Online Appendices for 'Portfolio optimisation using alternative risk measures'

Contents

Appendix A provides descriptive statistics for industry group and industry returns in Table A1. Tables A2 and A3 report returns across strategies for the pre-COVID-19 and COVID-19 periods. Tables A4 and A5 report the corresponding Sharpe ratios.

Appendix B reports the results of optimisation over different risk measures. Results are reported in Table B1, followed by a discussion of the results.

Appendix A: Descriptive statistics and further results

Table A1: Industry group and industry descriptive statistics

Panel A: Industry groups

Industry group	Mean	Median	Standard Deviation	Sample Variance	Kurtosis	Skewness	Shapiro-Wilk test statistic
Auto & compo	0.0004	0.0003	0.0136	0.0002	5.3548	-0.1891	0.9355
Banks	0.0001	0.0002	0.0130	0.0002	11.8867	-0.3390	0.8873
Coml/prof svs	0.0003	0.0006	0.0092	0.0001	10.5138	-0.6380	0.9108
Cons dur/app	0.0004	0.0008	0.0110	0.0001	8.7260	-0.3955	0.9218
Cap gds	0.0003	0.0005	0.0108	0.0001	11.1307	-0.4102	0.9000
Div fin	0.0003	0.0007	0.0132	0.0002	10.9341	-0.4144	0.8899
Energy	0.0001	0.0002	0.0153	0.0002	19.5538	-0.6273	0.8632
Fd/bev/tob	0.0003	0.0005	0.0079	0.0001	11.2491	-0.8148	0.9090
Fd/staples rtl	0.0003	0.0005	0.0081	0.0001	11.2411	-0.4442	0.9129
H/c eq/svs	0.0005	0.0008	0.0102	0.0001	12.2063	-0.5980	0.8943
H/h pers prd	0.0003	0.0004	0.0082	0.0001	8.0001	-0.3127	0.9288
Cons svs	0.0004	0.0006	0.0112	0.0001	19.5892	-0.4640	0.8587
Insurance	0.0003	0.0006	0.0112	0.0001	15.6296	-0.7062	0.8687
Materials	0.0002	0.0004	0.0116	0.0001	7.4511	-0.3908	0.9326
Media & entertainment	0.0005	0.0008	0.0120	0.0001	7.2619	-0.5482	0.9160
Ph/bio l sci	0.0003	0.0006	0.0087	0.0001	5.6356	-0.2635	0.9444
Real estate	0.0002	0.0006	0.0095	0.0001	20.7693	-1.2327	0.8535
Retailing	0.0006	0.0008	0.0117	0.0001	6.8187	-0.6095	0.9179
S/con&s/con eq	0.0007	0.0010	0.0157	0.0002	5.8975	-0.3091	0.9374
S/w & svs	0.0006	0.0008	0.0126	0.0002	9.5172	-0.3435	0.9086
T/cm svs	0.0001	0.0002	0.0083	0.0001	6.5252	-0.4287	0.9439
Tch h/w/eq	0.0006	0.0009	0.0127	0.0002	7.1251	-0.2824	0.9252
Transpt	0.0004	0.0006	0.0096	0.0001	8.9647	-0.5535	0.9205
Utilities	0.0001	0.0005	0.0091	0.0001	18.2991	-0.4907	0.8742

Panel B: Industries

Industry group	Mean	Median	Standard Deviation	Sample Variance	Kurtosis	Skewness	Shapiro-Wilk test statistic
Aero/defense	0.0005	0.0005	0.0129	0.0002	16.4468	-0.3578	0.8661
Air frt/logs	0.0003	0.0004	0.0118	0.0001	5.0117	-0.1327	0.9414
Airlines	0.0001	0.0003	0.0147	0.0002	11.6437	-0.4684	0.9125
Automobiles	0.0004	0.0003	0.0143	0.0002	5.5557	-0.0944	0.9359
Auto compo	0.0003	0.0005	0.0125	0.0002	5.4877	-0.4145	0.9497
Coml banks	0.0001	0.0002	0.0130	0.0002	11.8503	-0.3357	0.8964
Biotec	0.0006	0.0005	0.0126	0.0002	3.7624	-0.1364	0.9614
Bldg prd	0.0003	0.0005	0.0117	0.0001	4.5456	-0.2873	0.9583
Beverages	0.0003	0.0004	0.0088	0.0001	12.5104	-0.7348	0.9067
Coml svs/sup	0.0003	0.0006	0.0088	0.0001	11.2473	-0.8829	0.9114
Comms eq	0.0002	0.0004	0.0135	0.0002	7.3578	-0.2763	0.9291
Cons finance	0.0005	0.0006	0.0176	0.0003	19.5479	0.1123	0.8591
Chemicals	0.0003	0.0006	0.0106	0.0001	7.9763	-0.5358	0.9308
Capital mkts	0.0003	0.0005	0.0135	0.0002	10.4843	-0.3708	0.9060
Con mat	0.0002	0.0001	0.0149	0.0002	6.9636	-0.3111	0.9356
Con & eng	0.0002	0.0001	0.0128	0.0002	10.3152	-0.4082	0.9165
Cpu & per	0.0008	0.0006	0.0154	0.0002	6.1795	-0.1657	0.9360
Cont & pack	0.0004	0.0006	0.0120	0.0001	10.3834	-0.3509	0.9168
Div fin svs	0.0004	0.0005	0.0132	0.0002	9.0578	-0.3974	0.9001
Div cons svs	0.0002	0.0000	0.0241	0.0006	1,147.5377	25.8173	0.4179
Distributors	0.0003	0.0005	0.0150	0.0002	20.4125	0.1673	0.8794
Div t/cm svs	-0.0000	0.0002	0.0090	0.0001	6.9638	-0.3032	0.9425
Elec eq	0.0003	0.0004	0.0122	0.0001	9.0336	-0.1963	0.9340
Elt/eq/ins/cm	0.0004	0.0006	0.0110	0.0001	3.5350	-0.3374	0.9690
En eq & svs	-0.0000	0.0000	0.0213	0.0005	15.3662	-0.5191	0.9022

Table A1 continued…

Elec util	0.0002	0.0005	0.0093	0.0001	18.9194	-0.4312	0.8824
Fd/staples rtl	0.0003	0.0005	0.0081	0.0001	11.2411	-0.4442	0.9180
Fd prd	0.0003	0.0004	0.0078	0.0001	6.8990	-0.5262	0.9489
Gas util	0.0002	0.0002	0.0079	0.0001	8.1896	-0.7689	0.9465
Hh dur	0.0002	0.0004	0.0114	0.0001	6.7769	-0.4298	0.9452
H/c tech	0.0007	0.0006	0.0153	0.0002	5.8854	0.4283	0.9498
Hh prd	0.0003	0.0005	0.0089	0.0001	11.4986	-0.0378	0.9076
Ht/rest/leis	0.0004	0.0006	0.0113	0.0001	19.2512	-0.4505	0.8695
H/c eq & supplies	0.0004	0.0007	0.0103	0.0001	7.6908	-0.5551	0.9293
Insurance	0.0003	0.0006	0.0112	0.0001	15.6296	-0.7062	0.8809
Inds cong	0.0002	0.0004	0.0116	0.0001	9.6232	-0.2081	0.9183
In p p&en tr	0.0001	0.0003	0.0124	0.0002	6.9187	-0.6316	0.9432
It services	0.0005	0.0008	0.0122	0.0001	12.0319	-0.2254	0.9059
Leis eq/prd	0.0002	0.0004	0.0116	0.0001	4.9847	-0.4602	0.9552
Life sci t&svs	0.0007	0.0009	0.0134	0.0002	3.5205	-0.3213	0.9566
Marine	0.0003	0.0004	0.0149	0.0002	2.3146	-0.0732	0.9797
Machinery	0.0003	0.0005	0.0117	0.0001	6.3061	-0.1834	0.9446
Media	0.0003	0.0006	0.0112	0.0001	7.5034	-0.6617	0.9273
Met & min	0.0000	0.0003	0.0154	0.0002	4.9424	-0.1309	0.9608
M/line rtl	0.0004	0.0005	0.0107	0.0001	16.4268	-1.0830	0.9058
Multi util	0.0001	0.0005	0.0101	0.0001	15.2501	-0.4507	0.8930
Int/cat rtl	0.0010	0.0008	0.0171	0.0003	4.4364	-0.0860	0.9474
Oil,gas&c.fuel	0.0001	0.0001	0.0150	0.0002	20.2322	-0.6140	0.8818
Pap/for prd	0.0003	0.0007	0.0144	0.0002	3.1257	-0.2549	0.9683
Pharm	0.0003	0.0006	0.0082	0.0001	5.9556	-0.2935	0.9483
Pers prd	0.0003	0.0005	0.0102	0.0001	3.8741	-0.1528	0.9634
H/c prov/svs	0.0006	0.0007	0.0120	0.0001	14.7334	-0.4408	0.8920
Prof svs	0.0004	0.0007	0.0106	0.0001	8.2939	-0.4159	0.9323
Re mgt & dev	0.0001	0.0003	0.0098	0.0001	3.8764	-0.2688	0.9616
Equity reits	0.0003	0.0007	0.0108	0.0001	21.1858	-1.0996	0.8662
Road & rail	0.0004	0.0007	0.0102	0.0001	7.7305	-0.4811	0.9378
S/con&s/con eq	0.0007	0.0010	0.0157	0.0002	5.8975	-0.3091	0.9457
Spec rtl	0.0005	0.0007	0.0115	0.0001	25.1069	-1.1092	0.8842
Software	0.0006	0.0008	0.0135	0.0002	7.9712	-0.2627	0.9268
Txt/app/lux	0.0005	0.0008	0.0135	0.0002	6.5736	-0.1954	0.9383
Tobacco	0.0002	0.0005	0.0102	0.0001	8.6334	-0.8091	0.9231
Trad cos/dis	0.0003	0.0003	0.0108	0.0001	4.5411	-0.0038	0.9568
Transpt inf	0.0002	0.0003	0.0119	0.0001	16.7440	-0.6682	0.8945
Thrfts/mge fin	-0.0002	0.0000	0.0109	0.0001	8.3836	-0.6210	0.8716
W/l t/cm svs	0.0003	0.0005	0.0100	0.0001	3.2986	-0.1904	0.9700
Water util	0.0004	0.0006	0.0114	0.0001	13.3377	0.0533	0.9077

Notes: This table reports descriptive statistics for industry groups and industry returns. The Shapiro-Wilk is applied to test for normality and the null hypothesis that the daily returns are normally distributed normally is rejected in all instances (all p-values <=10e^{-25}). Index names are as per Refinitiv Eikon ticker names for replicability.

Table A2: Annualised strategy returns prior to 1 January 2020

Tier	Calculation Period	Raw/ EWMA	V	SD	DSV	DSSD	MAD	SAD	VaR0.1	VaR0.05	CVaR0.1	CVaR0.05
Panel A												
Sector	**Daily**	**Raw**	11.98%	12.67%	12.75%	9.49%	12.49%	11.58%	9.81%	9.66%	12.56%	12.15%
		EWMA	11.20%	11.21%	8.65%	9.06%	11.46%	11.64%	11.17%	10.99%	12.13%	11.27%
	Weekly	**Raw**	11.90%	12.63%	11.93%	10.99%	12.72%	11.49%	10.49%	8.04%	12.17%	12.92%
		EWMA	10.92%	12.67%	11.34%	12.43%	14.96%	14.32%	13.39%	13.37%	7.25%	7.71%
	Monthly	**Raw**	10.51%	11.15%	10.42%	11.19%	10.68%	12.57%	9.70%	10.07%	11.40%	11.61%
		EWMA	7.19%	10.46%	6.79%	8.61%	10.57%	10.51%	10.44%	10.24%	7.51%	10.15%
Industry Group	**Weekly**	**Raw**	9.44%	11.70%	9.56%	10.62%	11.34%	12.75%	9.31%	12.35%	13.72%	13.40%
		EWMA	9.05%	13.19%	10.87%	13.12%	12.57%	12.73%	12.81%	13.27%	7.68%	8.71%
	Monthly	**Raw**	9.93%	11.51%	10.78%	10.84%	10.93%	12.13%	11.47%	10.29%	12.32%	12.67%
		EWMA	5.78%	8.36%	9.83%	10.72%	9.10%	10.66%	8.40%	8.20%	11.00%	8.87%
Industry	**Weekly**	**Raw**	5.60%	6.28%	5.13%	10.43%	5.08%	14.18%	11.26%	12.07%	10.22%	10.24%
		EWMA	5.74%	3.52%	9.03%	8.15%	4.72%	7.69%	3.33%	3.36%	2.12%	1.32%
	Monthly	**Raw**	9.37%	8.26%	7.47%	7.85%	8.29%	7.54%	11.62%	7.12%	8.45%	12.64%
		EWMA	6.81%	5.41%	12.26%	7.26%	6.89%	5.87%	7.43%	7.86%	2.88%	3.35%
Panel B												
Raw			9.82%	10.60%	9.72%	10.20%	10.22%	11.75%	10.52%	9.94%	11.55%	12.23%
EWMA			8.10%	9.26%	9.82%	9.91%	10.04%	10.49%	9.57%	9.61%	7.22%	7.34%
Panel C												
Sector			10.62%	11.80%	10.31%	10.30%	12.15%	12.02%	10.83%	10.40%	10.50%	10.97%
Industry Group			9.52%	8.55%	11.19%	10.26%	11.32%	10.98%	12.07%	10.50%	11.03%	11.18%
Industry			6.88%	5.87%	8.47%	8.42%	6.24%	8.82%	8.41%	7.60%	5.92%	6.89%
Panel D												
Overall			8.96%†††	9.93%***	9.77%	10.05%	10.13%***	11.12%††	10.05%	9.78%	9.39%	9.79%
Delta (V)			0.00%	0.97%	0.81%	1.10%	1.17%	2.16%	1.09%	0.82%	0.43%	0.83%
Delta (SD)			-0.97%	0.00%	-0.16%	0.12%	0.20%	1.19%	0.12%	-0.15%	-0.54%	-0.14%

Notes: This table shows the annualised returns for the period preceding 1 January 2020 for each of the 140 strategies as well as average returns aggregated by Raw/EWMA categorisation and by Tier, and finally overall. V = variance, SD = standard deviation, DSV = downside semi-variance, DSSD = downside semi-deviation, MAD = mean absolute deviation, SAD = semi-absolute deviation, VaR0.1 = 10% value at risk, VaR0.05 = 5% value at risk, CvaR0.1 = 10% conditional value at risk, CvaR0.05 = 5% conditional value at risk. Overall is the average annualised return across all strategies optimised using that risk measure. Delta (V) and Delta (SD) are returns for strategies optimised using that risk measure less returns for strategies optimised using variance and SD, respectively, being the risk measures traditionally used in portfolio optimisation.

Statistical significance based on Wilcoxon Signed-Ranks tests:

Relative to variance-optimised benchmark:	* p <= .01	** p <= .05	*** p <= .1
Relative to standard deviation-optimised benchmark:	† p <= .01	†† p <= .05	††† p <= .1

Table A3: Annualised strategy returns after 1 January 2020

Tier	Calculation Period	Raw/ EWMA	V	SD	DSV	DSSD	MAD	SAD	VaR0.1	VaR0.05	CVaR0.1	CVaR0.05
						Panel A						
Sector	**Daily**	**Raw**	2.23%	5.68%	5.03%	15.71%	6.07%	16.02%	7.72%	6.23%	1.73%	5.41%
		EWMA	11.50%	0.95%	2.21%	3.46%	1.14%	-0.27%	1.51%	2.82%	-0.14%	4.50%
	Weekly	**Raw**	6.80%	8.91%	2.94%	24.32%	10.63%	20.50%	6.68%	8.20%	9.90%	8.60%
		EWMA	10.15%	11.41%	17.41%	8.42%	20.44%	20.67%	10.28%	10.25%	-1.56%	6.86%
	Monthly	**Raw**	14.71%	10.92%	11.22%	20.36%	20.03%	25.30%	8.23%	15.37%	9.71%	13.01%
		EWMA	9.42%	15.32%	11.21%	18.37%	15.29%	16.01%	12.96%	15.31%	14.15%	18.83%
Industry Group	**Weekly**	**Raw**	8.62%	24.29%	11.47%	24.65%	17.15%	7.97%	16.60%	22.32%	21.35%	26.36%
		EWMA	15.65%	39.86%	29.50%	41.71%	48.34%	44.83%	40.47%	38.72%	42.38%	42.49%
	Monthly	**Raw**	18.83%	26.04%	18.73%	21.92%	24.55%	22.05%	17.25%	19.32%	27.83%	25.53%
		EWMA	9.52%	18.72%	16.06%	21.85%	18.45%	18.60%	16.82%	17.60%	15.73%	15.73%
Industry	**Weekly**	**Raw**	9.84%	13.41%	26.47%	27.88%	12.61%	18.43%	28.72%	20.16%	13.22%	26.84%
		EWMA	-0.19%	27.22%	25.91%	24.56%	22.59%	10.11%	21.99%	21.75%	8.69%	17.12%
	Monthly	**Raw**	4.70%	22.43%	0.98%	25.75%	19.47%	10.69%	20.90%	13.59%	19.86%	19.78%
		EWMA	-0.90%	7.15%	17.21%	15.45%	21.21%	9.92%	9.41%	8.55%	-13.20%	-13.19%
						Panel B						
Raw			9.39%	15.95%	10.98%	22.94%	15.79%	17.28%	15.16%	15.03%	14.80%	17.93%
EWMA			7.88%	17.23%	17.07%	19.12%	21.07%	17.12%	16.21%	16.43%	9.44%	13.19%
						Panel C						
Sector			9.13%	8.87%	8.34%	15.11%	12.27%	16.37%	7.90%	9.70%	5.63%	9.53%
Industry Group			13.15%	27.23%	18.94%	27.53%	27.12%	23.36%	22.78%	24.49%	26.83%	27.53%
Industry			3.36%	17.55%	17.64%	23.41%	18.97%	12.29%	20.25%	16.01%	7.14%	12.64%
						Panel D						
Overall			8.63%††	16.59%**	14.03%	21.03%*†††	18.43%*	17.20%**	15.68%**	15.73%*	12.12%††	15.56%**
Delta (V)			0.00%	7.96%	5.39%	12.40%	9.79%	8.57%	7.05%	7.09%	3.49%	6.93%
Delta (SD)			-7.96%	0.00%	-2.57%	4.44%	1.83%	0.61%	-0.91%	-0.87%	-4.47%	-1.03%

Notes: This table shows the annualised returns for the period following 1 January 2020 for each of the 140 strategies as well as average returns aggregated by Raw/EWMA categorisation and by Tier, and finally overall. V = variance, SD = standard deviation, DSV = downside semi-variance, DSSD = downside semi-deviation, MAD = mean absolute deviation, SAD = semi-absolute deviation, VaR0.1 = 10% value at risk, VaR0.05 = 5% value at risk, CvaR0.1 = 10% conditional value at risk, CvaR0.05 = 5% conditional value at risk. Overall is the average annualised return across all strategies optimised using that risk measure. Delta (V) and Delta (SD) are returns for strategies optimised using that risk measure less returns for strategies optimised using variance and SD, respectively, being the risk measures traditionally used in portfolio optimisation.

Statistical significance based on Wilcoxon Signed-Ranks tests:

Relative to variance-optimised benchmark: * p <= .01 ** p <= .05 *** p <= .1

Relative to standard deviation-optimised benchmark: † p <= .01 †† p <= .05 ††† p <= .1

Table A4: Sharpe ratios prior to 1 January 2020

Tier	Calculation Period	Raw/EWMA	V	SD	DSV	DSSD	MAD	SAD	VaR0.1	VaR0.05	CVaR0.1	CVaR0.05
Panel A												
Sector	**Daily**	**Raw**	1.08	1.07	1.06	0.79	1.04	0.99	0.82	0.81	1.06	1.02
		EWMA	0.96	0.92	0.70	0.73	0.94	0.96	0.91	0.90	0.99	0.87
	Weekly	**Raw**	1.04	1.03	0.98	0.93	1.04	0.99	0.87	0.64	1.00	1.06
		EWMA	0.94	1.02	0.96	0.99	1.21	1.17	1.09	1.09	0.56	0.57
	Monthly	**Raw**	1.00	0.98	0.97	1.10	0.93	1.04	0.86	0.87	1.01	1.02
		EWMA	0.63	0.89	0.54	0.72	0.92	0.91	0.88	0.87	0.69	0.77
Industry Group	**Weekly**	**Raw**	0.76	0.90	0.74	0.77	0.87	0.95	0.68	0.93	1.05	1.02
		EWMA	0.66	0.97	0.75	1.01	0.94	0.95	0.94	0.98	0.55	0.66
	Monthly	**Raw**	1.01	0.99	1.04	0.95	0.96	1.06	1.07	0.88	1.08	1.14
		EWMA	0.56	0.71	0.80	0.87	0.77	0.90	0.74	0.71	0.69	0.59
Industry	**Weekly**	**Raw**	0.42	0.39	0.36	0.64	0.31	0.88	0.72	0.77	0.62	0.61
		EWMA	0.40	0.21	0.57	0.56	0.30	0.53	0.20	0.20	0.08	0.04
	Monthly	**Raw**	0.93	0.72	0.74	0.69	0.70	0.65	1.00	0.64	0.76	1.08
		EWMA	0.69	0.50	0.94	0.61	0.59	0.50	0.74	0.74	0.12	0.14
Panel B												
Raw			0.89	0.87	0.84	0.84	0.84	0.94	0.86	0.79	0.94	0.99
EWMA			0.69	0.75	0.75	0.78	0.81	0.85	0.79	0.78	0.53	0.52
Panel C												
Sector			0.94	0.98	0.87	0.88	1.01	1.01	0.91	0.86	0.88	0.89
Industry Group			0.75	0.89	0.83	0.90	0.89	0.96	0.85	0.88	0.84	0.85
Industry			0.61	0.46	0.65	0.63	0.47	0.64	0.67	0.59	0.39	0.47
Panel D												
Overall			0.79	0.81	0.80	0.81	0.82	0.89†††	0.82	0.79	0.73	0.76
Delta (V)			-	0.02	0.01	0.02	0.03	0.10	0.03	-0.00	-0.06	- 0.03
Delta (SD)			- 0.02	-	- 0.01	0.00	0.02	0.08	0.02	-0.02	-0.07	- 0.05

Notes: This table shows annualised returns for each of the 140 strategies undertaken in the study as well as average returns aggregated by Raw/EWMA categorisation and by Tier, and finally overall. V = variance, SD = standard deviation, DSV = downside semi-variance, DSSD = downside semi-deviation, MAD = mean absolute deviation, SAD = semi-absolute deviation, VaR0.1 = 10% value at risk, VaR0.05 = 5% value at risk, CVaR0.1 = 10% conditional value at risk, CVaR0.05 = 5% conditional value at risk.

Statistical significance based on Wilcoxon Signed-Rank tests:

Relative to variance-optimised benchmark: * p <= .01 ** p <= .05 *** p <= .1

Relative to standard deviation-optimised benchmark: † p <= .01 †† p <= .05 ††† p <= .1

Table A5: Sharpe ratios after 1 January 2020

Tier	Calculation Period	Raw/EWMA	V	SD	DSV	DSSD	MAD	SAD	VaR0.1	VaR0.05	CVaR0.1	CVaR0.05
						Panel A						
Sector	**Daily**	**Raw**	0.07	0.22	0.19	0.66	0.24	0.68	0 .30	0.23	0.05	0.20
		EWMA	0.53	0.01	0.07	0.12	0.02	- 0.04	0.04	0.10	- 0.04	0.19
	Weekly	**Raw**	0.28	0.35	0.10	1.15	0.43	0.82	0.26	0.33	0.40	0.33
		EWMA	0.44	0.47	0.72	0.34	0.87	0 .88	0.42	0.41	- 0.10	0.27
	Monthly	**Raw**	0.84	0.53	0.60	1.17	1.01	1.38	0.44	0.80	0.46	0.63
		EWMA	0.53	0.86	0.65	0.93	0.86	0.91	0.72	0.86	0.83	1.05
Industry Group	**Weekly**	**Raw**	0.30	0.87	0.41	0.87	0.65	0.32	0.62	0.82	0.76	0.93
		EWMA	0.73	1.52	1.29	1.69	1.83	1.70	1.53	1.47	1.39	1.44
	Monthly	**Raw**	0.74	0.96	0.80	0.84	0.91	0.84	0.61	0.75	1.04	0.96
		EWMA	0.37	0.69	0.62	0.79	0.74	0.70	0.63	0.66	0.51	0.50
Industry	**Weekly**	**Raw**	0.35	0.50	1.02	1.06	0.48	0.62	1.21	0.63	0.50	0.79
		EWMA	-0.06	1.08	1.08	1.00	0.93	0.39	0.90	0.89	0.18	0.45
	Monthly	**Raw**	0.18	0.82	0.02	0.96	0.71	0.41	0.72	0.49	0.7	0.76
		EWMA	-0.07	0.26	0.64	0.58	0.82	0.34	0.34	0.32	- 0.37	- 0.37
						Panel B						
Raw			0.40	0.61	0.45	0.96	0.63	0.73	0.59	0.58	0.56	0.66
EWMA			0.35	0.70	0.73	0.78	0.87	0.70	0.65	0.67	0.34	0.51
						Panel C						
Sector			0.45	0.41	0.39	0.73	0.57	0.77	0.36	0.46	0.27	0.45
Industry Group			0.54	1.01	0.78	1.05	1.03	0.89	0.85	0.93	0.92	0.96
Industry			0.10	0.66	0.69	0.90	0.74	0.44	0.79	0.58	0.26	0.41
						Panel D						
Overall			0.37††	0.65**	0.59	0.87*††	0.75*	0.71**	0.62***	0.63**	0.45†	0.58***
Delta (V)			-	0.28	0.21	0.49	0.37	0.34	0.25	0.25	0.08	0.21
Delta (SD)			- 0.28	-	- 0.07	0.22	0.10	0.06	-0.03	-0.03	-0.20	-0.07

Notes: This table shows annualised returns for each of the 140 strategies undertaken in the study as well as average returns aggregated by Raw/EWMA categorisation and by Tier, and finally overall. V = variance, SD = standard deviation, DSV = downside semi-variance, DSSD = downside semi-deviation, MAD = mean absolute deviation, SAD = semi-absolute deviation, VaR0.1 = 10% value at risk, VaR0.05 = 5% value at risk, CVaR0.1 = 10% conditional value at risk, CVaR0.05 = 5% conditional value at risk.

Statistical significance based on Wilcoxon Signed-Rank tests:

Relative to variance-optimised benchmark: * $p <= .01$ ** $p <= .05$ *** $p <= .1$

Relative to standard deviation-optimised benchmark: † $p <= .01$ †† $p <= .05$ ††† $p <= .1$

Appendix B: Portfolio risk for optimised portfolios

Table B1: Portfolio risk for optimised portfolios

		V	SD	DSV	DSSD	MAD	SAD	VaR0.1	VaR0.05	CVaR0.1	CVaR0.05	Average	Max Drawdown
Panel A: Strategy risk per risk measure													
Risk measure used for optimisation	V	0.08%	2.77%	0.11%	3.28%	1.82%	2.09%	2.38%	3.49%	4.44%	6.08%	2.65%	23.5%
	SD	0.09%	3.01%	0.12%	3.47%	1.99%	2.22%	2.47%	3.66%	4.73%	6.51%	2.83%	23.1%
	DSV	0.08%	2.90%	0.11%	3.37%	1.90%	2.10%	2.56%	3.69%	4.75%	6.56%	2.80%	23.8%
	DSSD	0.08%	2.91%	0.11%	3.35%	1.92%	2.08%	2.20%	3.40%	4.52%	6.33%	2.69%	22.1%
	MAD	0.09%	3.00%	0.12%	3.46%	1.98%	2.20%	2.46%	3.57%	4.62%	6.36%	2.79%	22.9%
	SAD	0.09%	2.99%	0.12%	3.48%	1.98%	2.21%	2.42%	3.66%	4.56%	6.29%	2.78%	24.6%
	VaR0.1	0.09%	2.93%	0.11%	3.38%	1.96%	2.15%	2.59%	3.67%	4.67%	6.37%	2.79%	23.4%
	VaR0.05	0.09%	2.98%	0.12%	3.42%	1.99%	2.18%	2.46%	3.57%	4.64%	6.44%	2.79%	24.0%
	CVaR0.1	0.09%	2.93%	0.11%	3.38%	1.94%	2.16%	2.40%	3.81%	4.76%	6.55%	2.81%	22.1%
	CVaR0.05	0.10%	3.11%	0.12%	3.49%	2.05%	2.21%	2.61%	3.74%	4.93%	6.83%	2.92%	23.3%
Panel B: Rankings per risk measure													
Risk measure used for optimisation	V	1	1	1	1	1	2	2	2	1	1	1.3	7
	SD	9	9	8	8	9	10	7	6	7	7	8.0	4
	DSV	2	2	3	3	2	3	8	8	8	9	4.8	8
	DSSD	3	3	2	2	3	1	1	1	2	3	2.1	1
	MAD	8	8	7	7	7	7	5	3	4	4	6.0	3
	SAD	7	7	9	9	6	8	4	5	3	2	6.0	10
	VaR0.1	5	5	4	4	5	4	9	7	6	5	5.4	6
	VaR0.05	6	6	6	6	8	6	6	4	5	6	5.9	9
	CVaR0.1	4	4	5	5	4	5	3	10	9	8	5.7	2
	CVaR0.05	10	10	10	10	10	9	10	9	10	10	9.8	5

Notes: Panel A shows average risk measures for strategies optimised using each risk measure, while panel B shows the ranks each strategy ordered by portfolio risk. Average in Table B shows the average of the ranks for portfolios optimised with each risk measure.

The results in Table B1 indicate that although variance-optimised strategy strategies do not perform well in generating favourable annualised returns and on a risk-adjusted basis, they perform particularly well in terms of minimising risk across measures. SAD, on the other hand, is associated with intermediate levels of risk relative to the other risk measures and has the highest maximum drawdown (24.6%), although it produces the highest Sharpe ratio. This suggests that favourable returns drive performance rather than low risk. This analysis also indicates that strategies generally produce consistent rankings across risk measures and not just the risk measure used for optimisation purposes.

The results of optimising over the different risk measures reported in Table B1 are not counterintuitive when considering the penalties imposed on optimisation by minimising each risk measure. The underlying reasons for the relative riskiness of portfolios optimised using different risk measures are not discussed in the literature. However, consideration of the mathematical formulation of each risk measure shows which assets result in an increase in the final value of the risk measure and which do not, with particular reference to whether minimising a risk measure results in stricter or more lenient exclusion of assets in the portfolio. If the exclusion of assets from the portfolio as a result of minimising risk is viewed as a penalty, then the most extreme penalty applied is likely to be that of variance, which penalises all large movements away from the mean return, with larger movements away from the mean penalised more than smaller movements, because variance is the sum of squared differences. This is evident in the first row of Panel B which shows that the average rank across all risk measures is the lowest for variance-optimised portfolios, which also has the lowest or second lowest of every portfolio risk measure of all strategies (rank is 1 or 2 for all strategies). Downside variance is similar, but does not penalise upside deviations which variance penalises, with the third row of Panel B showing that it has the second or third lowest portfolio risk for all risk measures other than VaR and CVaR. Conversely, VaR and CVaR have penalties which apply only to the tail, resulting in low penalties being applied during optimisation, with CVaR0.05 performing particularly poorly in terms of reducing risk across all risk measures, as shown in the last row of Panel B. Somewhere in between the two, MAD applies penalties to both upside and downside deviations from the mean return but has no increased weighting applied to returns far away from the mean, and semi-absolute deviation is similar, but only penalises downside deviations from the mean. The risk of the portfolios optimised using these two risk measures is accordingly in the middle of the range, with both having an average rank of six (Average column of Panel B).

In summary, the application of heavier or lighter risk penalties to the optimisation process is evident in Table B1, where the risk of investment strategies optimised using each risk measure is generally inversely proportional to the extremity of each risk measure's penalty. Several conclusions can be drawn from the relative risk of the different strategies. First, while the classical MPT variance-optimised strategy did not perform well in terms of returns (Panel D, Table 3) and risk-adjusted returns (Panel D, Table 4), it performed extremely well in terms of minimising risk across all risk measures used to measure the risk of a strategy. The opposite is true of semi-absolute deviation, which has intermediate levels of risk, as indicated by the risk measures, and the highest maximum drawdown of any strategy. This implies that its high Sharpe ratio is more a function of high returns than of low risk. A second conclusion is that a strategy's impact on risk is generally consistent across all risk measures, not just the risk measure being used to optimise a portfolio. This is evident from the lack of rank dispersion across portfolio risk (across columns) for each portfolio (in each row) in Panel B, where, for example, variance-optimised portfolios rank between 1 and 2 for all portfolio risk measures, CVaR0.05-optimised portfolios rank between 9 and 10, and DSSD-optimised portfolios rank 1 and 3 for all portfolio risk measures.