Not-for-Publication Appendix of Additional Results for "Structural Breaks and GARCH Models of Exchange Rate Volatility"

David E. Rapach
Department of Economics
Saint Louis University
3674 Lindell Boulevard
Saint Louis, MO 63108-3397
Phone: 314-977-3601
Fax: 314-977-1478
E-mail: rapachde@slu.edu

Jack K. Strauss
Department of Economics
Saint Louis University
3674 Lindell Boulevard
Saint Louis, MO 63108-3397
Phone: 314-977-3813
Fax: 314-977-1478
E-mail: strausjk@slu.edu

October 31, 2006

Table A1: Empirical coverage frequencies for out-of-sample forecasts of 5% VaR

Model	Canada	Denmark	Germany	Japan	Norway	Switzerland	U.K.	U.S. (trade-weighted)
A. $s = 1$								
GARCH(1,1) expanding window	0.064 [0.17]	0.054 [0.69]	0.058 [0.42]	0.038 [0.20]	0.052 [0.84]	0.058 [0.42]	0.040 [0.29]	0.062 [0.23]
RiskMetrics	0.060 [0.32]	0.058 [0.42]	0.062 [0.23]	0.050 [1.00]	0.052 [0.84]	0.062 [0.23]	0.044 [0.53]	0.062 [0.23]
FIGARCH(1,*d*,1) expanding window	0.064 [0.17]	0.058 [0.42]	0.050 [1.00]	0.044 [0.53]	0.054 [0.69]	0.058 [0.42]	0.046 [0.68]	0.060 [0.32]
GARCH(1,1) 0.50 rolling window	0.062 [0.23]	0.058 [0.42]	0.054 [0.69]	0.042 [0.40]	0.054 [0.69]	0.062 [0.23]	0.046 [0.68]	0.068 [0.08]
GARCH(1,1) 0.25 rolling window	0.064 [0.17]	0.050 [1.00]	0.056 [0.55]	0.044 [0.53]	0.054 [0.69]	0.066 [0.12]	0.054 [0.69]	0.076 [0.01]
GARCH(1,1) weighted ML	0.058 [0.42]	0.054 [0.69]	0.056 [0.55]	0.058 [0.42]	0.048 [0.84]	0.060 [0.32]	0.044 [0.53]	0.066 [0.12]
GARCH(1,1) with breaks	0.052 [0.84]	0.050 [1.00]	0.046 [0.68]	0.038 [0.20]	0.050 [1.00]	0.066 [0.12]	0.054 [0.69]	0.070 [0.05]
Moving average	0.048 [0.84]	0.046 [0.68]	0.050 [1.00]	0.050 [1.00]	0.044 [0.53]	0.056 [0.55]	0.052 [0.84]	0.068 [0.08]
B. $s = 20$								
GARCH(1,1) expanding window	0.058	0.023	0.027	0.029	0.081	0.048	0.058	0.069
RiskMetrics	0.054	0.058	0.054	0.054	0.081	0.071	0.067	0.075
FIGARCH(1,*d*,1) expanding window	0.027	0.019	0.025	0.031	0.037	0.027	0.069	0.052
GARCH(1,1) 0.50 rolling window	0.062	0.044	0.035	0.031	0.077	0.052	0.064	0.064
GARCH(1,1) 0.25 rolling window	0.058	0.033	0.033	0.029	0.069	0.052	0.071	0.069
GARCH(1,1) weighted ML	0.037	0.033	0.029	0.044	0.056	0.056	0.073	0.067
GARCH(1,1) with breaks	0.027	0.024	0.023	0.029	0.077	0.054	0.069	0.064
Moving average	0.027	0.019	0.025	0.031	0.037	0.027	0.069	0.052
C. $s = 60$								
GARCH(1,1) expanding window	0.086	0.066	0.066	0.000	0.082	0.054	0.045	0.106
RiskMetrics	0.082	0.091	0.095	0.048	0.086	0.073	0.054	0.118
FIGARCH(1,*d*,1) expanding window	0.070	0.068	0.063	0.002	0.054	0.036	0.050	0.120
GARCH(1,1) 0.50 rolling window	0.088	0.082	0.086	0.007	0.086	0.068	0.052	0.127
GARCH(1,1) 0.25 rolling window	0.088	0.077	0.082	0.007	0.082	0.073	0.054	0.134
GARCH(1,1) weighted ML	0.082	0.073	0.082	0.011	0.068	0.061	0.052	0.127
GARCH(1,1) with breaks	0.066	0.066	0.048	0.000	0.079	0.073	0.052	0.120
Moving average	0.070	0.068	0.063	0.002	0.054	0.036	0.050	0.120
D. $s = 120$								
GARCH(1,1) expanding window	0.129	0.000	0.000	0.000	0.013	0.000	0.000	0.003
RiskMetrics	0.113	0.000	0.000	0.000	0.010	0.000	0.000	0.008
FIGARCH(1,*d*,1) expanding window	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.008
GARCH(1,1) 0.50 rolling window	0.136	0.000	0.000	0.000	0.016	0.000	0.000	0.008
GARCH(1,1) 0.25 rolling window	0.123	0.000	0.000	0.000	0.016	0.000	0.000	0.008
GARCH(1,1) weighted ML	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.003
GARCH(1,1) with breaks	0.089	0.000	0.000	0.000	0.018	0.000	0.000	0.005
Moving average	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.008

Notes: The table reports the proportion of actual exchange rate returns that are below the 5% VaR forecast. *P*-values for the Christoffersen (1998) likelihood-ratio statistic corresponding to a test of the null hypothesis of correction unconditional coverage are given in brackets.

Table A2: Out-of-sample exchange rate return volatility forecasting results, $s = 120$

Model	Canada	Denmark	Germany	Japan
A. $MSFE^{*}_{s,i}$				
GARCH(1,1) expanding window	110.405 [0.30] {0.23}	286.356 [0.05] {0.13}	259.898 [0.14] {0.13}	343.551 [0.20] {0.21}
RiskMetrics	1.208 [0.11] {0.02}	1.071 [0.13] {0.05}	1.199 [0.18] {0.07}	1.502 [0.06] {0.02}
FIGARCH(1,*d*,1) expanding window	0.653 [0.87] {0.54}	0.925 [0.06] {0.18}	0.969 [0.08] {0.13}	**0.562** [1.00] {1.00}
GARCH(1,1) 0.50 rolling window	1.068	**0.552**	**0.675**	1.026
GARCH(1,1) 0.25 rolling window	1.065	0.680	0.827	0.741
GARCH(1,1) weighted ML	1.398	0.874	1.008	0.629
GARCH(1,1) with breaks	0.817	1.110	0.960	1.000
Moving average	**0.624**	1.113	1.292	0.655
B. $MVaR_{s,i}$				
GARCH(1,1) expanding window	0.783 [0.13] {0.22}	0.588 [0.00] {0.00}	0.577 [0.02] {0.00}	0.623 [0.00] {0.00}
RiskMetrics	0.930 [0.17] {0.05}	0.921 [0.52] {0.51}	**0.932** [0.77] {1.00}	0.862 [0.29] {0.25}
FIGARCH(1,*d*,1) expanding window	0.947 [0.15] {0.32}	0.981 [0.00] {0.00}	0.989 [0.00] {0.00}	0.934 [0.00] {0.00}
GARCH(1,1) 0.50 rolling window	0.999	**0.917**	0.947	0.980
GARCH(1,1) 0.25 rolling window	0.979	0.941	0.961	0.945
GARCH(1,1) weighted ML	0.858	0.938	0.950	0.842
GARCH(1,1) with breaks	0.796	0.935	0.982	0.999
Moving average	**0.795**	0.973	0.992	**0.835**

Model	Norway	Switzerland	U.K.	U.S. (trade-weighted)
C. $MSFE^{*}_{s,i}$				
GARCH(1,1) expanding window	255.631 [0.58] {0.00}	264.805 [0.42] {0.14}	309.725 [0.42] {0.36}	**76.596** [1.00] {1.00}
RiskMetrics	1.932 [0.15] {0.04}	1.609 [0.05] {0.01}	1.616 [0.03] {0.01}	2.137 [0.04] {0.00}
FIGARCH(1,*d*,1) expanding window	1.333 [0.20] {0.01}	1.027 [0.39] {0.01}	0.843 [0.77] {0.47}	1.123 [0.75] {0.47}
GARCH(1,1) 0.50 rolling window	**0.862**	**0.717**	**0.826**	1.090
GARCH(1,1) 0.25 rolling window	0.885	0.939	0.925	1.200
GARCH(1,1) weighted ML	1.052	1.778	1.393	1.747
GARCH(1,1) with breaks	0.908	0.906	0.886	1.114
Moving average	1.474	1.663	1.245	1.781
D. $MVaR_{s,i}$				
GARCH(1,1) expanding window	0.518 [0.08] {0.12}	0.625 [0.01] {0.00}	0.603 [0.00] {0.00}	0.460 [0.00] {0.00}
RiskMetrics	1.041 [0.07] {0.03}	0.979 [0.23] {0.25}	0.947 [0.13] {0.06}	0.992 [0.07] {0.03}
FIGARCH(1,*d*,1) expanding window	1.063 [0.00] {0.00}	0.990 [0.01] {0.00}	0.956 [0.00] {0.00}	0.988 [0.00] {0.00}
GARCH(1,1) 0.50 rolling window	1.000	0.956	0.919	0.956
GARCH(1,1) 0.25 rolling window	**0.962**	**0.936**	**0.876**	**0.921**
GARCH(1,1) weighted ML	1.056	1.011	0.950	0.989
GARCH(1,1) with breaks	1.006	0.938	0.877	0.953
Moving average	1.081	1.003	0.962	0.995

Notes: Entries for the GARCH(1,1) expanding window model give the mean loss for this model. Entries for the other models give the ratio of the mean loss for each model to the mean loss for the GARCH(1,1) expanding window model. Bold entries denote the model with the smallest mean loss among all of the models. *P*-values for to the White (2000) $\bar{V}_l$ (Hansen (2005) T_n^{SPA}) statistics are given in brackets (curly brackets) and correspond to a test of the null hypothesis that none of the five competing models (two GARCH(1,1) rolling window, GARCH(1,1) weighted ML, GARCH(1,1) with breaks, and moving average models) has a lower expected loss than the benchmark model indicated on the left against the one-sided (upper-tail) alternative hypothesis that at least one of the competing models has a lower expected loss than the benchmark model; 0.00 indicates less than 0.005.

Table A3: Out-of-sample exchange rate return volatility forecasting results, $MVaR_{s,i}$ loss function calculated using bootstrapped standardized residuals, $s = 60$

Model	Canada	Denmark	Germany	Japan	Norway	Switzerland	U.K.	U.S. (trade-weighted)
GARCH(1,1) expanding window	0.439	0.486	0.479	0.382	0.535	0.506	0.470	0.483
RiskMetrics	1.051	1.049	1.060	1.100	1.028	1.130	1.052	1.012
FIGARCH(1,*d*,1) expanding window	0.977	0.983	1.007	0.986	0.992	1.000	0.993	0.973
GARCH(1,1) 0.50 rolling window	1.040	0.999	1.001	1.021	0.996	1.012	0.991	0.985
GARCH(1,1) 0.25 rolling window	1.035	0.985	0.986	1.013	0.965	0.992	**0.968**	1.010
GARCH(1,1) with breaks	**0.925**	**0.920**	**0.898**	1.003	0.995	0.995	0.988	0.977
Moving average	0.933	0.946	0.947	**0.972**	**0.892**	**0.948**	1.012	**0.919**

Notes: Entries for the GARCH(1,1) expanding window model give the mean loss for this model. Entries for the other models give the ratio of the mean loss for each model to the mean loss for the GARCH(1,1) expanding window model. Bold entries denote the model with the smallest mean loss among all of the models.

Table A4: Out-of-sample exchange rate return volatility forecasting results for the GJR-GARCH(1,1) and MS-GARCH(1,1) expanding window models

Model	Canada	Denmark	Germany	Japan	Norway	Switzerland	U.K.	U.S. (trade-weighted)
A. $MSFE^{*}_{s,i}$, $s=1$								
GJR-GARCH(1,1)	1.299	1.305	1.327	1.244	1.290	1.329	1.439	1.394
MS-GARCH(1,1)	1.000	0.997	0.994	0.997	1.001	0.996	1.001	0.998
B. $MVaR_{s,i}$, $s=1$								
GJR-GARCH(1,1)	1.935	1.854	1.889	1.792	1.843	2.007	2.166	2.184
MS-GARCH(1,1)	1.011	1.061	1.068	1.042	1.042	1.057	1.013	1.063
C. $MSFE^{*}_{s,i}$, $s=20$								
GJR-GARCH(1,1)	9.234	6.247	6.828	5.083	5.064	6.855	6.560	8.190
MS-GARCH(1,1)	0.930	1.589	1.799	3.305	2.981	1.316	1.349	2.115
D. $MVaR_{s,i}$, $s=20$								
GJR-GARCH(1,1)	2.221	1.424	1.441	1.119	1.516	1.387	1.662	1.874
MS-GARCH(1,1)	0.995	0.985	1.003	1.000	1.013	0.991	1.000	1.005
E. $MSFE^{*}_{s,i}$, $s=60$								
GJR-GARCH(1,1)	11.590	8.827	9.569	4.349	7.685	12.894	6.483	13.744
MS-GARCH(1,1)	1.816	26.912	11.816	144.487	209.346	4.623	6.723	30.806
F. $MVaR_{s,i}$, $s=60$								
GJR-GARCH(1,1)	2.072	1.294	1.322	0.810	1.256	1.141	1.128	1.626
MS-GARCH(1,1)	1.018	1.016	1.006	0.983	0.998	0.988	1.000	1.001
G. $MSFE^{*}_{s,i}$, $s=120$								
GJR-GARCH(1,1)	11.281	7.738	8.512	5.032	13.408	13.680	5.714	18.139
MS-GARCH(1,1)	99.345	824.747	57.878	44.384×10^{3}	8.238×10^{4}	12.042	70.679	500.02
H. $MVaR_{s,i}$, $s=120$								
GJR-GARCH(1,1)	1.895	0.830	0.831	0.860	1.190	0.843	0.722	0.893
MS-GARCH(1,1)	1.111	0.996	1.000	0.989	0.989	0.999	1.000	0.996

Notes: GJR-GARCH(1,1) is the asymmetric GARCH(1,1) model of Glosten et al. (1993) and is given by $e_t = h_t \varepsilon_t$, $\varepsilon_t \sim$ iid $N(0,1)$, and $h_t = \omega + \alpha e_{t-1}^2 (1-I) + \gamma e_{t-1}^2 I + \beta h_{t-1}$, where $I = 1$ when $e_{t-1} > 0$ and 0 otherwise. MS-GARCH(1,1) is the two-state Markov-switching GARCH(1,1) model of Haas et al. (2004) and is given by $e_t = h_{s_t} \varepsilon_t$, $\varepsilon_t \sim$ iid $N(0,1)$, $h_{s_t} = h_{1,t} = \omega_1 + \alpha_1 e_{t-1}^2 + \beta_1 h_{1,t-1}$ in state one, $h_{s_t} = h_{2,t} = \omega_2 + \alpha_2 e_{t-1}^2 + \beta_2 h_{2,t-1}$ in state 2, and the transition probabilities are given by $p_{ij} = [P(s_t = j \mid s_{t-1} = i)]$ for $i, j = 1, 2$. Each of the models is estimated using an expanding window. Entries give the ratio of the mean loss for the model indicated on the left to the mean loss for the benchmark GARCH(1,1) expanding window model.

Table A5: Out-of-sample exchange rate return volatility forecasting results, earlier out-of-sample period, $s = 60$

Model	Canada	Denmark	Germany	Japan	Norway	Switzerland	U.K.	U.S. (trade-weighted)
A. $MSFE^{*}_{s,i}$								
GARCH(1,1) expanding window	**49.203**	77.126	73.163	95.194	100.241	97.856	38.151	40.218
RiskMetrics	1.101	1.118	1.293	0.821	1.481	1.376	0.839	1.316
FIGARCH(1,*d*,1) expanding window	1.036	0.870	0.993	0.724	1.017	0.865	0.744	0.868
GARCH(1,1) 0.50 rolling window	1.125	0.751	0.902	0.859	0.990	0.857	0.700	0.918
GARCH(1,1) 0.25 rolling window	1.149	**0.731**	**0.886**	0.971	**0.892**	**0.674**	0.627	**0.660**
GARCH(1,1) weighted ML	1.568	0.927	1.170	0.394	1.396	0.945	0.867	0.930
GARCH(1,1) with breaks	1.095	0.837	1.164	1.000	1.007	0.754	**0.559**	0.835
Moving average	1.175	0.868	1.114	**0.358**	1.179	0.722	0.695	0.849
B. $MVaR_{s,i}$								
GARCH(1,1) expanding window	0.656	**0.530**	**0.525**	0.455	0.921	0.480	0.405	**0.508**
RiskMetrics	1.008	1.576	1.603	1.106	1.193	1.464	**0.883**	1.396
FIGARCH(1,*d*,1) expanding window	1.011	1.063	1.036	0.976	1.003	1.035	0.972	1.044
GARCH(1,1) 0.50 rolling window	1.076	1.205	1.187	0.987	1.018	1.046	0.948	1.149
GARCH(1,1) 0.25 rolling window	1.025	1.109	1.123	**0.934**	**0.845**	**0.990**	0.931	1.010
GARCH(1,1) weighted ML	1.001	1.346	1.376	0.953	1.157	1.100	0.888	1.177
GARCH(1,1) with breaks	1.000	1.125	1.210	1.000	1.043	0.991	0.924	1.090
Moving average	**0.907**	1.099	1.107	1.000	1.035	1.023	0.900	1.049

Notes: Entries for the GARCH(1,1) expanding window model give the mean loss for this model. Entries for the other models give the ratio of the mean loss for each model to the mean loss for the GARCH(1,1) expanding window model. Bold entries denote the model with the smallest mean loss among all of the models.