.
C: Banks rated C possess adequate intrinsic financial strength. Typically, they will be institutions with more limited but still valuable business franchises. These banks will display either acceptable financial fundamentals within a predictable and stable operating environment, or good financial fundamentals within a less predictable and stable operating environment.
D: Banks rated D display modest intrinsic financial strength, potentially requiring some outside support at times. Such institutions may be limited by one or more of the following factors: a weak business franchise; financial fundamentals that are deficient in one or more respects; or an unpredictable and unstable operating environment.
E: Banks rated E display very modest intrinsic financial strength, with a higher likelihood of periodic outside support or an eventual need for outside assistance. Such institutions may be limited by one or more of the following factors: a weak and limited business franchise; financial fundamentals that are materially deficient in one or more respects; or a highly unpredictable or unstable operating environment.
Note: Where appropriate, a + modifier will be appended to ratings below the A category and a $-$ modifier will be appended to ratings above the E category to distinguish those banks that fall in the higher and lower ends, respectively, of the generic rating category

II: Global Long-Term Rating Scale

Aaa Obligations rated Aaa are judged to be of the highest quality, subject to the lowest level of credit risk.
Aa Obligations rated Aa are judged to be of high quality and are subject to very low credit risk.
A Obligations rated A are judged to be upper-medium grade and are subject to low credit risk.
Baa Obligations rated Baa are judged to be medium-grade and subject to moderate credit risk and as such may possess certain speculative characteristics.
Ba Obligations rated Ba are judged to be speculative and are subject to substantial credit risk.
B Obligations rated B are considered speculative and are subject to high credit risk.
Caa Obligations rated Caa are judged to be speculative of poor standing and are subject to very high credit risk.
Ca Obligations rated Ca are highly speculative and are likely in, or very near, default, with some prospect of recovery of principal and interest.
C Obligations rated C are the lowest rated and are typically in default, with little prospect for recovery of principal or interest.
Note: Moody's appends numerical modifiers 1, 2, and 3 to each generic rating classification from Aaa through Caa. The modifier 1 indicates that the obligation ranks in the higher end of its generic rating category; the modifier 2 indicates a mid-range ranking; and the modifier 3 indicates a ranking in the lower end of that generic rating category.

III: Global Short-Term Rating Scale

P-1 Issuers (or supporting institutions) rated Prime-1 have a superior ability to repay short-term

debt obligations.
P-2 Issuers (or supporting institutions) rated Prime-2 have a strong ability to repay short-term debt obligations.
P-3 Issuers (or supporting institutions) rated Prime-3 have an acceptable ability to repay short-term obligations.
NP Issuers (or supporting institutions) rated Not Prime do not fall within any of the Prime rating categories.

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