Bank insolvency risk and time-varying Z-score measures

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Abstract

We compare the different existing approaches to the construction of time-varying Z-score measures, plus an additional alternative one, using a panel of banks for the G20 group of countries covering the period 1992–2009. We examine which ways of estimating the moments used in these different approaches best fit the data, using a simple root mean squared error criterion. Our results are supportive of our alternative time-varying Z-score measure: it uses mean and standard deviation estimates of the return on assets calculated over full samples combined with current values of the capital-asset ratio, and is thus straightforward to implement.

JEL classification: G21

Key words: insolvency risk, Z-score, time-varying, mean squared error

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1. Introduction

The Z-score is a risk measure commonly used in the empirical banking literature to reflect a bank's probability of insolvency. It is generally attributed to Boyd and Graham (1986), Hannan and Hanweck (1988) and Boyd et al. (1993), and plays an important role in the assessment of both individual bank risk as well as overall financial stability. Its use in cross-sectional studies has become widespread due to its simplicity and the fact that it can be constructed using only accounting information; in contrast to market-based risk measures, it is also applicable to the substantial number of unlisted financial institutions. Starting with work by Boyd et al. (2006), Hesse and Čihák (2007) and Yeyati and Micco (2007), it is now also increasingly being implemented as a time-varying measure in panel studies. Despite this growing popularity, there appears so far to be a certain lack of consensus on what the best way of constructing such time-varying Z-score measures might be.

In this paper, we discuss the time-varying Z-score measures in use so far and propose a related alternative one; we then compare these measures using data on commercial, cooperative and savings banks for the G20 group of countries covering the period 1992–2009. We further examine which of the various ways of estimating the moments used in the different approaches to the computation of these time-varying Z-score measures best fit the data, using a simple root mean squared error criterion. Our results overall support the use of the alternative time-varying Z-score measure we propose, which uses mean and standard deviation estimates of the return on assets that are calculated over the full sample and combines these with current values of the capital-asset ratio. This approach to the construction of time-varying Z-score measures is furthermore straightforward to implement and does not drop initial observations, an inherent problem with rolling moments approaches.

Section 2 discusses the different approaches to the construction of time-varying Z-score measures considered, Section 3 evaluates them for a panel of commercial, cooperative and savings banks for the G20 group of countries, and Section 4 concludes the paper.

2. Different approaches to time-varying Z-score measures

To discuss the different approaches to the construction of time-varying Z-score measures currently in use in the literature, let us first recapitulate the established rationale for the use of Z-score measures more generally. As is common in the literature, we define bank insolvency as a state where $(car + roa) \leq 0$, with car being the bank's capital-asset ratio and roa its return on assets. Then, if roa is a random variable with mean μ_{roa} and finite variance σ^2_{roa}, Hannan and Hanweck (1988) and Boyd et al. (1993) point out that the Bienaymé-Chebyshev inequality allows us to state an upper bound of the probability of insolvency as

$$p(roa \leq -car) \leq Z^{-2} \tag{1}$$

$$\text{where } Z \equiv \frac{car + \mu_{roa}}{\sigma_{roa}} > 0 \tag{2}$$

The Z-score Z defined in Equation (2) is thus inversely related to an upper bound of the probability of insolvency $p(roa \leq -car)$, even for the weakest of distributional assumptions.[1]

[1]Strobel (2011) derives a related upper bound of the probability of insolvency for the special case where the bank's distribution of returns is unimodal.

The implementation of Z-score measures for cross-sectional analysis is largely uncontroversial; by comparison, the construction of time-varying Z-score measures to be used in panel analysis may appear less straightforward. However, it is sufficient to reiterate that the probabilistic interpretation of Z-score measures implies that μ_{roa} and σ_{roa} are moments of the distribution of roa that are possibly time-varying and need to be estimated as $\mu_{roa,t}$ and $\sigma_{roa,t}$ for time periods t. On the other hand, $(-car)$ is simply a "safety first" level of returns (in the spirit of Roy, 1952) delimiting the insolvency case; it could therefore plausibly be made directly time-varying using current period t values of car_t, or otherwise be represented by its mean $\mu_{car,t}$ which then would also need to be estimated for time periods t. Taking those two elements together would thus suggest time-varying Z-scores of either of the two following forms

$$Z_t = \frac{car_t + \mu_{roa,t}}{\sigma_{roa,t}} \quad \text{or} \quad Z_t = \frac{\mu_{car,t} + \mu_{roa,t}}{\sigma_{roa,t}} \tag{3}$$

The various approaches to the construction of time-varying Z-score measures currently in use in the literature, together with their first exponents, can then be classified as follows:

- Approach Z1: Boyd et al. (2006, section III.A) use moving mean and standard deviation estimates $\mu_{car,t}(n)$, $\mu_{roa,t}(n)$ and $\sigma_{roa,t}(n)$ (with window width $n = 3$) that are calculated for each period $t \in \{1 \ldots T\}$.

- Approach Z2: Yeyati and Micco (2007) use moving mean and standard deviation estimates $\mu_{roa,t}(n)$ and $\sigma_{roa,t}(n)$ (with window width $n = 3$) that are calculated for each period $t \in \{1 \ldots T\}$, and combine these with current period t values of car_t.

- Approach Z3: Hesse and Čihák (2007) use standard deviation estimates σ_{roa} that are calculated over the full sample $[1 \ldots T]$, and combine these with current period t values of car_t and roa_t.

- Approach Z4: Boyd et al. (2006, section III.B) use what might be called "instantaneous" standard deviation estimates $\sigma_{roa,t}^{inst} = |roa_t - \mu_{roa}|$, where the mean estimate μ_{roa} is calculated over the full sample $[1 \ldots T]$, and combine these with current period t values of car_t and roa_t.

Clearly, all these approaches are consistent with the probabilistic interpretation of Z-score measures discussed above. A further approach that is also consistent with this interpretation, but does not seem to have been used in the literature so far, would be

- Approach Z5: One could use mean and standard deviation estimates μ_{roa} and σ_{roa} that are calculated over the full sample $[1 \ldots T]$, and combine these with current period t values of car_t.

Which of these five approaches to constructing time-varying Z-score measures is then most appropriate in a given context is an inherently empirical question and will depend on the data under consideration; we will examine this issue further in the following section.

3. Evaluating different time-varying Z-score measures for the G20 countries

We now examine how the different ways of computing time-varying Z-score measures discussed in Section 2 compare when taken to the data. To this end, we examine a dataset of commercial, cooperative and savings banks for the G20 group of countries extracted from BvD Bankscope, covering the period 1992–2009. We manually clean for obvious outliers/erroneous data, and retain for each bank j the longest contiguous run of observations T_j while imposing a minimum of five observations; we end up with data for 14658 banks with an average of 10.4 years of observations. Table 1 gives a breakdown of the number of banks in our sample by country and bank type.

In Table 2 we give descriptive statistics of the five different time-varying Z-score measures. We observe three distinct clusters amongst these measures, consistently for all banks, for all three types of bank and for all G20 countries. Z1 and Z2 are very similar, with average means and standard deviations of these measures, as calculated per bank, in a medium range with an average coefficient of variation of 1.1. Z3 and Z5 are also very close to each other, with average means and standard deviations in a generally lower range and an also rather low average coefficient of variation of 0.1. Z4, on the other hand, gives results that are very different from the other measures, with average means and standard deviations in a much higher range, even running to four digits in the case of the US, and a much larger average coefficient of variation of 2.2. These three clusters are confirmed when examining the average correlation coefficients of these different measures, as presented in Table 3. In order to better understand the markedly different behavior of Z4, we examine some descriptive statistics of the components of these time-varying Z-score measures in Table 4. We note that the "instantaneous" standard deviation estimates $\sigma^{inst}_{roa,t}$ used in the calculation of Z4 can obtain extremely small values compared to the other measures, particularly for the case of the US, leading consequently to potentially very large values of Z-scores and quite substantial volatility in these measures, as observed in Table 2.

[Insert Tables 1–4]

We then take our investigation further by examining which of the various mean and standard deviation estimates that are used to compute the time-varying Z-score measures Z1–Z5 best fit the data, in the sense of producing minimum one-period-ahead forecast errors. Given the rather short time dimension of our panel, we opt for a simple root mean squared error (RMSE) criterion to evaluate which of the proposed approaches to calculate the means $\mu_{car,t}$ and $\mu_{roa,t}$ best fit the data. For this we explore which of the different estimates[2] $\mu^{est}_{car,t} \in \{\mu_{car,t}(2), \mu_{car,t}(3), \mu_{car,t}(4), \mu_{car,t}(5), \mu_{car}, car_t\}$ and $\mu^{est}_{roa,t} \in \{\mu_{roa,t}(2), \mu_{roa,t}(3), \mu_{roa,t}(4), \mu_{roa,t}(5), \mu_{roa}, roa_t\}$, respectively, minimize the (weighted) average RMSE of the N banks j given by

$$\sum_{j=1}^{N} \frac{T_j}{\sum_{j=1}^{N} T_j} \sqrt{\frac{1}{T_j} \sum_{t=1}^{T_j} \left(car_{j,t} - \mu^{est}_{car,j,t-1}\right)^2} \tag{4}$$

$$\sum_{j=1}^{N} \frac{T_j}{\sum_{j=1}^{N} T_j} \sqrt{\frac{1}{T_j} \sum_{t=1}^{T_j} \left(roa_{j,t} - \mu^{est}_{roa,j,t-1}\right)^2} \tag{5}$$

Note that we also examine rolling windows of size two, four and five in addition to the one of three most used in the literature previously.

[2]As defined in Section 2, moving mean estimates $\mu_{car,t}(n)$, $\mu_{roa,t}(n)$ (with window width n) are calculated for each period $t \in \{1 \dots T\}$, the mean estimates μ_{car}, μ_{roa} are calculated over the full sample $[1 \dots T]$, and car_t, roa_t are current period t values.

Finding a realized volatility measure is unfortunately much less straightforward when relying on (mostly annual) accounting data than in other contexts, where higher frequency data can normally be used to calculate these. We opt to rely on the "instantaneous" standard deviation estimates $\sigma^{inst}_{roa,t} = |roa_t - \mu_{roa}|$ introduced previously to represent realized volatility, and thus investigate which of the different standard deviation estimates[3] $\sigma^{est}_{roa,t} \in \{\sigma_{roa,t}(2), \sigma_{roa,t}(3), \sigma_{roa,t}(4), \sigma_{roa,t}(5), \sigma_{roa}, \sigma^{inst}_{roa,t}\}$ minimizes the (weighted) average RMSE of the N banks j given by

$$\sum_{j=1}^{N} \frac{T_j}{\sum_{j=1}^{N} T_j} \sqrt{\frac{1}{T_j} \sum_{t=1}^{T_j} \left(\sigma^{inst}_{roa,j,t} - \sigma^{est}_{roa,j,t-1}\right)^2} \quad (6)$$

Results are presented in Tables 5–7; all these measures are calculated for the full sample of all G20 countries, and then further broken down by bank type and individual country. We also test whether the average RMSE are significantly different from the minimum ones using two-sided paired t-tests.

We find that current values of the capital-asset ratio car_t provide the lowest average RMSE for the full sample of G20 countries, for commercial, cooperative and savings banks, and all individual countries in the sample (Table 5). We further observe that the mean of the return on assets as calculated over the full sample (μ_{roa}) provides the lowest average RMSE for the full sample of G20 countries, for commercial and cooperative banks, and all countries in the sample except China, Indonesia, Turkey and the USA

[3] Analogously to footnote 2, moving standard deviation estimates $\sigma_{roa,t}(n)$ (with window width n) are calculated for each period $t \in \{1 \dots T\}$, whereas the standard deviation estimate σ_{roa} is calculated over the full sample $[1 \dots T]$.

(Table 6). Current values of the return on assets roa_t, on the other hand, give, or are indistinguishable from, the lowest average RMSE for these particular four countries, and savings banks overall. Lastly, the standard deviation of the return on assets as calculated over the full sample (σ_{roa}) provides the lowest average RMSE for the full sample of G20 countries, for all three bank types, and all individual countries except Turkey and Indonesia, the latter of which however gives results that are indistinguishable across all measures (Table 7).

Taken together, these results overall support the use of the time-varying Z-score measure Z5, which uses mean and standard deviation estimates of the return on assets that are calculated over the full sample and combines these with current values of the capital-asset ratio. For specific subsamples, such as savings banks, or banks in China, Indonesia or the USA, the time-varying Z-score measure Z3, which uses standard deviation estimates of the return on assets calculated over the full sample together with current values of the capital-asset ratio and the return on assets, might be more appropriate given our results. This is consistent with our previous observation that these two measures do in fact behave very similarly for the sample under consideration (see Tables 2 and 3). Both measures have the added advantage of allowing the construction of time-varying Z-scores that are available over the full sample; this compares favorably with the rolling moment approach used in measures Z1 and Z2, which requires some initial observations to be dropped. Lastly, they also represent very straightforward approaches to implement, making them practical yet well-founded ways of constructing time-varying Z-score measures for a wide range of empirical issues in the banking and financial stability related literature.

[Insert Tables 5–7]

4. Conclusion

We discussed and compared different approaches to the construction of time-varying Z-score measures in use in the literature, proposing a related alternative one; for this we used a panel of commercial, cooperative and savings banks for the G20 group of countries covering the period 1992–2009. We also explored which ways of estimating the moments used in the different approaches to computing these time-varying Z-score measures best fit the data, using a simple root mean squared error criterion. Our results were overall supportive of the use of the alternative time-varying Z-score measure we proposed: this measure uses mean and standard deviation estimates of the return on assets that are calculated over the full sample and combines these with current values of the capital-asset ratio, making it a very straightforward measure to implement in the assessment of individual bank insolvency risk and financial stability more generally. This measure furthermore displays a fairly low level of intertemporal volatility on a per bank level, consistently for all three types of bank and for all G20 countries, stressing the importance of avoiding the introduction of potentially "spurious" volatility in the construction of such time-varying bank insolvency risk measures more generally.

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Table 1. Number of banks by country and type for G20 countries and period 1992--2009

	Commercial banks	Cooperative banks	Savings banks	Total number of banks	Average obs. per bank
Argentina	3	0	0	3	14.3
Australia	42	1	0	43	10.5
Brazil	144	2	0	146	9.5
Canada	59	20	3	82	10.2
China	13	1	0	14	9.5
France	267	100	30	397	11.2
Germany	248	1319	595	2162	11.5
India	66	6	0	72	11.7
Indonesia	16	0	0	16	9.9
Italy	182	512	64	758	11.5
Japan	152	521	1	674	11.1
Korea	28	2	2	32	9.9
Mexico	34	0	0	34	10.0
Russia	236	0	0	236	6.3
Saudi Arabia	11	0	0	11	14.2
South Africa	24	0	0	24	10.5
Turkey	39	2	0	41	7.4
UK	190	0	5	195	11.2
USA	8666	14	1038	9718	10.2
Total	10420	2500	1738	14658	10.4

Table 2. Descriptive statistics of different time-varying Z-score measures (calculated per bank), for G20 countries and period 1992—2009

	Z1		Z2		Z3		Z4		Z5	
	Mean per bank	St.dev. per bank	Mean per bank	St.dev. per bank	Mean per bank	St.dev. per bank	Mean per bank	St.dev. per bank	Mean per bank	St.dev. per bank
G20 banks										
Mean	174	192	175	195	45	4.9	1845	4126	45	4.5
St.dev.	342	634	349	646	77	17	174118	389981	77	17
Min	0.81	0.076	1	0.29	0.057	0	0.37	0	0.075	0
Max	13180	23926	13121	24796	4789	1754	2.10E+07	4.70E+07	4789	1753
Commercial banks										
Mean	123	120	123	120	37	4.5	381	879	37	4.2
St.dev.	171	316	170	306	42	20	13215	39519	42	20
Min	1.1	0.1	1.6	0.38	0.057	0	0.37	0	0.075	0
Max	5921	12258	5939	12537	2017	1754	1338834	4015505	2017	1753
Cooperative banks										
Mean	326	402	332	412	73	5.8	540	1095	74	5.4
St.dev.	601	1060	615	1088	155	8.9	4144	11260	155	9
Min	1.5	0.15	1.2	0.29	0.25	0.044	0.51	0.6	0.9	0.12
Max	13180	23926	13121	24796	4789	249	142438	463650	4789	249
Savings banks										
Mean	257	321	261	328	51	5.6	12486	27917	51	5.4
St.dev.	483	1034	500	1065	56	6.1	504253	1127557	56	6.2
Min	0.81	0.076	1	0.3	0.43	0.059	0.65	0.22	0.36	0.062
Max	8961	19434	9789	19654	1361	109	2.10E+07	4.70E+07	1360	110
Argentina										
Mean	57	56	52	48	20	5.2	44	36	20	5
St.dev.	81	79	73	63	30	4.4	66	52	29	4.7
Min	7.1	4.6	7.6	4.9	2.1	2	5	4.5	2.1	1.2
Max	150	148	137	120	54	10	120	97	54	10
Australia										
Mean	73	74	74	76	21	5.2	93	126	20	4.8
St.dev.	85	151	85	151	15	4.8	124	189	15	4.7
Min	4.7	1.4	4.1	1.5	0.057	0.13	0.55	0.38	0.14	0.29
Max	529	960	532	963	66	24	529	711	66	23
Brazil										
Mean	38	35	38	37	14	4.2	104	183	14	3.8
St.dev.	38	53	39	57	14	5.1	501	1075	14	5.1
Min	2.5	0.64	2.7	0.85	0.11	0.49	1	1	0.18	0.11
Max	210	351	225	362	87	56	5609	12175	88	55
Canada										
Mean	95	91	95	92	31	5	151	234	31	4.7
St.dev.	94	193	93	196	29	6.8	329	618	29	6.8
Min	6.7	4.3	8.7	4.9	0.69	0.57	0.7	0.47	0.61	0.0003
Max	691	1662	694	1690	174	58	2852	4787	173	57
China										
Mean	155	128	148	125	41	11	169	259	41	11
St.dev.	102	113	98	105	24	9	184	316	24	9.3
Min	32	22	36	19	12	1.4	22	18	12	1.9
Max	370	354	379	358	95	34	670	980	95	34
France										
Mean	143	153	147	161	39	7.5	248	463	39	7
St.dev.	165	317	173	336	45	8.2	1005	2054	45	8.1
Min	1.1	0.73	1.6	1.1	0.46	0.48	1.9	0.38	0.52	0.17
Max	1226	3547	1274	3763	411	73	16750	28773	410	72
Germany										
Mean	443	568	453	583	89	8.6	607	1209	89	8.3
St.dev.	690	1335	713	1379	176	44	4409	11959	176	44
Min	2.5	0.28	1.4	0.85	0.37	0.091	1.5	0.53	0.39	0.12
Max	10104	23926	11051	24796	4789	1754	142438	463650	4789	1753
India										
Mean	94	101	102	120	28	4.2	111	179	28	3.8
St.dev.	97	181	147	327	41	3.8	176	391	41	3.8
Min	10	5.2	11	6	2.5	0.82	4.5	3.4	2.2	0.25
Max	501	1178	1108	2652	303	25	1141	2866	304	25

Indonesia										
Mean	73	59	74	59	35	5.4	213	362	35	4.9
St.dev.	43	32	43	32	31	4.7	378	834	31	4.5
Min	30	18	32	16	5.9	1.5	22	9	6.3	1.3
Max	210	120	203	114	130	21	1526	3367	130	20
Italy										
Mean	131	134	129	132	39	4.3	254	528	39	3.9
St.dev.	136	294	133	288	26	3.5	702	2061	26	3.6
Min	2	0.36	1.6	0.29	0.47	0.044	1.2	0.31	0.075	0.13
Max	1831	5980	1825	5957	260	42	11514	28167	260	43
Japan										
Mean	179	265	181	268	28	3.2	241	535	28	2.6
St.dev.	575	994	574	991	32	2.9	1219	3778	32	2.9
Min	1.5	0.15	1.2	0.4	0.25	0.31	0.51	0.65	0.13	0.11
Max	13180	21419	13121	21312	229	39	24914	78574	229	38
Korea										
Mean	45	54	44	54	10	2.5	121	212	10	1.8
St.dev.	35	106	35	106	8.9	1.1	345	690	9	1.1
Min	3.5	0.75	4.3	1.7	0.11	0.78	0.37	1.6	0.28	0.23
Max	192	616	194	617	36	5.5	1976	3939	37	4.5
Mexico										
Mean	43	52	44	55	13	5.6	68	91	13	5.2
St.dev.	53	92	53	90	12	7	118	156	12	7
Min	5.7	2.6	5.2	2.9	2	0.8	4.2	3.5	2.1	0.39
Max	277	495	256	462	64	38	689	862	64	38
Russia										
Mean	88	95	83	83	31	7.8	613	1009	31	7.6
St.dev.	379	753	307	562	35	12	6995	12110	35	12
Min	6.3	0.63	6.2	0.89	2	0.28	5.7	2.9	2.3	0.14
Max	5808	11568	4669	8620	283	107	107441	185991	283	107
Saudi Arabia										
Mean	121	164	123	164	23	2.8	88	101	23	2.2
St.dev.	82	151	88	155	21	1.9	82	75	21	2
Min	54	50	54	47	5.2	1.5	19	18	5.2	0.81
Max	324	456	352	489	83	8	308	243	83	8.1
South Africa										
Mean	102	108	104	111	31	5.3	137	194	31	4.9
St.dev.	149	235	156	257	33	4.7	180	306	33	4.8
Min	10	5.9	10	2.8	1.7	1.3	5	3	1.7	0.83
Max	722	1159	771	1282	122	21	762	1368	122	20
Turkey										
Mean	33	27	32	28	13	3	60	81	13	2.4
St.dev.	25	27	24	29	14	2.3	158	273	14	2.2
Min	4	1.7	3.8	0.97	0.71	0.49	1.5	0.75	0.28	0.31
Max	108	100	104	115	64	9.5	1022	1740	64	8.5
United Kingdom										
Mean	100	103	99	104	28	6.1	191	414	28	5.7
St.dev.	157	246	159	250	29	5.2	644	2059	29	5.3
Min	2.1	0.31	2.5	1	0.6	0.1	1.8	0.91	0.3	0.14
Max	1959	2903	2005	2949	210	29	6379	23688	210	30
USA										
Mean	127	120	128	121	39	4	2574	5810	39	3.7
St.dev.	147	281	147	281	34	4.3	213705	478636	34	4.4
Min	0.81	0.076	1	0.3	0.43	0	0.65	0	0.36	0
Max	5921	12258	5939	12537	576	149	2.10E+07	4.70E+07	576	150

The time-varying Z-score measure Z1 uses three-period moving mean and standard deviation estimates $\mu_{car,t}(3)$, $\mu_{roa,t}(3)$ and $\sigma_{roa,t}(3)$; Z2 uses moving mean and standard deviation estimates $\mu_{roa,t}(3)$ and $\sigma_{roa,t}(3)$, combined with period t values of car_t; Z3 uses standard deviation estimates σ_{roa} calculated over the full sample, combined with period t values of car_t and roa_t; Z4 uses "instantaneous" standard deviation estimates $\sigma^{inst}_{roa,t} = \left| roa_t - \mu_{roa} \right|$, where the mean estimate μ_{roa} is calculated over the full sample, combined with period t values of car_t and roa_t; Z5 uses mean and standard deviation estimates μ_{roa} and σ_{roa} calculated over the full sample, combined with period t values of car_t.

Table 3. Average correlation coefficients of different time-varying Z-score measures (calculated per bank), for G20 countries and period 1992-2009

	Z1	Z2	Z3	Z4
G20 banks				
Z2	0.98			
Z3	0.12	0.17		
Z4	0.13	0.13	0.11	
Z5	0.068	0.11	0.91	0.092
Commercial banks				
Z2	0.98			
Z3	0.12	0.17		
Z4	0.12	0.13	0.11	
Z5	0.054	0.11	0.9	0.089
Cooperative banks				
Z2	0.99			
Z3	0.12	0.15		
Z4	0.15	0.15	0.14	
Z5	0.11	0.14	0.93	0.11
Savings banks				
Z2	0.99			
Z3	0.13	0.17		
Z4	0.1	0.098	0.095	
Z5	0.093	0.13	0.93	0.081
Argentina				
Z2	0.93			
Z3	-0.11	0.093		
Z4	0.14	0.27	0.52	
Z5	-0.2	0.0017	0.95	0.41
Australia				
Z2	0.96			
Z3	0.18	0.26		
Z4	0.2	0.22	0.16	
Z5	0.13	0.22	0.9	0.14
Brazil				
Z2	0.92			
Z3	0.068	0.21		
Z4	0.18	0.2	0.14	
Z5	0.041	0.2	0.9	0.13
Canada				
Z2	0.98			
Z3	0.057	0.13		
Z4	0.15	0.14	0.029	
Z5	0.0078	0.079	0.91	0.018
China				
Z2	0.97			
Z3	0.13	0.22		
Z4	0.082	0.1	0.058	
Z5	0.16	0.25	0.97	0.042
France				
Z2	0.97			
Z3	0.11	0.18		
Z4	0.11	0.12	0.12	
Z5	0.09	0.17	0.96	0.12
Germany				
Z2	0.99			
Z3	0.1	0.12		
Z4	0.13	0.13	0.11	
Z5	0.096	0.12	0.93	0.091

India				
Z2	0.96			
Z3	0.22	0.22		
Z4	0.094	0.1	0.11	
Z5	0.19	0.2	0.94	0.1
Indonesia				
Z2	0.99			
Z3	0.23	0.29		
Z4	0.02	0.026	0.32	
Z5	0.21	0.27	0.98	0.3
Italy				
Z2	0.98			
Z3	0.0069	0.053		
Z4	0.096	0.1	0.13	
Z5	-0.0086	0.037	0.94	0.11
Japan				
Z2	0.98			
Z3	0.34	0.37		
Z4	0.17	0.18	0.27	
Z5	0.31	0.35	0.9	0.19
Korea				
Z2	0.99			
Z3	0.47	0.5		
Z4	0.36	0.35	0.23	
Z5	0.46	0.49	0.89	0.26
Mexico				
Z2	0.94			
Z3	0.3	0.39		
Z4	0.31	0.35	0.3	
Z5	0.26	0.36	0.96	0.28
Russia				
Z2	0.91			
Z3	0.11	0.28		
Z4	0.27	0.32	0.16	
Z5	0.047	0.23	0.92	0.15
Saudi Arabia				
Z2	1			
Z3	-0.076	-0.062		
Z4	-0.0052	-0.0099	-0.088	
Z5	-0.073	-0.051	0.89	-0.097
South Africa				
Z2	0.97			
Z3	-0.086	-0.022		
Z4	0.24	0.24	0.064	
Z5	-0.11	-0.046	0.95	0.057
Turkey				
Z2	0.93			
Z3	0.092	0.21		
Z4	0.019	0.076	0.36	
Z5	0.045	0.17	0.9	0.33
United Kingdom				
Z2	0.93			
Z3	0.019	0.13		
Z4	0.063	0.082	0.098	
Z5	0	0.11	0.94	0.11
USA				
Z2	0.99			
Z3	0.12	0.16		
Z4	0.12	0.12	0.096	
Z5	0.05	0.093	0.9	0.078

Definitions of time-varying Z-scores Z1-Z5: see Table 2.

Table 4. Descriptive statistics of components of time-varying Z-scores, for G20 countries and period 1992—2009

	car_t	roa_t	σ_{roa}	$\sigma^{inst}_{roa,t}$	$\sigma_{roa,t}(3)$
G20 banks					
Mean	10.84	0.78	0.72	0.54	0.36
St. dev.	10.11	2.76	1.97	2.03	1.38
Min	0	-165.83	0.002	1.2e-07	0.000049
Max	100	193.57	72.47	176.21	91.97
Commercial banks					
Mean	12.06	0.95	0.86	0.65	0.43
St. dev.	11.04	3.03	2.12	2.21	1.49
Min	0	-165.83	0.0038	1.1e-06	0.0003
Max	100	193.57	66.91	176.21	91.36
Cooperative banks					
Mean	7.32	0.36	0.27	0.2	0.16
St. dev.	4.32	0.58	0.34	0.39	0.3
Min	0	-17.02	0.002	3.0e-06	0.000077
Max	100	17.54	8.55	16.48	10.33
Savings banks					
Mean	9.25	0.44	0.58	0.44	0.27
St. dev.	9.18	2.95	2.27	2.3	1.61
Min	0	-104.43	0.0044	1.2e-07	0.000049
Max	100	153.16	72.47	135.09	91.97
Argentina					
Mean	36.27	-0.73	3.39	2.71	2.09
St. dev.	31.58	3.98	1.77	2.71	2.08
Min	3.77	-14.43	1.29	0.25	0.08
Max	95.61	6.4	5.56	12.35	7.68
Australia					
Mean	9.23	0.47	1.84	1.19	0.62
St. dev.	11.84	7.33	6.65	6.8	3.74
Min	0.62	-151.2	0.072	0.0013	0.0027
Max	100	15.69	45.43	136.24	70.25
Brazil					
Mean	20.17	2.12	3.23	2.36	2.02
St. dev.	18.39	5.81	4.03	4.59	3.98
Min	0.3	-97.18	0.07	0.00024	0.013
Max	99.52	58.15	36.23	92.25	57.28
Canada					
Mean	11.38	1.05	2.18	1.43	0.97
St. dev.	16.03	8.06	7.28	7.47	5.7
Min	0.45	-14.26	0.04	0.00051	0.0008
Max	100	193.57	55.72	176.21	91.36
China					
Mean	20.51	0.71	0.55	0.44	0.25
St. dev.	25.92	0.93	0.49	0.6	0.37
Min	1.47	-4.19	0.05	0.0014	0.0073
Max	99.46	4.28	1.6	4.36	2.59
France					
Mean	10.39	0.64	0.94	0.7	0.47
St. dev.	12.82	3.65	2.11	2.21	1.48
Min	0	-79.92	0.03	0.000079	0.0004
Max	99.75	66.18	31.77	58.18	33.91
Germany					
Mean	6.11	0.28	0.26	0.19	0.14
St. dev.	6.5	1.47	1.19	1.27	0.96
Min	0	-111.32	0.002	3.0e-06	0.000049
Max	100	100.98	35.23	96.67	55.08
India					
Mean	7.53	0.84	0.62	0.47	0.33
St. dev.	7.9	1.03	0.63	0.75	0.53
Min	0.06	-6.65	0.06	0.0011	0.00073
Max	98.55	9.38	3.59	6.93	4

Indonesia					
Mean	16.72	1.88	1.07	0.82	0.54
St. dev.	11.3	2.03	1.13	1.32	0.7
Min	3.87	-5.16	0.15	0.0012	0.04
Max	69.28	16.98	4.67	13.02	5.73
Italy					
Mean	11.94	0.73	0.52	0.39	0.26
St. dev.	6.75	1.35	1.01	1.07	0.63
Min	0.6	-42.34	0.05	0.000052	0.00037
Max	100	54.27	19.77	44.21	24.88
Japan					
Mean	5.72	0.03	0.5	0.37	0.3
St. dev.	4.34	1.17	0.87	0.93	0.6
Min	0	-59.84	0.03	0.000018	0.00014
Max	100	21.23	19.76	53.27	25.26
Korea					
Mean	5.09	0.14	1.09	0.77	0.6
St. dev.	2	1.48	0.82	1.12	0.86
Min	0.31	-9.2	0.11	0.00046	0.0036
Max	17.36	5.15	3.39	8.03	4.06
Mexico					
Mean	18.46	0.86	2.35	1.89	1.41
St. dev.	17.43	4.41	2.3	2.7	1.89
Min	0.44	-24.59	0.23	0.01	0.01
Max	99.24	26.24	8.7	19.21	11.9
Russia					
Mean	20.92	1.59	1.43	1.11	0.91
St. dev.	14.49	2.58	1.65	1.89	1.36
Min	0.81	-31.12	0.06	0.000046	0.0013
Max	97.87	29.83	12.98	27.88	16.15
Saudi Arabia					
Mean	11.26	1.92	1.09	0.76	0.49
St. dev.	2.99	1.44	0.85	1.16	0.84
Min	2.87	-6.28	0.13	0.01	0.01
Max	27.05	12.55	3.18	10.64	4.99
South Africa					
Mean	16.71	1.64	1.82	1.31	1.19
St. dev.	15.92	3.67	2.39	2.71	2.26
Min	0.85	-26.82	0.11	0.002	0.0022
Max	81.05	25.61	8.64	26.01	14.61
Turkey					
Mean	18.56	1.79	3.23	2.37	2.01
St. dev.	17.93	5.62	3.75	4.35	3.72
Min	1.87	-55.95	0.22	0.0011	0.03
Max	91.64	23.45	20.6	50.22	29.03
United Kingdom					
Mean	15.76	1.19	1.68	1.2	0.81
St. dev.	18.34	4.96	3.42	3.62	2.74
Min	0.14	-67.19	0.01	0.00015	0.00055
Max	100	80.99	29.24	74.58	37.38
USA					
Mean	11.88	0.92	0.75	0.57	0.36
St. dev.	9.93	2.84	1.94	2	1.28
Min	0	-165.83	0.01	1.2e-07	0.0003
Max	100	188.44	72.47	147.28	91.97

car_t is banks' capital-asset ratio and roa_t their return on assets; σ_{roa} is the standard deviation estimate of *roa* over full samples; $\sigma^{inst}_{roa,t} = \left| roa_t - \mu_{roa} \right|$ is the "instantaneous" standard deviation estimate, where the mean estimate μ_{roa} is calculated over the full sample; $\sigma_{roa,t}(3)$ is the three-period moving standard deviation estimate of *roa*.

Table 5. Average Root Mean Squared Error for various estimators of time-varying means of the capital-asset ratio, for G20 subsamples and period 1992--2009

	Number of banks	Average Root Mean Squared Error (RMSE)					
		$\mu_{car,t}(2)$	$\mu_{car,t}(3)$	$\mu_{car,t}(4)$	$\mu_{car,t}(5)$	μ_{car}	car_t
G20 banks	14658	1.547	1.680	1.810	1.992	1.803	1.424
Commercial banks	10420	1.874	2.022	2.168	2.388	2.131	1.738
Cooperative banks	2500	0.654	0.738	0.816	0.895	0.873	0.570
Savings banks	1738	1.131	1.253	1.371	1.511	1.427	1.018
Argentina	3	12.796	13.125	13.018	13.039	12.335	11.105
Australia	43	4.547	4.855	5.078	5.290	4.994	4.050
Brazil	146	7.045	7.569	8.175	8.553	7.517	6.636
Canada	82	4.642	5.120	5.533	5.831	5.448	4.088
China	14	5.743	6.803	7.541	7.980	7.168	4.557
France	397	2.740	2.958	3.141	3.326	3.087	2.515
Germany	2162	0.763	0.849	0.929	1.010	1.019	0.689
India	72	1.409	1.577	1.856	2.121	1.901	1.253
Indonesia	16	3.593	3.878	4.347	4.806	4.371	3.339
Italy	758	1.240	1.393	1.529	1.682	1.546	1.067
Japan	674	0.726	0.791	0.865	0.931	0.835	0.671
Korea	32	1.172	1.294	1.399	1.499	1.366	1.075
Mexico	34	8.367	9.101	9.841	10.353	9.294	7.566
Russia	236	5.468 NSD	6.021	6.672	7.196	6.092	5.175
Saudi Arabia	11	1.744	1.821	1.843	1.898	1.821	1.577
South Africa	24	5.004	5.542	5.810	6.202	5.529	4.332
Turkey	41	5.007 NSD	5.547	6.082	6.331	5.309 NSD	4.927
United Kingdom	195	4.505	5.004	5.471	5.931	5.339	4.284
USA	9718	1.530	1.648	1.765	1.971	1.756	1.416

Minimum average RMSE are highlighted in grey; the superscript NSD marks values not significantly different at the 5% level from the minimum ones using a two-sided paired t-test. μ_{car} is the mean of the capital-asset ratio *car* calculated over full samples; car_t is the period t value of *car*; $\mu_{car,t}(2)$ is the two-period moving average of *car*, analogously for $\mu_{car,t}(3)$ etc.

Table 6. Average Root Mean Squared Error for various estimators of time-varying means of the return on assets, for G20 subsamples and period 1992--2009

	Number of banks	Average Root Mean Squared Error (RMSE)					
		$\mu_{roa,t}(2)$	$\mu_{roa,t}(3)$	$\mu_{roa,t}(4)$	$\mu_{roa,t}(5)$	μ_{roa}	roa_t
G20 banks	14658	0.709	0.732	0.753	0.775	0.676	0.700
Commercial banks	10420	0.860	0.888	0.913	0.940	0.820	0.846
Cooperative banks	2500	0.293	0.289	0.290	0.293	0.253	0.307
Savings banks	1738	0.525	0.553	0.581	0.602	0.534	0.507
Argentina	3	3.897	3.774	3.822	3.968	3.400	4.060
Australia	43	2.293	2.310	2.322	2.338	2.108	2.326
Brazil	146	3.654	3.544	3.486	3.486	3.034	4.011
Canada	82	2.986	2.890	2.887	2.890	2.556	3.399
China	14	0.617	0.661	0.687	0.714	0.611	0.555
France	397	0.909	0.909	0.935	0.971	0.850	0.926
Germany	2162	0.255	0.258	0.260	0.267	0.230	0.269
India	72	0.603	0.634	0.643	0.654	0.555	0.591
Indonesia	16	0.773^{NSD}	0.766	0.819	0.950	0.869	0.788^{NSD}
Italy	758	0.473	0.480	0.492	0.514	0.452	0.471
Japan	674	0.532	0.518	0.518	0.516	0.438	0.563
Korea	32	1.221	1.234	1.196	1.162	0.928	1.272
Mexico	34	2.434^{NSD}	2.454	2.579	2.698	2.333	2.508
Russia	236	1.704	1.721	1.755	1.836	1.552	1.746
Saudi Arabia	11	1.365	1.412	1.405	1.388	1.279	1.297^{NSD}
South Africa	24	2.580	2.560	2.500	2.471	2.167	2.847
Turkey	41	1.443	1.928	2.286	2.407	1.919	1.512^{NSD}
United Kingdom	195	1.660	1.609	1.622	1.644	1.460	1.830
USA	9718	0.747	0.784	0.813	0.840	0.734	0.711

Minimum average RMSE are highlighted in grey; the superscript NSD marks values not significantly different at the 5% level from the minimum ones using a two-sided paired t-test. μ_{roa} is the mean of the return on assets *roa* calculated over full samples; roa_t is the period t value of *roa*; $\mu_{roa,t}(2)$ is the two-period moving average of *roa*, analogously for $\mu_{roa,t}(3)$ etc.

Table 7. Average Root Mean Squared Error for various estimators of time-varying standard deviations of the return on assets, for G20 subsamples and period 1992--2009

	Number of banks	Average Root Mean Squared Error (RMSE)					
		$\sigma_{roa,t}(2)$	$\sigma_{roa,t}(3)$	$\sigma_{roa,t}(4)$	$\sigma_{roa,t}(5)$	σ_{roa}	$\sigma_{roa,t}^{inst}$
G20 banks	14658	0.583	0.553	0.537	0.538	0.476	0.541
Commercial banks	10420	0.704	0.668	0.650	0.652	0.579	0.656
Cooperative banks	2500	0.227	0.220	0.217	0.216	0.191	0.225
Savings banks	1738	0.457	0.428	0.411	0.403	0.351	0.398
Argentina	3	2.795	2.255	2.209	2.103	1.861	2.870
Australia	43	2.026	1.999	1.997	2.004	1.659	1.907
Brazil	146	2.744	2.705	2.709	2.695	2.233	2.928
Canada	82	2.564	2.543	2.544	2.537	2.000	2.675
China	14	0.490	0.457	0.440	0.425	0.358	0.384^{NSD}
France	397	0.751	0.741	0.711	0.706	0.636	0.735
Germany	2162	0.212	0.206	0.204	0.205	0.180	0.207
India	72	0.486	0.450	0.444	0.455	0.406	0.447
Indonesia	16	0.708^{NSD}	0.682^{NSD}	0.672^{NSD}	0.699^{NSD}	0.663^{NSD}	0.643
Italy	758	0.384	0.361	0.348	0.354	0.325	0.353
Japan	674	0.396	0.385	0.388	0.389	0.335	0.391
Korea	32	0.809	0.848	0.868	0.895	0.768	1.085
Mexico	34	1.861	1.757	1.692	1.661	1.451	1.716
Russia	236	1.365	1.265	1.268	1.281	1.128	1.321
Saudi Arabia	11	1.150	1.152	1.127	1.116	0.974	1.201
South Africa	24	1.964	1.867	1.899	1.874	1.575	2.126
Turkey	41	1.740	1.780	2.028	2.231	2.047	1.195
United Kingdom	195	1.387	1.361	1.356	1.392	1.237	1.403
USA	9718	0.618	0.580	0.558	0.557	0.497	0.557

Minimum average RMSE are highlighted in grey; the superscript NSD marks values not significantly different at the 5% level from the minimum ones using a two-sided paired t-test. σ_{roa} is the standard deviation of the return on assets *roa* calculated over full samples; $\sigma_{roa,t}^{inst} = \left| roa_t - \mu_{roa} \right|$ is the "instantaneous" standard deviation, where the mean μ_{roa} is calculated over full samples of *roa*; $\sigma_{roa,t}(2)$ is the two-period moving standard deviation of *roa*, analogously for $\sigma_{roa,t}(3)$ etc.