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Banking Efficiency in the Nordic Countries: A Four-Country Malmquist Index Analysis*

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ABSTRACT

This report provides evidence of the relative competitiveness of the banking industries in the Nordic countries in 1990. The nonparametric Data Envelopment Analysis (DEA) methodology is used for calculating the efficiency of the Nordic banks relative to the national and the pooled data sets. The report also computes slacks and uses a newly developed method for ranking efficient units according to their importance as benchmarks for inefficient units. This ranking is used in an analysis of the sensitivity of the results to ostensible productive outliers.

Contents

1 Introduction

The economic integration within the European Union and the European Economic Area has opened for more intense competition on the European retail banking markets, which may potentially result in a substantial structural change within the banking industries. Banks chartered in one country are allowed to set up branches in any other country, subject to the regulations of their home country. Political authorities in most countries consider the banking industry a key sector for the smooth functioning of their national economies and are likely to take a strong interest in the development of this industry. Thus, the competitiveness of the national banking industries will be an issue of great concern.

This report considers the relative efficiency of the banking industries in Denmark (D), Finland (F), Norway (N) and Sweden (S) as observed in the year 1990. These four Nordic neighbouring countries are part of the European Economic Area, and they constitute a region where cultural barriers to entry in one of the other three countries are minimal. We shall consider differences in average banking productivity between the four countries and also the spread of efficiency levels within each country.

The basic methodological approach is to formulate a best practice production frontier for the banking industries in each country and also a Nordic frontier based on the pooled cross section data. The production frontier will be specified as piecewise linear in the four outputs and three inputs for which we have been able to collect comparable data. The structures of the Nordic banking sectors are examined by studying the efficiency of the individual banks. Using Data Envelopment Analysis (DEA) as the way of establishing the frontier, we determine whether individual banks are efficient by comparing them to the best practice frontier determined by the observation set[1]. Malmquist indices (Berg

[1]The nonparametric framework has previously been applied to banking sector data by e.g. Aly *et al.* (1990), Berg *et al.* (1991, 1992), Elyasiani and Mehdian (1992), Elyasiani, Mehdian and Rezvanian (1994), English *et al.* (1993), Favero and Papi (1995), Ferrier and Lovell (1990), Ferrier

et al. 1992) will be used to characterize the productivity differences between banks in different countries. This allows for a decomposition of the productivity differences into one term representing the banks' productivity levels relative to their respective national best practice frontiers, and one term representing the difference between the national frontiers. This report contains a more detailed analysis than Berg *et al.* (1993b), which is an earlier report from the same Nordic project. See also Berg *et al.* (1993a). The Danish banking sector is included in the present study, the number of specified outputs has been increased from three to four and the number of specified inputs from two to three. Furthermore, slack adjusted efficiency scores have been computed and the units are ranked according to their importance as reference units, using a method suggested by Torgersen (1992; cf. Torgersen *et al.* 1994). The robustness of the results to possible data errors is examined.

The DEA method is briefly introduced in section 2, where the Malmquist index and the slack adjusted efficiency measures are also defined. The data are presented and the specification of inputs and outputs is described in section 3. Section 4 presents the empirical results, and finally we provide some concluding remarks and summarize the results in section 5.

2 The methodology

The DEA approach defines a non-parametric frontier which serves as a benchmark for efficiency measures. We will apply the "classical" Farrell (1957) measure as defined and extended in Førsund and Hjalmarsson (1974, 1979, 1987). Following Charnes *et al.* (1978) who originated the DEA approach, the Farrell efficiency scores are calculated by establishing only one facet of the frontier at a time. The frontier is revealed relative to each observed

et al. (1993), Ferrier *et al.* (1994), Fukuyama (1993,1995) Greil and Schmidt (1995), and Rangan *et al.* (1988).

bank by calculating an artificial benchmark bank. This benchmark is a linear combination of efficient banks in the same or a different sample.

We shall mainly use the input saving Farrell efficiency measure, which is defined as the ratio between the potential use of inputs with frontier technology and the actual use of input, keeping output constant. Formally, with multi-output frontier technology and different countries, the Farrell input saving efficiency measure[2] based on frontier technology for country i, for a unit k, observed in country j, is defined by:

$$E_{ijk} = \min_{\alpha}\{\alpha : F_i(y_j^k, \alpha x_j^k) \leq 0)\}, \quad i, j \in T \tag{1}$$

where α is the scaling factor, y_j^k is the output vector, x_j^k is the input vector, $F_i(\cdot)$ is the transformation function (with standard properties) describing frontier technology, i is the country of the frontier technology, j is the country of the observations and T the set of countries. When comparing the Nordic countries, two lines of approach are possible: (a) comparing the countries pairwise based on each country's frontier, as in Berg *et al.* (1993b), and (b) forming a common frontier and comparing each country with this frontier as in Berg *et al.* (1993a). We include the pooled Nordic data set, κ, among the possible reference technologies, i.e. $\kappa \in T$. We assume that no unit observed in country i can perform better than the frontier technology, $F_i(\cdot)$, of the same country, i.e. a deterministic frontier (Førsund *et al.*, 1980) is adopted. When $i = j$, the efficiency measure must be between zero and one. When $i \neq j$ the measure will be larger than one if the observation is outside the reference frontier technology.

To obtain the efficiency scores a LP problem is solved for each bank. Assuming M outputs, N inputs and a benchmark sample of K banks, i.e. (y^k, x^k), $k = 1, \ldots, K$, where $x^k = (x_1^k, x_2^k, \ldots, x_n^k, \ldots, x_N^k)$ and $y^k = (y_1^k, y_2^k, \ldots, y_m^k, \ldots,$

[2]The Farrell input-saving efficiency measure is identical to the inverse of the Shephard input distance function, see e. g. Färe *et al.* (1985).

y^k_M), the formal problem for bank k can most conveniently be stated as follows:

$$E_{ijk} = \min_{z_{ijk},\alpha} \alpha \tag{2}$$

$$\text{s.t. } z_{ijk}Y_i \geq y^k \tag{3}$$

$$z_{ijk}X_i \leq \alpha x^k \tag{4}$$

$$\sum_{\ell=1}^{K} z_{ijk\ell} = 1 \tag{5}$$

$$z_{ijk} \in \Re^K_+ \tag{6}$$

$$\alpha \in \Re_+. \tag{7}$$

where Y_i is the (K, M) matrix of outputs in the benchmark sample, X_i is the (K, N) matrix of inputs in the benchmark sample, and $z_{ijk} = (z_{ijk1}, z_{ijk2}, \ldots, z_{ijk\ell}, \ldots, z_{ijkK})$ is the vector of intensity weights defining the benchmark bank to be compared with bank k. E_{ijk}, y^k and x^k were defined above and $\tilde{K} = \{1, 2, \ldots, K\}$ will be used to denote the set of units under evaluation, and $\tilde{N} = \{1, 2, \ldots, n, \ldots, N\}$ will denote the set of inputs.

2.1 Scale properties

As for the scale properties of the frontier function, variable returns to scale (VRS), as implied by (5), may seem to be the natural assumption since the degree of scale economies in banking is a classical issue, and since the efficiency scores obtained are then more robust to misspecification and data errors. But it should be noted that our sample is thin at large bank sizes, at least for the individual countries. With a variable returns to scale technology the largest bank will always appear as fully efficient, only because of a lack of truly efficient banks for comparison (cf. Berg, Førsund and Janssen, 1991). The assumption of constant returns to scale. (CRS), which corresponds to an unrestricted sum of weights z_{ijk} (restriction (5) omitted), allows us to compare large banks with much smaller banks and thus avoid having them appear as artificially efficient. Since each assumption has its advantages, we shall use both assumptions in our empirical applications.

2.2 The Malmquist index

In order to identify productivity differences between two banks the Malmquist productivity index can be used (see Malmquist, 1953, and Caves *et al.*, 1982a and 1982b). The productivity index is based on binary comparisons between two different production units, denoted 1 and 2 for short. Only quantities are involved, and at least one technology has to be known. As a convention we will compare unit 2 with unit 1, i.e. expressions involving unit 2 will be in the numerator and expressions involving unit 1 will be in the denominator.

The idea of what Caves *et al.* (1982b) termed the Malmquist unit 1 input based productivity index is to find the minimal proportional scaling of inputs for unit 2, such that its scaled input vector and its observed output vector are just on the production surface of unit 1[3]. In order to obtain circularity of the index the original Caves *et al.* (1982a) index was generalised in Berg *et al.* (1992). Although we will use the index in a cross section setting and thus do not need chainability as such, we prefer the chain version. For a comparison between two units observed in countries 1 and 2, with frontier technology $F_i(\cdot)$ from country i as reference ($i \in T$), the index is defined as[4]:

$$M_i(1,2) = \frac{E_{i2}}{E_{i1}} = \frac{\min_\alpha\{\alpha : F_i(y_2, \alpha x_2) = 0\}}{\min_\alpha\{\alpha : F_i(y_1, \alpha x_1) = 0\}}, \quad i, 1, 2 \in T, \tag{8}$$

where unit indices are suppressed and country indices 1 and 2 used instead.

The numerator shows the proportional adjustment of the observed input vector of the country no. 2 unit required to be on the frontier function of the reference country i with observed outputs, and the denominator shows the

[3]Caves *et al.* made use of the Shephard (1953) concept of distance functions when defining the proportional scaling, without noticing the direct connection with Farrell (1957) efficiency measures (see Førsund and Hjalmarsson, 1974, 1979 and 1987). The connection has been pointed out by Färe *et al.* (1985), and follows directly from the definitions of distance functions and Farrell efficiency measures. The Shephard concept of an input distance function is the inverse of the definition of the Farrell input saving measure.

[4]In this report we will use the input-based measure. The definition of the output-based measure, based on scaling the output vector, follows straightforwardly from applying the output-increasing Farrell efficiency measure, see Førsund (1990).

proportional adjustment of the observed input vector of the country no. 1 unit for observed outputs to be on the same country i frontier function. Note that both measures may be larger than one. If $M_i > 1$, then the country no. 2 unit is more productive than the country no. 1 unit. Productivity comparisons are traditionally performed by calculating total factor productivity, i.e. comparing an aggregate of outputs to an aggregate of inputs. Using the ratio of efficiency scores means that the relative distance from the same frontier in the input dimension is used as an indicator of productivity. The productivity difference due to different scale properties at the two points on the frontier function will then be captured by the definition (8).

In the presence of inefficient observations, differences in productivity are the net effect of differences in efficiency relative to national frontiers and in the national frontier production functions. The Malmquist productivity index, $M_i(1,2), i \in T$, can be multiplicatively decomposed into two parts showing the catching up MC(1, 2) and the pure technology shift $\mathrm{MF}_i(1,2)$:

$$M_i(1,2) = \frac{E_{i2}}{E_{i1}} = \frac{E_{22}}{E_{11}} \times \frac{E_{i2}/E_{22}}{E_{i1}/E_{11}} = MC(1,2) \times MF_i(1,2) \qquad (9)$$
$$i = \text{reference technology}, \quad i, 1, 2 \in T.$$

The frontier technology change is a relative change between country i technology and country 2 technology on the one hand, and country i technology and country 1 technology on the other hand. The measure of distance between technology i and 2 is based on the observation of unit 2, and the measure of distance between technology i and 1 is based on the observation of unit 1. The frontier change term measures the distance between technologies 2 and 1, but it is a distance measured relative to the common reference technology i. When calculating the efficiency scores in the Malmquist index, the subscript i points to the observations belonging to that definition of the production set. Observations 1 and 2 need not belong to the set spanning the frontier. A general problem is then that these scores may not exist in the VRS case. The standard solution is to impose CRS when calculating the Malmquist indices, because then we know that it is possible to relate all observations to the frontier technology, $\tilde{\imath}$[5].

2.3 Slack-adjusted efficiency measures

The Farrell efficiency measures involve proportional reduction of all inputs when moving to the frontier, without a decrease in the production of outputs. Many authors have noted (c.f. Torgersen *et al.* 1994) that it is inherent in the LP-formulation of the DEA model that not all inefficiency will be captured by the radial efficiency measures, but that slacks also have to be considered when judging the extent of inefficiency.

Torgersen *et al.* (1994) suggested a slack-adjusted input-saving efficiency measure, E_{ijk}^n, that expresses the total extent of inefficiency. This measure is a directional measure and is for unit k defined as the potential use x_{jn}^{kP} of an input n on the frontier as a fraction of observed input, x_{jn}^k:

$$E_{ijk}^n := \frac{x_{jn}^k E_{ijk} - s_n^{kx}}{x_{jn}^k} = \frac{x_{jn}^{kR} - s_n^{kx}}{x_{jn}^k} = \frac{x_{jn}^{kP}}{x_{jn}^k}, \quad \forall k \in \tilde{K}, \quad \forall n \in \tilde{N}, \tag{10}$$

where x_{jn}^{kP} is the total potential input, x_{jn}^{kR} is the potential input due to radial savings and $s^{kx} = (s_1^{kx}, s_2^{kx}, \ldots, s_n^{kx}, \ldots, s_N^{kx})$ is the optimal slack vector in (4). Based on the slack-adjusted efficiency scores, Torgersen *et al.* (1994) also introduced a directional industry efficiency measure for input n as:

$$I^{nP} := \sum_{k \in K} E_{ijk}^n \frac{x_{jn}^k}{\sum_{k \in K} x_{jn}^k}, \quad \forall n \in \tilde{N}. \tag{11}$$

This measure shows the total potential use of an input n for the whole industry as a fraction of the observed industry use. The measure is analogous to the usual industry efficiency measure based on radial efficiency scores which is

[5]Bjurek (1994, chapter 5) proposes a solution to this problem in the VRS case by redefining the Malmquist index to a new Malmquist Total Factor Productivity index by forming the ratio between Malmquist output and input quantity indices as defined in Caves *et al.* (1982b).

also computed using observed shares as weights:

$$I^{nR} := \sum_{k \in K} E_{ijk} \frac{x_{jn}^{k}}{\sum_{k \in K} x_{jn}^{k}}, \quad \forall n \in \tilde{N}. \tag{12}$$

Finally, an aggregate measure is computed in order to judge the importance of including the slack. This measure, σ_{jn}, is defined for each input, n, by expressing the total saving in input n due to slack relative to the potential total saving:

$$\sigma_{jn} := \frac{\sum_{k \in K}(x_{jn}^{kR} - x_{jn}^{kP})}{\sum_{k \in K}(x_{jn}^{k} - x_{jn}^{kP})} = \frac{\sum_{k \in K}(E_{ijk} - E_{ijk}^{n})x_{jn}^{k}}{\sum_{k \in K}(1 - E_{ijk}^{n})x_{jn}^{k}}, \quad \forall n \in \tilde{N}. \tag{13}$$

2.4 Ranking the efficient units and identifying outliers

The efficiency scores for efficient units equal one, thus only the inefficient units can be ranked on the basis of the scores. Torgersen *et al.* (1994) proposed to rank the efficient units according to their importance as a benchmark by utilizing the fact that the efficient units act as reference points for the inefficient units[6]. For each efficient unit $\hat{k}$, the fraction of the total aggregated potentials for saving in input n for which it acts as reference unit, is defined (Torgersen *et al.* 1994) as:

$$\rho_{jn}^{\hat{k}} := \frac{\sum_{k \in \tilde{K}} z_{ijk}(x_{jn}^{k} - x_{jn}^{kP})}{\sum_{k \in \tilde{K}}(x_{jn}^{k} - x_{jn}^{kP})}, \quad \forall n \in \tilde{N}, \quad \hat{k} \in \tilde{K}. \tag{14}$$

For the efficient unit $\hat{k}$, the potential for saving is zero, i.e. $x_{jn}^{\hat{k}} - x_{jn}^{\hat{k}P} = 0$, and for the inefficient unit k which does not have $\hat{k}$ as reference unit the weight is zero, i.e $z_{ijk\hat{k}} = 0$. This implies that the measure $\rho_{jn}^{\hat{k}}$ expresses the fraction of the total aggregated potential for saving in input n that is represented by the

[6]In Andersen and Petersen (1993), the ranking of efficient observations is done by removal of efficient units, one at a time, from the frontier set and computing "super efficiency" scores for these units. Such scores may be computed by calculating the appropriate Malmquist indices. But note that the super efficiency scores may not exist due to the removed unit under investigation being outside the frontier.

inefficient units that have the efficient unit $\hat{k}$ as a *referent* (cf. the terminology in Charnes *et al.* 1978). The inefficient units are generally evaluated relative to several efficient units. Because the input savings are weighted with the optimal weights z_{ijk}, all the efficient units together define the whole potential within each input, i.e. $\sum_{k \in \tilde{K}} \rho_{jn}^{k} = 1, \forall n \in \tilde{N}$.

3 The data

The data set consists of observations from 945 banks in the year 1990, 182 of them being Danish, 502 Finnish, 141 Norwegian and 120 Swedish[7]. They constitute practically the entire banking industries of the four countries. The banks omitted are all quite small. The data have been collected from the Supervisory Authority of Financial Affairs in Denmark, from official bank statistics in Finland and Norway and from the published annual account reports in Sweden.

The need for comparable data from different countries imposes strong restrictions on the variables that we are able to use. We have chosen to represent bank output by a vector consisting of four variables, namely total deposits[8] from other than financial institutions (y_1), total loans to other than financial institutions[9] (y_2), the number of branches (y_3) and guarantees given to customers (y_4). Loans, deposits and guarantees will be measured in value terms. To convert values in local currencies into a common currency, we used the purchasing power parity (PPP) rate as computed by the OECD.

[7]Twenty small Finnish banks were omitted due to data collection problems. The Danish, Norwegian and Swedish data sets also contain somewhat fewer banks than actually existed in 1990, because the bank structure as at the end of 1991 has been imposed, and because a few small banks or newly established banks have been omitted even in these countries.

[8]Exclusive of funding on money market terms. But the Finnish data include deposits from other financial institutions than banks.

[9]For Finland, loans include bonds held as long term investments, but not loans granted by state funds and channeled through the balance sheets of private banks. Leasing is included for Denmark and Norway, whereas Finnish and Swedish banks were not allowed to run this activity in 1990.

The new output relative to the previous report in Berg *et al.* (1993b) come from the specification of guarantees as an additional banking activity. The latter may be zero for many small banks and will prevent these banks from appearing as reference units relative to large banks, where the provision of guarantees is an important activity[10].

Notice that both loans and deposits will be treated as outputs. The reason is that both activities are highly resource consuming with substantial value added. Money market funding, on the other hand, mainly involves interest costs and will be ignored. The latter is in contrast to the recommendations of Berger and Humphrey (1992), but in line with the view expressed by Benston *et al.* (1982, p. 9). Branches are defined as an output representing the availability of banking services. Alternatively, it could have been regarded as an input dedicated to the production of deposits.

For the production of its outputs, the bank is assumed to utilize real resources as represented by three inputs, namely real capital defined as book values of machinery and equipment, but not of buildings (x_1), labour measured in man-hours per year (x_2) and materials measured as non-labour and non-capital operating expenses (x_3). Summary statistics of outputs and inputs are shown in table 1.

4 Empirical results

In order to perform intercountry comparisons, we have merged the data into a pooled Nordic set. The variables are defined in the same way for all countries[11].

[10]Relative to the specification of output in Berg *et al.* (1993a), we have in this paper not been able to disaggregate total loans into loans to households and loans to other sectors, because these Danish data were not available.

[11]One source of bias in the pooled data set should be noted: In Finland and in Norway, payment transactions are processed in the individual banks to a larger extent than in Denmark and in Sweden, where most of the work regarding payment transactions is done at centralized institutions. We do not have the information needed to take this difference properly into account, but we have, as suggested

Table 1: Summary statistics on inputs and outputs for the study

	Units	Mean	Std.dev.	Minimum	Maximum
		The Danish banks (N=182)			
x_1	1,000 NOK	14810.33	87809.02	0	836925.12
x_2	Hours	443401.12	2397979.73	1633.00	23954803.60
x_3	1,000 NOK	34098.98	164999.50	24.3754000	1603530.39
y_1	Million NOK	3036.90	17887.01	0.4122622	184855.17
y_2	Million NOK	2839.63	16467.35	0.3645712	161833.95
y_3	Number	16.8956044	77.7795090	1.0000000	712.0000000
y_4	Million NOK	759339.19	4651979.72	0	52534919.76
		The Finnish banks (N=502)			
x_1	1,000 NOK	8281.39	62640.65	10.7100000	934491.90
x_2	Hours	157721.12	1012817.80	2000.00	15187000.00
x_3	1,000 NOK	13812.75	93175.10	87.2100000	1493632.00
y_1	Million NOK	798.5654840	4693.12	9.8639100	67342.39
y_2	Million NOK	1230.86	7958.03	4.8179700	111003.17
y_3	Number	6.5936255	26.7403087	1.0000000	432.0000000
y_4	Million NOK	582878.29	4558363.78	0	68152050.00
		The Norwegian banks (N=141)			
x_1	1,000 NOK	29090.57	135139.46	164.0000000	1182531.00
x_2	Hours	379150.85	1462003.88	3655.90	11633460.00
x_3	1,000 NOK	37858.31	147735.50	348.0000000	1115386.00
y_1	Million NOK	1529.97	5385.69	25.2490000	43967.06
y_2	Million NOK	3261.49	13639.96	20.1860000	123974.53
y_3	Number	13.1134752	35.9402465	1.0000000	233.0000000
y_4	Million NOK	550519.75	3333413.43	0	31511990.00
		The Swedish banks (N=120)			
x_1	1,000 NOK	26052.43	87457.42	5.2500000	732388.70
x_2	Hours	599363.18	1937908.60	1300.00	13345240.00
x_3	1,000 NOK	91617.30	346085.80	50.4000000	3106661.00
y_1	Million NOK	5518.50	20222.78	5.9976000	147029.70
y_2	Million NOK	7398.78	29251.61	2.8119000	198695.57
y_3	Number	26.9333333	67.9688180	1.0000000	515.0000000
y_4	Million NOK	1987574.33	9033160.05	0	72920930.00

Note: NOK = Norwegian currency units.

We have calculated the efficiency for each of the banks relative to its own national frontier ($i \in \{D, F, N, S\}$) and relative to the pooled technology ($i = \kappa$). A common technology base facilitates comparisons across countries, but it should be noted that the choice of base will influence the results. In this report we have chosen the pooled Nordic data set to define the reference technology, but any country could also have been used (cf. Malmquist 1953, section 7).

4.1 Individual country results

The indidual country results are similar to those reported by Berg *et al* (1993b) for Finland, Norway and Sweden and by Bukh (1994) for Denmark. Thus, we will only briefly summarize the individual results in this report. We found that the efficiency spreads between banks were most important in Finland and in Norway and least important in Denmark and in Sweden. Comparing the best practice frontiers of the four countries, we found the highest share of the banking industry on the frontier, i.e. with efficiency equal 1, in Denmark and in Sweden, and the lowest share in Finland.

Table 2: Structural efficiency measures for the individual samples: efficiency scores for the average and the largest units in each country

	Denmark		Finland		Norway		Sweden	
	Largest	Average	Largest	Average	Largest	Average	Largest	Average
CRS	1.0000	0.8228	0.5013	0.4978	0.8248	0.5374	0.9153	0.7851
VRS	(1.00)	0.8582	(1.00)	0.5308	(1.00)	0.7786	(1.00)	0.8431

Table 2 shows the efficiency score of the largest national banks evaluated relative to their own national frontiers, and the efficiency score of the average banks in the national data sets. Irrespective of scale assumption, the average Danish and Swedish banks were found to be relatively more efficient than

by Berg *et al.* (1993b), tried to capture the essential differences between the production activities of the four banking industries by an output vector consisting of four components.

the Finnish and Norwegian average banks in the national data sets, with the Norwegian average bank being more efficient than the average Finnish and the Danish average bank more efficient than the Swedish average bank.

Under the assumption of VRS, the largest bank in each country is evaluated as efficient compared to the frontier technology. This is a consequence of the evaluation procedure, cf. section 2.1. Specifying CRS, the largest Swedish, Norwegian and Finnish banks are inefficient, while the largest Danish bank is fully efficient. The magnitude of efficiency scores for the largest banks, show the same picture as for the average banks, i.e. the largest Danish and Swedish bank being more efficient than the largest Norwegian bank, which, in turn, is more efficient than the largest Finnish bank, relative to their national frontiers.

4.2 Pooled Nordic data set

Figure 1 shows the distribution of efficiency scores for the VRS specification based on the merged data set. The efficiency scores are measured along the vertical axis, and each histogram represents one individual bank with the width of the histogram being proportional to its share of total Nordic loans. The distribution splits into two with the efficient units representing 56 % percent of total Nordic loans. The large Swedish and Danish banks remain efficient in a Nordic setting, but most large Finnish and Norwegian banks are now inefficient. The inefficient part shows a mix of small and large banks.

When specifying CRS, the results are, as shown in figure 2, more mixed, but we may identify four parts of the distribution. The range of efficiency scores between 0.3 and 0.5 is dominated by large Finnish and Norwegian banks. The range from 0.5 to 0.6 includes one large Finnish and the second largest Danish bank. The large Swedish banks maintain their high level of efficiency similar to the individual country and the VRS results, and together with one Danish and one Finnish bank they dominate the efficiency score range between 0.6 and 0.85. Finally, the range 0.85 to 1.0 consist of several small banks from Sweden, Denmark and Finland, which are all evaluated as fully efficient.

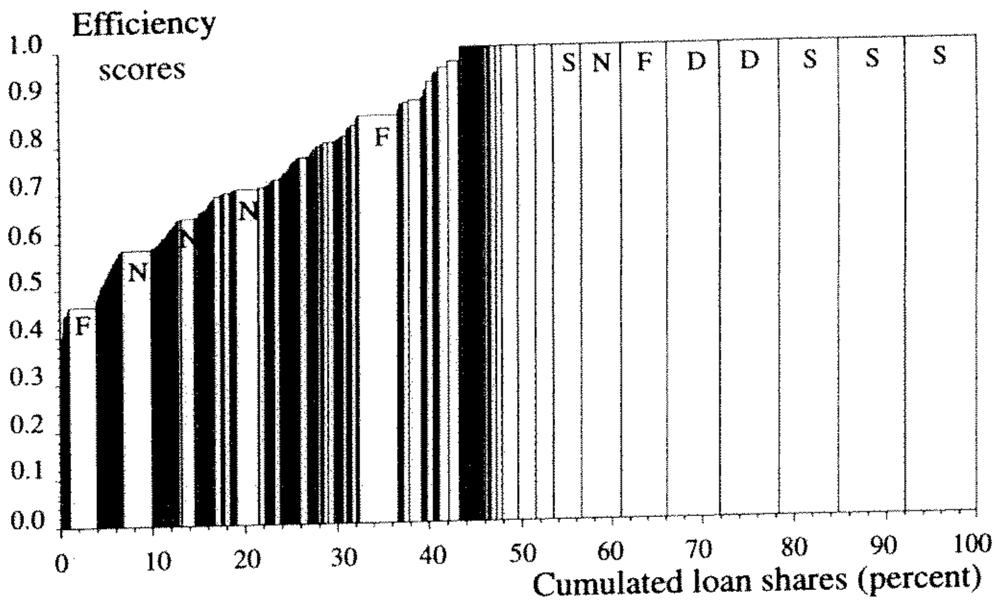


Figure 1: Pooled data: The distribution of input-saving efficiency against cumulated loan share, variable returns to scale

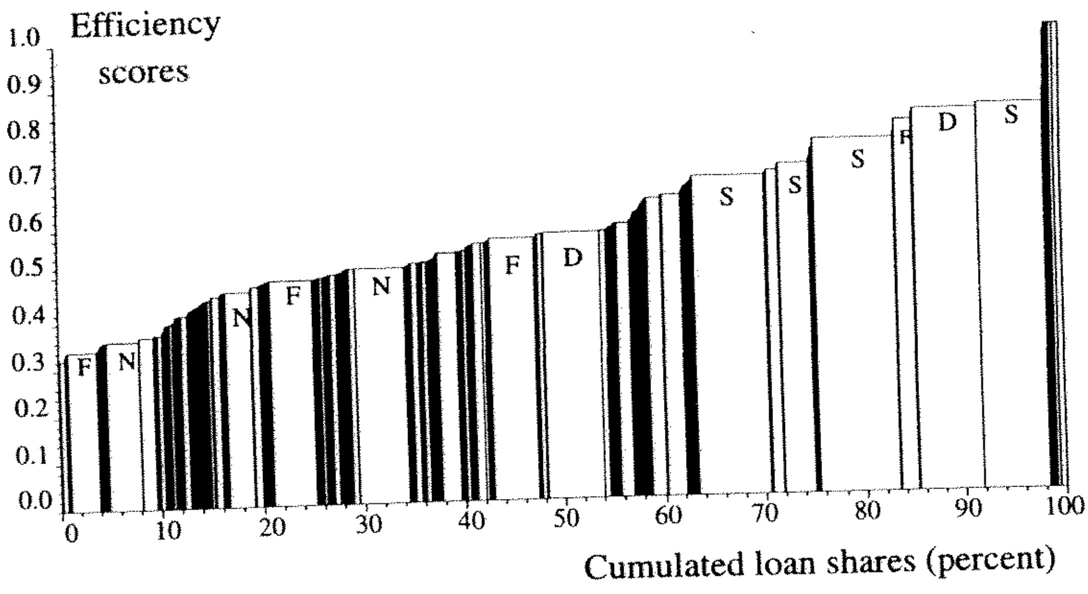


Figure 2: Pooled data: The distribution of input-saving efficiency against cumulated loan share, constant returns to scale

A summary of the efficiency scores is reported in table 3 for each country separately. The efficiency score of the average unit in each country, is listed first under the assumption of CRS and VRS respectively. These efficiency scores are not structural efficiency measures in the traditional sense (e.g. as in Førsund and Hjalmarsson 1974). Rather they should be interpreted as a measure of the efficiency spread in the individual countries, and together they provide a picture of the structure of the Nordic banking sector. The results indicate that technical inefficiency is of importance in each country, with the highest inefficiency found in Finland and Norway.

Table 3: Efficiency for the national average banks and industry efficiency measures for the pooled sample calculated for each country separately under the assumption of VRS

	Efficiency score for the national average bank		Industry efficiency measures (weighted by inputs)					
	CRS	VRS	I^{1P}	I^{1R}	I^{2P}	I^{2R}	I^{3P}	I^{3R}
Denmark	0.55	0.78	0.87	0.90	0.90	0.90	0.89	0.89
Finland	0.42	0.52	0.78	0.84	0.77	0.80	0.77	0.77
Norway	0.40	0.54	0.46	0.75	0.74	0.74	0.73	0.73
Sweden	0.65	0.85	0.81	0.92	0.92	0.92	0.93	0.93

The usual input specific industry efficiency measures, I^{nR}, are computed according to (12) and by including the slacks, the slack adjusted industry efficiency measures, I^{nP}, are computed according to (11). The industry measures, which are weighted by the inputs, are significantly higher for all countries than the structural efficiency measures. This indicates that efficiency is correlated with size in the sample. Using the industry efficiency measures, the Danish and the Swedish banking sectors are found to be relatively more efficient than the Norwegian and the Finnish banking sectors, with the Finnish banking sector being more efficient than the Norwegian. The radial measures and the slack adjusted measures are almost identical for all four countries in the direction of x_2 (labour) and x_3 (materials), whereas the slack adjusted measures are significantly smaller in the direction of x_1 (book value of machinery and equipment). The same picture is revealed by the computation of the importance of slack according to equation (13), where we found $\sigma_1 = 0.462$, $\sigma_2 = 0.044$ and $\sigma_3 = 0.014$. This means that the inclusion of slack has very little importance in the direction of x_2 and x_3, while the potential savings in input x_1 are increased by 46 % when slack is taken into consideration. This could indicate problems related to the specification of real capital (x_1), but it could also indicate that the use of machinery and equipment is a major source of inefficiency. This would be the case especially for the Norwegian, Finnish and Swedish banking sectors, where the difference between the radial and the slack adjusted industry measures is the largest.

4.3 Productivity comparisons

In table 4, we report comparisons between the largest banks of each country and between the average banks. The average banks are included as a way of revealing structural information. As shown in section 2.2, the productivity differences can be split into a component due to differences in efficiency (cathing-up) and another component due to technology differences (technology shift).

The national average banks

The Norwegian average bank has a 4 % higher productivity than the Finnish one within the VRS specification, but it is 6 % less productive in the CRS specification. In both cases, the technology and the efficiency component work in opposite directions, so that the Norwegian average bank is more efficient than the Finnish one relative to its national frontier. The difference between the Finnish and the Swedish average banks is substantial within both the VRS and the CRS specification, and the difference between the Finnish and the Danish

Table 4: Intercountry productivity comparisons. Average and largest units in each country (the pooled Nordic sample is used as frontier technology)

Country (First country=1, second country=2)	Malmquist productivity index $M_\kappa(1,2)$ VRS	CRS	Efficiency component $MC(1,2)$ VRS	CRS	Technology component $MF_\kappa(1,2)$ VRS	CRS
Finland-Norway:						
Largest unit	1.16	1.02	1.00	1.65	1.16	0.62
Average unit	1.04	0.94	1.47	1.08	0.71	0.87
Finland-Sweden						
Largest unit	1.16	1.39	1.00	1.82	1.16	0.76
Average unit	1.64	1.55	1.59	1.58	1.03	0.98
Finland-Denmark						
Largest unit	1.16	1.67	1.00	1.99	1.16	0.84
Average unit	1.51	1.32	1.62	1.65	0.94	0.80
Norway-Sweden						
Largest unit	1.00	1.36	1.00	1.11	1.00	1.23
Average unit	1.59	1.64	1.08	1.46	1.46	1.12
Norway-Denmark						
Largest unit	1.00	1.63	1.00	1.21	1.00	1.35
Average unit	1.46	1.40	1.10	1.53	1.32	0.91
Denmark-Sweden						
Largest unit	1.00	0.83	1.00	0.92	1.00	0.91
Average unit	1.09	1.18	0.98	0.95	1.11	1.23

average banks presents the same picture, the Danish and Swedish banks being 32-64% more efficient than the Finnish. This difference is due to the efficiency component, whereas the technology component is either negligible or work in the opposite direction. Our finding on the efficiency component is in accordance with the structual efficiency measures in table 3.

The Danish and Swedish average banks are also more productive than the Norwegian ones, the productivity gap ranging from 40 to 64 %. In the VRS

4.4 The frontier banks

The banks spanning the Nordic frontier are shown in table 5. The number of times that the banks appear in the reference set of *inefficient* banks is shown in column 2 for the VRS tehcnology and for the CRS technology in column 3. If a bank is evaluated as efficient, but only appear in its own reference, it should be regarded as a "self-evaluator", as remarked by Charnes *et al.* (1985, p. 110). These banks are marked with an asterisk ($*$) in table 5, columns 2 and 3. The next columns characterize the frontier banks in terms of number of branches and three output ratios.

The VRS frontier is spanned by 67 non-dominated banks. Denmark has 20 banks on the frontier, Finland 19, Norway 6 and Sweden 22 banks. Most of the efficient banks appear in the reference sets of other banks, but two large Danish banks and seven Swedish banks appear only in their own reference sets. The frontier banks in each country have a smaller share of retail loans in their portfolios than the national average, but higher ratios of guarantees to lending than their national averages. In all countries the average frontier bank has lower deposit/loan ratios than its national averages, but they have larger deposits per branch.

In the CRS case, there are 29 non-dominated banks on the frontier, and 25 of them appear in the reference set of other banks, i.e. four are self-evaluators. Of the reference banks, 12 are from Denmark, 6 from Finland, 4 from Norway and 7 from Sweden. Two small Swedish banks and two Danish banks are self-evaluators. We notice that all frontier banks are quite small, with a maximum of 12 branches. The capital/hour ratio of frontier banks shows considerable variation, in particular among the Danish and Swedish banks. Norwegian and Swedish frontier banks have ratios higher than their national averages as often as they have ratios below average, whereas three of the four Finnish frontier banks have ratios lower than average.

The largest banks of each country have very similar loan/deposit ratios. Deposits per branch are also similar in the largest Norwegian and Swedish

Table 5: Report of dominance; the frequency of the non-dominated banks' appearance in the reference set of inefficient banks in the CRS and the VRS case (self-evaluators marked with an ∗)

ID number	VRS	CRS	No. of Branches	Loan/ deposits	Deposits/ branches	Capital/ hours
Denmark						
5079	501	453	1	0.114	0.5304	0.011
5033	179	386	1	1.292	1.6848	0.008
5031	63	1	1	0.866	1.0856	0.116
5132	61	141	2	0.980	0.0004	0.000
5029	59	.	712	0.876	0.2596	0.035
5078	47	15	12	0.884	0.1248	0.000
5138	46	2	1	0.884	0.0004	0.000
5012	46	.	3	0.384	0.0085	0.038
5173	33	73	1	0.197	0.0104	0.000
5175	11	10	1	0.703	0.0161	0.000
5045	10	.	1	0.086	2.4693	0.027
5035	9	∗	58	0.637	0.1755	0.000
5108	9	.	10	0.667	0.0917	0.005
5092	7	.	34	0.949	0.0653	0.013
5153	5	6	1	0.410	0.0066	0.000
5178	3	.	1	0.428	0.0016	0.000
5089	3	5	2	0.697	0.1648	0.000
5159	1	∗	1	0.304	0.0096	0.000
5001	∗	.	301	1.010	0.1567	0.018
5028	∗	.	701	0.981	0.2080	0.040
Finland						
3294	607	791	2	2.156	0.7644	0.0243
3429	374	623	2	0.842	0.0451	0.0088
3351	220	61	4	0.627	0.1243	0.0165
3322	205	.	6	0.599	0.0236	0.0148
3106	151	.	8	0.751	0.0496	0.0843
3405	141	.	5	1.388	0.0411	0.0175
3357	99	.	21	1.128	0.0530	0.0265
3206	94	158	1	0.693	0.0177	0.0061
3317	49	.	27	1.095	0.0474	0.0562
3195	44	54	1	0.896	0.1131	0.0065
3140	33	.	5	0.808	0.0254	0.0107

ID number	VRS	CRS	No. of Branches	Loan/ deposits	Deposits/ branches	Capital/ hours
3225	31	.	5	0.815	0.0408	0.0049
3216	29	.	1	0.488	0.0099	0.0054
3423	23	.	23	1.581	0.0826	0.0277
3501	13	.	101	1.272	0.1099	0.0965
3497	11	.	432	1.648	0.1559	0.0740
3029	10	19	1	0.920	0.0342	0.0034
3388	6	.	19	1.933	0.0732	0.0636
3502	3	.	4	15.219	0.7238	0.0470
Norway						
2136	97	70	1	2.486	1.8698	0.0978
2066	45	28	1	1.049	0.6524	0.0319
2059	41	.	2	0.868	0.1112	0.1300
2065	26	1	3	1.055	0.1692	0.0076
2141	13	24	1	12.284	0.1198	0.1733
2091	1	.	59	2.232	0.0567	0.0373
Sweden						
1163	355	750	1	0.695	0.0289	0.1631
1144	258	.	5	0.629	0.0400	0.0403
1104	119	.	515	1.441	0.2182	0.0251
1122	102	.	81	0.853	0.0637	0.0333
1164	69	252	1	0.856	0.0273	0.0440
1114	15	.	17	0.830	0.0503	0.0192
1102	9	.	230	1.840	0.1810	0.0500
1107	8	.	232	1.351	0.6338	0.0425
1166	6	.	1	0.469	0.0060	0.0022
1165	5	9	1	0.640	0.0154	0.0396
1160	5	8	1	0.598	0.0098	0.0140
1101	3	5	27	2.150	0.2589	0.0187
1116	3	.	108	0.837	0.0791	0.0315
1111	1	.	345	1.527	0.3385	0.0549
1121	1	.	65	0.895	0.0612	0.0508
1161	*	*	1	0.840	0.0199	0.0662
1221	*	*	1	0.830	0.0787	0.0015
1113	*	.	40	0.976	0.1252	0.0096
1115	*	.	48	0.832	0.1077	0.0260
1118	*	.	52	0.920	0.0852	0.0298
1125	*	.	192	1.847	0.1366	0.0516
1151	*	.	7	0.629	0.0357	0.0567

Note: CRS indicate appearances in the CRS case, and VRS in the VRS case.

banks, but the largest Finnish bank has a much lower level of deposits per branch. This may be explained by the fact that in Finland regulations of the deposit rate have spurred the establishment of a very large number of branches to compete for deposits. The capital/hours ratios of the largest banks are much closer than the national averages, but with a higher ratio in Norway and Sweden than in Finland.

4.5 The reference units

Table 5 gives some indication of which banks influence the computations the most. In order to investigate this issue in more details we computed each bank's importance as a reference unit from equation (14). Table 6 ranks the efficient units by their fraction of total aggregated potential reduction of each input for which they act as referencing unit. This identifies not only the most important reference units, but it also reveals the units measured as efficient because they are specialized (cf. Torgersen *et al.* 1994).

Out of the 68 efficient banks in the VRS case, only about 25 are individually acting as reference unit for more than 1 % of the total inefficiency, and 13 banks are self-referencing units, i.e. they have $z_{ii} = 1$, and the rest of the weights are zero[12]. Four of the banks, three Swedish and one Finnish, act as reference unit for about 30 % of the inefficiency, whereas the 10 most important referencing banks act as reference unit for about 50 % of the total aggregated potentials within each input.

Figures 3, 4 and 5 show graphically for each of the three inputs the potential reduction defined by individual reference banks. In the left pie chart we show the shares for the individual units, while we have aggregated the shares by country in the right pie chart. In the case of "real capital" in figure 3, the

[12] Some of the smallest Danish banks have $x_1 = 0$. This constitutes a potential problem, because the banks involved can only be evaluated as inefficient in comparison with other banks with a similar zero-pattern. Several of these banks are evaluated as efficient, but because of their specialized character, they are virtually without importance as reference units.

Table 6: The relative importance of units in referencing savings potential for the inputs

Rank	ID	Country	ρ_1	ρ_2	ρ_3
1	1102	Sweden	19.1%	7.0%	7.8%
2	1104	Sweden	7.7%	8.3%	10.0%
3	1122	Sweden	7.7%	8.1%	9.9%
4	3106	Finland	6.6%	7.3%	7.0%
5	3317	Finland	4.6%	6.0%	5.0%
6	3294	Finland	4.5%	5.5%	5.0%
7	1101	Sweden	4.1%	2.0%	2.2%
8	1111	Sweden	3.8%	0.0%	0.0%
9	2136	Norway	3.6%	6.3%	8.5%
10	3501	Finland	3.6%	3.2%	3.1%
11	5079	Denmark	3.2%	4.9%	4.8%
12	3497	Finland	3.2%	6.9%	2.9%
13	5029	Denmark	3.0%	0.6%	0.4%
14	3423	Finland	2.5%	2.9%	2.4%
15	1125	Sweden	2.2%	0.0%	0.0%
16	3502	Finland	1.9%	3.0%	4.3%
17	1144	Sweden	1.9%	2.4%	2.7%
18	3357	Finland	1.8%	3.2%	2.5%
19	3322	Finland	1.8%	3.5%	2.8%
20	1163	Sweden	1.7%	2.4%	2.5%
21	5031	Denmark	1.6%	1.4%	1.9%
22	3429	Finland	1.4%	2.9%	2.3%
23	1116	Sweden	1.4%	0.8%	1.0%
24	2091	Norway	1.2%	0.8%	0.8%
25	5045	Denmark	1.1%	1.2%	1.6%
26	5033	Denmark	0.9%	0.9%	1.3%
27	3405	Finland	0.8%	1.1%	0.8%
28	3351	Finland	0.6%	1.3%	0.8%
29	3388	Finland	0.5%	0.6%	0.5%
30	5012	Denmark	0.4%	0.5%	0.6%

Note: Of the 68 efficient banks, only the 30 most important units (according to ρ_1) are shown

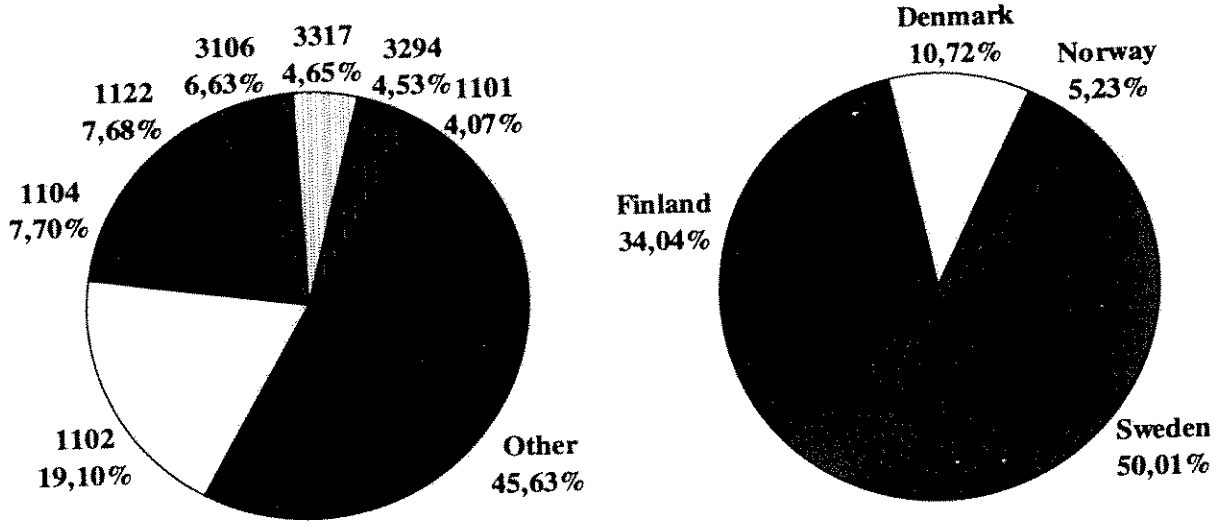


Figure 3: ρ_1: The share of potential reduction of input x_1 (real capital) for which the individual unit refer. Individual banks and grouped by country.

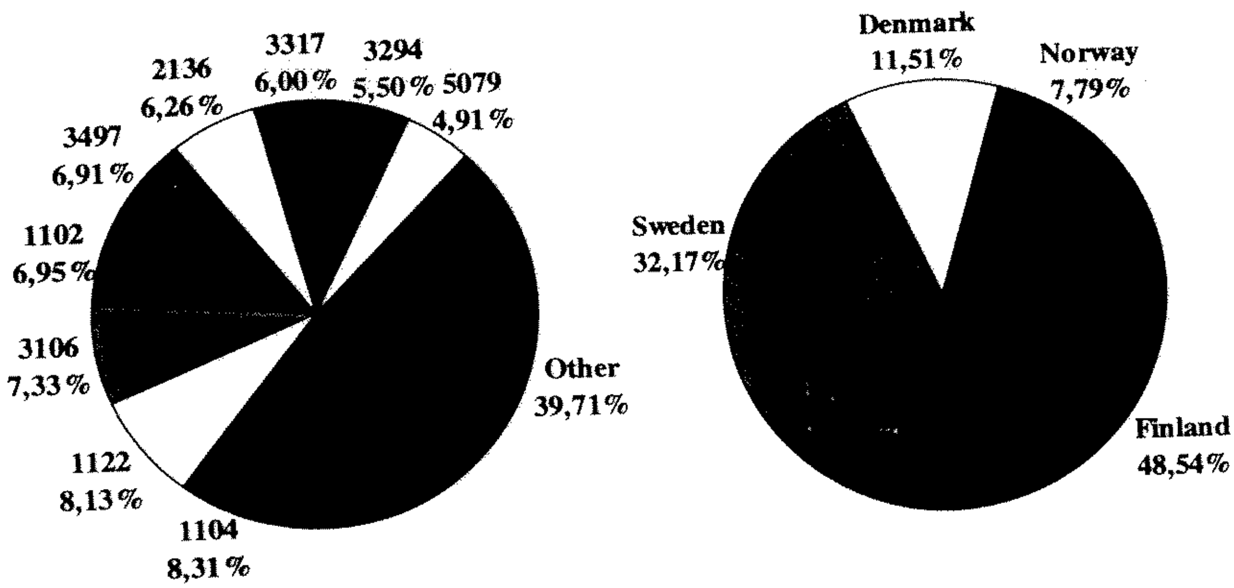
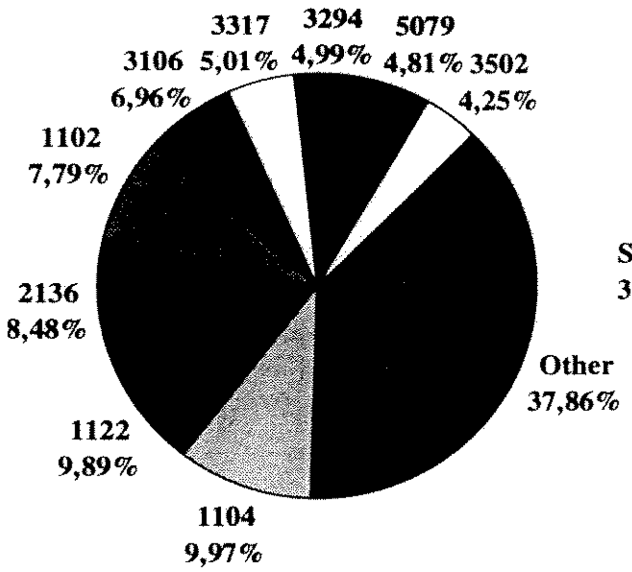


Figure 4: ρ_2: The share of potential reduction of input x_2 (labour) for which the individual unit refer. Individual banks and grouped by country.



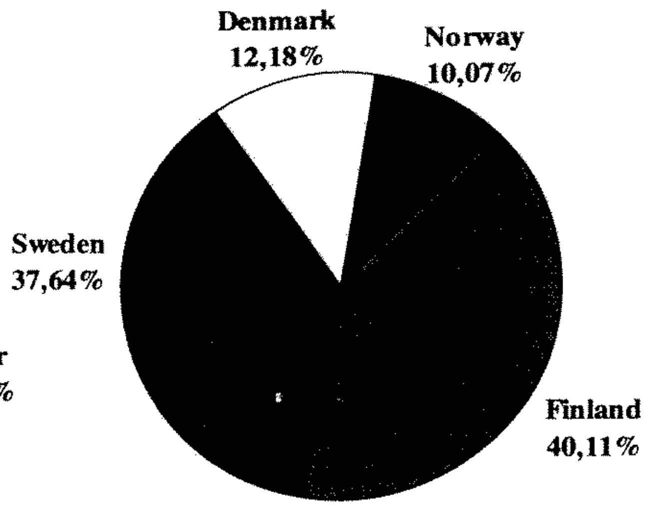


Figure 5: ρ_3: The share of potential reduction of input x_3 (materials) for which the individual unit refer. Individual banks and grouped by country.

Swedish banks are individually acting as reference units for 50.0 % of the total inefficiency while the Finnish banks act as reference unit for 34.0 % of the inefficiency. The Danish and the Norwegian banks are less important as reference units, acting as reference unit for 10.7 % and 5.2 %, respectively.

Figure 4 shows the case of "labour" where the importance of the Finnish and Swedish banks as reference units are reversed, since the Finnish banks act as reference units for 48.6% of the inefficiency while the Swedish banks act as reference for 32.2 %. Finally, figure 5 shows the case of "materials" where the Finnish and the Swedish banks act as reference for 40.1 % and 37.64 % respectively of the ineffiency. In the three cases. the share of total inefficiency for which the Danish banks act as reference units vary from 10.7 % to 12.2 % while the shares of Norwegian banks vary from 5.2 % to 10.1 %.

Table 7: Sensitivity testing: The effect of deleting the most important original frontier banks from the sample (VRS case)

Deleted observation		N	Arithmetic mean	Std. dev.	Median	Minimum
(full sample)		950	0.670	0.164	0.655	0.253
1102	Sweden	949	0.670	0.164	0.655	0.253
1104	Sweden	948	0.674	0.165	0.658	0.253
1122	Sweden	947	0.675	0.167	0.659	0.253
3106	Finland	946	0.676	0.167	0.659	0.253
3317	Finland	945	0.676	0.167	0.659	0.253
3294	Finland	944	0.704	0.166	0.693	0.253
1101	Sweden	943	0.704	0.165	0.693	0.253
1111	Sweden	942	0.704	0.165	0.693	0.253
2136	Norway	941	0.704	0.165	0.693	0.253
3501	Finland	940	0.704	0.165	0.693	0.253

4.6 Sensitivity analysis

To investigate the stability of the frontier for our pooled data set, we have deleted the 10 frontier banks with the highest ρ_1 from the sample, one at a time, starting with the most dominating bank, i.e. the one with the highest ρ_1. The influence in the direction of x_1 has been chosen arbitrarily, and we could have measured the influence in any direction. It should be noted that our choice of x_1 (book value of machinery and equipment) as direction of the sensitivity analysis could potentially bias the analysis because the measures of x_1 are the least reliable ones. But since the correlations between ρ_1, ρ_2 and ρ_3 are very high (cf. table 6) we do not regard this as a serious problem.

In table 7, the arithmetic mean of the efficiency scores is shown for the VRS case, when the 10 frontier banks with the highest ρ_1 are deleted from the data

Table 8: Sensitivity testing: Correlation matrix for the effect of deleting original frontier banks from the sample, one at a time (VRS case)

	Number of banks deleted from the data set										
	0	1	2	3	4	5	6	7	8	9	10
		.166	.224	.163	.213	.143	.177	.094	.117	.032	.083
0		.0001	.0001	.0001	.0001	.0001	.0001	.0039	.0003	.3293	.0106
		949	948	947	946	945	944	943	942	941	940
	.159		.167	.206	.131	.167	.107	.173	.097	.107	.057
1	.0001		.0001	.0001	.0001	.0001	.0010	.0001	.0027	.0011	.0784
	949		948	947	946	945	944	943	942	941	940
	.218	.163		.196	.261	.181	.222	.100	.166	.132	.142
2	.0001	.0001		.0001	.0001	.0001	.0001	.0021	.0001	.0001	.0001
	948	948		947	946	945	944	943	942	941	940
	.158	.200	.189		.447	.509	.425	.192	.108	.150	.121
3	.0001	.0001	.0001		.0001	.0001	.0001	.0001	.0009	.0001	.0002
	947	947	947		946	945	944	943	942	941	940
	.215	.124	.251	.465		.596	.623	.157	.181	.099	.134
4	.0001	.0001	.0001	.0001		.0001	.0001	.0001	.0001	.0023	.0001
	946	946	946	946		945	944	943	942	941	940
	.166	.159	.172	.525	.633		.560	.237	.143	.172	.082
5	.0001	.0001	.0001	.0001	.0001		.0001	.0001	.0001	.0001	.0121
	945	945	945	945	945		944	943	942	941	940
	.182	.122	.204	.441	.653	.596		.185	.231	.156	.197
6	.0001	.0002	.0001	.0001	.0001	.0001		.0001	.0001	.0001	.0001
	944	944	944	944	944	944		943	942	941	940
	.100	.178	.115	.177	.148	.227	.182		.198	.259	.1923
7	.0020	.0001	.0004	.0001	.0001	.0001	.0001		.0001	.0001	.0001
	943	943	943	943	943	943	943		942	941	940
	.125	.103	.172	.121	.167	.136	.220	.195		.373	.430
8	.0001	.0015	.0001	.0002	.0001	.0001	.0001	.0001		.0001	.0001
	942	942	942	942	942	942	942	942		941	940
	.051	.104	.145	.150	.107	.156	.145	.245	.395		.726
9	.1164	.0014	.0001	.0001	.0010	.0001	.0001	.0001	.0001		.0001
	941	941	941	941	941	941	941	941	941		940
	.081	.070	.146	.136	.124	.090	.179	.182	.445	.775	
10	.0133	.0329	.0001	.0001	.0001	.0057	.0001	.0001	.0001	.0001	
	940	940	940	940	940	940	940	940	940	940	

Note: The upper right triangle shows Sperman's rank correlation (ties being replaced with the mean rank). The lower left triangle shows Pearson's coefficient between actual efficiency scores. Each cell in the table shows test statistic, probability of $H_0 : \tau = 0$ and the number of observations for the calculation.

set. The mean efficiency score is seen to be very stable at 0.67-0.68, jumping to 0.70 when we delete the 6th observation. Also the standard deviation, the mean and the minimum efficiency score are almost unchanged. The same picture is revealed by table 8, where we show the correlation between efficiency scores relative to the VRS frontier when the most influential observations are deleted from the data set, one at a time. The upper right triangle shows the Spearman rank correlation coefficient, calculated with a mean rank for ties between frontier units, and the lower left triangle shows the Pearson correlation coefficient. As more of the original frontier banks are deleted, the rank correlation decreases very slowly. This high level of correlation with the original ranking demonstrates that our results are robust to possible data errors among the original frontier banks.

5 Concluding remarks

Data Envelopment Analysis has been applied to the banking industries of the four Nordic countries, Denmark, Finland, Norway and Sweden. Productivity differences between banks from different countries have been measured by Malmquist indices and decomposed into one term describing different distances from the national best practice frontiers and another describing the difference between these national frontiers. Both radial and slack adjusted efficiency scores were computed, and the efficient banks were ranked according to their importance as reference units. This ranking has been used in an analysis of the sensitivity of the results to ostensible productive outliers.

The large banks from each country are the most likely ones to start operating outside their national markets, and their relative efficiency is therefore a question of particular interest. We found that the largest Danish and Swedish banks were among the most efficient units in our pooled Nordic sample, whereas only one large Finnish bank and one large Norwegian bank had efficiency scores above 0.9. This indicates that the Danish and Swedish banks are in the best position to expand in a common Nordic banking market. Whether such development should be countered or welcomed by national governments is up to objectives It should be remarked that the data set used in the analysis set is from 1990 and that the structure of the sector have changed since then due to mergers, entries and exits. Since the year of analysis some Nordic banks have actually set up branches in the other Nordic countries and the effect of this development is of course not pictured in the present study. We are, however, working on an extension of the study into a time series cross section framework.

The conclusions from the study are largely independent of whether we assume variable or constant returns to scale along the best practice frontier. Assuming variable returns to scale, we find that more than 55 % of the loans are generated from fully efficient banks, but with constant returns to scale the efficient loan share is close to zero. But note that the efficient self-evaluators in the VRS case almost all disappear from the efficient set in the CRS case.

This reflects the fact that returns to scale are found to be strongly decreasing along the frontier. However, we are not comfortable with this finding, because the output vector is likely to be a less satisfactory measure of the true production activities in large banks than in the smaller ones. This should lead us to comparing banks of approximately the same size only, as we do in the VRS case, and without drawing inferences about economies of scale. On the other hand, there are few large banks and by assuming VRS, we might find most of these large banks efficient merely for the lack of truly efficient observations of large banks. This should lead us to comparing large banks with smaller banks as we do in the CRS case. We have reported results under both the VRS and the CRS specifications, and we have confidence in the results that are common to both alternatives only.

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