CFRM 507
Project 1 Report
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Introduction

As the new portfolio manager for a firm's Non-US Equity Fund, we have been asked to restructure the fund in a cost-effective manner while freeing up capital to cover the redemption requests of unhappy shareholders. The goal is to recommend a strategy that limits the realization of taxes, minimizes transaction costs and maintains portfolio weights within specified tolerances of benchmark weights.

Data

The Benchmark data file contains the list of securities as well as the characteristics of each security. The portfolio holdings data file contains a list of the Non-US Equity Fund current holdings by tax lot.

Implementation

The problem is modeled as a linear programming problem in R and solved using glpkAPI. For this report, the professor's R code is used. After running the R code, we retrieve the optimal value of the objective function and optimal values of the variables to determine the optimal strategy. We performs sensitivity analysis on the budget constraint (by looking at its dual value) to understand how does the objective change with an increase or decrease in the RHS value of this constraint.

Results

1. **What is the optimal strategy of purchases and sales to maximize the value of the fund after rebalancing?**

Table1 and Table 2 in the appendix give a breakdown of the amount purchases and sold for each security. Table 3 gives a breakdown of the dollar amount in each security after rebalancing is complete. These tables will guide the portfolio manager about the optimal strategy i.e., which securities to sell and how much, which ones to buy and how much.

Sales are made from the original investments held and purchases are made from the available 3585 securities. $24518353.85 of purchases and $39577313 of sales are made.

The optimal value of the objective function that minimizes total transaction costs and tax liability is $ 58959.67. The net realized gains and net realized losses are $0 each resulting in a tax liability of $0. $ 58959.67 is the total transaction cost incurred after rebalancing out of which $19614.68 is the total transaction costs from purchases and $39344.99 is the total transaction costs from sales.

Optimal Value of fund after rebalancing is $ 54867403.

2. **What are the sector, capitalization tier and Developed versus Emerging Market exposures as a % of the total portfolio after transactions are completed?**

The sector, capitalization tier and Developed versus Emerging Market exposures as a % of the total portfolio after rebalancing are given below

Table: Sector Caps as % weight of total portfolio

Sector	Percent
Communication Services	0.06379945
Consumer Discretionary	0.1238102
Consumer Staples	0.104827
Energy	0.02895163
Financials	0.1540116
Health Care	0.1101211
Industrials	0.1507565
Information Technology	0.1125763
Materials	0.0797153
Real Estate	0.03422793
Utilities	0.03720296

The sector cap table shows that there is a decent diversification across most of the sectors except Real Estate and Utilities, which are around 3.4%.

Table: Cap Tier caps as % weight of total portfolio

Cap Tier	Percent
large	0.867365
Mid	0.1036418
small	0.02899318

The Cap Tier table clearly shows that the portfolio manager should mainly invest in large cap stocks.

Table: Market caps as % weight of total portfolio

Market	Percent
Developed	0.8305609
Emerging	0.1694391

The market cap table clearly shows that the portfolio manager should mainly invest in developed market stocks.

In the tables above, sum of weights is 1 for the portfolio.

3. **How much money will shareholders lose to taxes and transaction costs?**

Shareholders lose $58959.67 to transaction costs and $0 to taxes.

The optimal value of the objective function that minimizes total transaction costs and tax liability is $ 58959.67. The net realized gains and net realized losses are $0 each resulting in $0 taxes.

4. **How would that have changed for each $100 reduction in shareholder redemptions?**

For this, we need to do sensitivity analysis on the budget constraint. The getRowDualGLPK(lp,2) function returns the shadow price for this constraint. The shadow price is -$0.0005311617 for each $1 reduction in shareholder redemptions which means a shadow price of -$0.05311617 for each $100 reduction in shareholder redemptions. This means that the objective value increases by $0.05311617 for each $100 reduction in shareholder redemptions. The transaction costs increase at the same rate for each $100 reduction in shareholder redemptions while the tax liability remains at $0. This is true for as long as the shareholder redemptions remain between 1.40428e+07 and 1.50598e+07. Also, in that range the securities bought and sold do not change assuming no change in RHS of other constraints. However, this does not mean that the amount bought or sold remains unchanged, it only means that the particular security remains same within the optimal solution.

Given below is the relevant part from sensitivity report generated by GLPK solver using CVXR

```
GLPK 4.65 - SENSITIVITY ANALYSIS REPORT
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Problem:

Objective:  58959.67179 (MINimum)


   No. Row name     St      Activity         Slack   Lower bound       Activity      Obj coef
Obj value at Limiting

                                          Marginal   Upper bound          range         range
break point variable

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..


     2              NU       1.5e+07         .           1.5e+07    1.40428e+07          -Inf
59468.08713

                                           -.00053       1.5e+07    1.50598e+07        .00053
58927.93446
```

5. **Any other valuable insights you can share.**

The portfolio value before rebalancing was $69926363 and its value after rebalancing is $ 54867403. The difference between the two is $15058960 which is exactly equal to the sum of redemption requests of 15 million dollars and the $58960 of transaction costs incurred during the rebalancing. This means that portfolio manager is able to pay the redemption requests with rebalancing.

After rebalancing, most of the investments are in large cap tier and developed market. A possible reason for higher investment in large cap stocks and developed markets is the lower transaction costs as per the problem statement.

By investing in large cap tier and developed markets, the firm gets the benefit of reduced risk exposure to emerging markets (as well as small cap stocks) which tend to be riskier than developed markets due to factors like political instability. The potential downside of this approach is the lack of diversification.

We can check the Sector cap, cap tier cap and market cap before rebalancing to get a better idea of how those weights changed after the rebalancing.

Table: Sector Caps as % weight of total portfolio before and after rebalancing

Sector	Percent before rebalancing	Percent after rebalancing
Communication Services	0.05093458	0.06379945
Consumer Discretionary	0.1071865	0.1238102
Consumer Staples	0.04095301	0.104827
Energy	0. 01227485	0.02895163
Financials	0.1244364	0.1540116
Health Care	0.08547512	0.1101211
Industrials	0.2184411	0.1507565
Information Technology	0.1198076	0.1125763
Materials	0.1413883	0.0797153
Real Estate	0.09036716	0.03422793
Utilities	0.008735302	0.03720296

We can see that Industrials, Information technology, Materials and Real Estate sectors were reduced during the rebalancing period.

Table: Cap Tier caps as % weight of total portfolio before and after rebalancing

Cap Tier	Percent before rebalancing	Percent after rebalancing
large	0.3141483	0.867365
Mid	0.3875756	0.1036418
small	0.2982761	0.02899318

Before rebalancing, the portfolio was reasonably well diversified in cap tier caps with mid cap being the highest weight. After rebalancing, we have a very high weight in large cap stocks.

Table: Market caps as % weight of total portfolio

Market	Percent before rebalancing	Percent after rebalancing
Developed	0.7725281	0.8305609
Emerging	0.2274719	0.1694391

The weight in developed markets was increased but for that for emerging markets was decreased during rebalancing, perhaps due to the lower transaction costs.

Conclusion

The constrained linear optimization solution gives a good understanding of the securities that the portfolio manager should trade. The best course of action will be dependent on the risk preferences of the investors. Since this is an equity fund, we would expect the fund to take a greater amount of risk to achieve greater returns (assuming we can't trade fixed income or bonds). The higher investment in large cap and developed markets through the optimization solution tends to suggest otherwise.

Extra credit

1. How would the formulation change if the goal is to minimize the number of trades?

We will introduce following new variables

$isPurchased_i = 1\ if\ security\ i\ is\ purchased\ and\ 0\ otherwise$

$isSold_k = 1\ if\ security\ k\ is\ sold\ and\ 0\ otherwise$

$numTransactions = \sum_{i=1}^{3585} isPurchased_i + \sum_{k=1}^{250} isSold_k$

We do not need to change constraints and variables in the professor's formulation. We include them all in the problem formulation.

The new formulation is

$minimize\ numTransactions$
$Subject\ to$
$isPurchased_i,\ isSold_k\ are\ binary$ for each security i and security k respectively
$numTransactions\ is\ integer\ and\ numTransactions \geq 0$

Include all constraints from Professor's formulation including non negativity
Include all variables from Professor's formulation

2. What is the minimum number of securities that can be held while satisfying assumptions 4, 5, 6, and 8?

We introduce following variables
$isHeld_i = 1\ if\ ith\ security\ is\ held\ and\ 0\ otherwise$

$numSecurities = \sum_{i=1}^{3585} isHeld_i$ which is the total number of securities held in the portfolio.

We already have variables X_i and Wwhich is the dollar amount invested in security after rebalancing and portfolio's total value after rebalancing respectively.

$X_i = 0 \Rightarrow isHeld_i = 0$ as the dollar amount is zero we cannot be holding that security.
Similarly, $X_i > 0 \Rightarrow isHeld_i = 1$ as the dollar amount is greater than zero we must be holding that security.

These conditions can be modeled as follows

$isHeld_i \geq (1/M) \; * \; X_i$
$isHeld_i \leq M * X_i$
M is a very large positive number

Let us check now

Test	Result
X_i = 0	$isHeld_i$ = 0
X_i > 0	$isHeld_i$ = 1
$isHeld_i$ = 0	X_i = 0
$isHeld_i$ = 1	X_i > 0

Problem formulation can be written as

$minimize\ numSecurities$
$subject\ to$
$isHeld_i \geq (1/M) \; * \; X_i$
$isHeld_i \leq M * X_i$
M is a very large positive number
$isHeld_i$ is binary for each security i
$numSecurities$ is an integer variable

We also include following constraints from professor's formulation
0.95 ∗ SectorWeight ∗W ≤ $Sector^T X$ ≤ 1.05 ∗ SectorWeight ∗W: Sector bounds
0.92 ∗MarketWeight ∗W ≤ $Market^T X$ ≤ 1.08 ∗MarketWeight ∗W: Market bounds
0.9 ∗ CapTierWeight ∗ W ≤ $CapTier^T X$ ≤ 1.1 ∗ CapTierWeight ∗ W: Capitalization tier bounds
$S_k \leq Value_k$
Non-negative variables as stated in the professor's formulation: W, P_i, X_i, S_k

The optimal value comes out to be 0 securities that need to be held to meet assumptions 4,5,6 and 8 in the problem.

I am providing my R code in the appendix in case it helps.

Appendix

Table 1: Strategy for Purchases (securities not listed in the table below were not purchased)

Row Number	$ purchased
9	383557
10	1509766
48	144129.8
93	562369.9
161	1588501
357	619933.9
690	2768578
821	3620480
1504	4555991
1699	3517431
1722	5243660
2030	3956.248

Table 2: Strategy for Sales (securities not listed in the table below were not sold)

Row Number	$ Sold
1	456872
2	53907
3	37890
5	297946
6	336784
7	52649
8	24414
9	288585
10	329199
11	91124
12	492201
14	448050
15	301050
16	825955
17	44660
19	76713
20	462224
21	88938
24	316690
25	86317
27	63804
29	154432

30	820456
31	8580
33	273730
34	32464
36	16528
37	110480
38	164430
39	153264
43	546987
44	12765
47	158912
48	178816
49	99171
50	322392
51	126000
53	115696
57	373200
59	752495
60	27500
61	184560
65	150161
66	976635
69	435834
71	225623
73	464912
74	566602
75	731216
77	436896
78	193644
80	224856
81	319378
82	210300
84	13048
85	410478
86	732972
89	170794
90	399912
92	708750
93	352314
94	55656
96	690084
100	767059.5
103	173352

104	490390
105	33056
107	47489
109	282821
110	63376
113	341250
114	73044
117	85744
118	677648
119	24056
120	292220
121	314820
123	187000
124	840000
125	199023
127	111565
128	266608
129	491634
130	329966
131	335654
133	153665
134	388408
136	145233
139	35906
140	536424
141	193644
142	434992
143	321687
144	99150.83
145	453790
146	261240
147	747144
152	135338
153	322392
154	321290
157	413200
159	121920
160	107302
164	388668
165	23844
166	93177
167	39375
168	111960

169	362153
171	236538
172	349316
173	606424
175	511005
177	29796
178	1575
179	99756
183	59687.67
184	59185
185	220380
188	202995
190	70070
191	28483
192	18261
196	458238
197	236078
198	113400
199	89388
200	107660
203	80806
205	128616
209	324756
210	253650
215	130130
217	136530
218	347150
219	295925
220	339955
221	77133
227	414966
230	22112
233	168958
235	429234
236	429234
237	78717
238	35332
239	673365
241	66114
243	507300
244	69524
245	57580
246	16256

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Table 3: Strategy for Securities. The table below shows the $ Amount invested in each security after rebalancing. The table below includes amounts that are not zero within some tolerance (1.0e-5).

Row number	$ Amount
1	1.00E-05
4	1.00E-05
9	383557
10	1509766
11	1.00E-05
12	1.00E-05
15	1.00E-05
17	1.00E-05
18	1.00E-05
19	1.00E-05
24	1.00E-05
25	1.00E-05
26	1.00E-05
28	1.00E-05
31	1.00E-05
32	1.00E-05
33	1.00E-05
40	1.00E-05
42	1.00E-05
43	1.00E-05
45	1.00E-05
48	144129.8
49	1.00E-05
50	1.00E-05
51	1.00E-05
55	1.00E-05
57	1.00E-05
58	1.00E-05
64	1.00E-05
65	1.00E-05
69	1.00E-05
71	1.00E-05
72	1.00E-05
75	1.00E-05
76	1.00E-05
78	1.00E-05
85	1.00E-05

87	1.00E-05
91	1.00E-05
93	562369.9
95	1.00E-05
97	1.00E-05
100	1.00E-05
104	1.00E-05
105	1.00E-05
108	1.00E-05
110	1.00E-05
111	1.00E-05
114	1.00E-05
115	1.00E-05
116	1.00E-05
117	1.00E-05
123	1.00E-05
137	1.00E-05
144	1.00E-05
151	1.00E-05
154	1.00E-05
155	1.00E-05
160	1.00E-05
161	1588501
162	1.00E-05
163	1.00E-05
165	1.00E-05
166	1.00E-05
169	1.00E-05
170	1.00E-05
171	1.00E-05
172	1.00E-05
175	1.00E-05
176	1.00E-05
184	828984.2
192	1.00E-05
196	1.00E-05
200	1.00E-05
203	1.00E-05
205	1.00E-05
210	1.00E-05
212	1524380
213	1.00E-05
216	1.00E-05

221	1.00E-05
222	1.00E-05
227	1.00E-05
228	1.00E-05
229	1.00E-05
230	1.00E-05
232	1.00E-05
234	1.00E-05
235	1.00E-05
236	1.00E-05
238	1.00E-05
242	1.00E-05
244	1.00E-05
245	58648
249	1.00E-05
253	1.00E-05
259	1.00E-05
262	1.00E-05
266	1.00E-05
270	1.00E-05
271	1.00E-05
277	1.00E-05
283	1.00E-05
284	1.00E-05
287	1.00E-05
290	1.00E-05
291	1.00E-05
293	1.00E-05
294	1.00E-05
295	1.00E-05
297	1.00E-05
298	1.00E-05
299	1.00E-05
303	1.00E-05
305	1.00E-05
306	1.00E-05
307	1.00E-05
309	1.00E-05
313	1.00E-05
314	1.00E-05
315	1.00E-05
317	1.00E-05
320	1.00E-05

321	1.00E-05
322	1.00E-05
323	1.00E-05
324	1.00E-05
326	1.00E-05
330	1.00E-05
332	1.00E-05
334	1.00E-05
336	1.00E-05
339	1.00E-05
340	1.00E-05
341	1.00E-05
342	1.00E-05
347	1.00E-05
350	1.00E-05
351	1.00E-05
354	1.00E-05
357	619933.9
360	1.00E-05
361	1.00E-05
364	1.00E-05
365	1.00E-05
368	1.00E-05
372	1.00E-05
374	1.00E-05
376	1.00E-05
380	1.00E-05
388	1.00E-05
389	1.00E-05
392	1.00E-05
406	1.00E-05
409	1.00E-05
411	1.00E-05
412	1.00E-05
414	1.00E-05
415	1.00E-05
419	1.00E-05
421	1.00E-05
424	1.00E-05
425	1.00E-05
428	1.00E-05
429	1.00E-05
436	1.00E-05

441	1.00E-05
443	1.00E-05
446	1.00E-05
447	1.00E-05
450	1.00E-05
454	1.00E-05
457	1.00E-05
458	1.00E-05
461	1.00E-05
462	1.00E-05
463	1.00E-05
466	1.00E-05
468	1.00E-05
469	1.00E-05
472	1.00E-05
473	1.00E-05
475	1.00E-05
478	1.00E-05
487	1.00E-05
490	1.00E-05
491	1.00E-05
496	1.00E-05
500	1.00E-05
501	1.00E-05
502	1.00E-05
503	1.00E-05
504	1.00E-05
505	1.00E-05
507	1.00E-05
508	1.00E-05
513	1.00E-05
515	1.00E-05
517	1.00E-05
518	1.00E-05
523	1.00E-05
524	1.00E-05
525	1.00E-05
526	1.00E-05
532	1.00E-05
534	1.00E-05
536	1.00E-05
537	1.00E-05
538	1.00E-05

541	1.00E-05
542	1.00E-05
543	1.00E-05
545	1.00E-05
546	1.00E-05
552	1.00E-05
560	1.00E-05
561	1.00E-05
562	1.00E-05
563	1.00E-05
567	1.00E-05
575	1.00E-05
576	1.00E-05
580	1.00E-05
581	1.00E-05
584	1.00E-05
589	1.00E-05
592	1.00E-05
594	1.00E-05
601	1.00E-05
609	1.00E-05
612	1.00E-05
624	1.00E-05
625	1.00E-05
626	1.00E-05
628	1.00E-05
630	1.00E-05
632	1.00E-05
636	1.00E-05
640	1.00E-05
642	1.00E-05
643	1.00E-05
649	1.00E-05
652	1.00E-05
653	1.00E-05
654	1.00E-05
658	1.00E-05
659	1.00E-05
670	1.00E-05
672	1.00E-05
673	1.00E-05
674	1.00E-05
677	1.00E-05

678	1.00E-05
679	1.00E-05
680	1.00E-05
683	1.00E-05
684	1.00E-05
686	1.00E-05
690	3298120
692	1.00E-05
699	1.00E-05
701	1.00E-05
703	1.00E-05
704	1.00E-05
705	1.00E-05
706	1.00E-05
708	1.00E-05
709	1.00E-05
712	1.00E-05
713	1.00E-05
715	1.00E-05
729	1.00E-05
732	1.00E-05
739	1.00E-05
742	1.00E-05
747	1.00E-05
752	1.00E-05
754	1.00E-05
757	1.00E-05
759	1.00E-05
760	1.00E-05
761	1.00E-05
769	1.00E-05
771	1.00E-05
775	1.00E-05
778	1.00E-05
781	1.00E-05
785	1.00E-05
788	1.00E-05
790	1.00E-05
791	1.00E-05
792	1.00E-05
794	1.00E-05
798	1.00E-05
799	1.00E-05

800	1.00E-05
801	1.00E-05
804	1.00E-05
807	1.00E-05
808	1.00E-05
810	1.00E-05
811	1.00E-05
814	1.00E-05
817	1.00E-05
818	1.00E-05
820	1.00E-05
821	4812881
823	1.00E-05
824	1.00E-05
826	1.00E-05
828	1.00E-05
829	1.00E-05
830	1.00E-05
834	1.00E-05
835	1.00E-05
836	1.00E-05
837	1.00E-05
841	1.00E-05
845	1.00E-05
847	1.00E-05
848	1.00E-05
853	1.00E-05
858	1.00E-05
860	1.00E-05
862	1.00E-05
876	1.00E-05
880	1.00E-05
883	1.00E-05
889	1.00E-05
890	1.00E-05
894	1.00E-05
904	1.00E-05
905	1.00E-05
910	1.00E-05
912	1.00E-05
914	1.00E-05
917	1.00E-05
925	1.00E-05

926	1.00E-05
928	1.00E-05
929	1.00E-05
931	1.00E-05
934	1.00E-05
939	1.00E-05
941	1.00E-05
942	1.00E-05
944	1.00E-05
946	1.00E-05
948	1.00E-05
950	1.00E-05
952	1.00E-05
954	1.00E-05
955	1.00E-05
960	1.00E-05
961	1.00E-05
962	1.00E-05
965	1.00E-05
969	1.00E-05
975	1.00E-05
976	1.00E-05
978	1.00E-05
984	1.00E-05
985	1.00E-05
989	1.00E-05
992	1.00E-05
1000	1.00E-05
1001	1.00E-05
1002	1.00E-05
1005	1.00E-05
1006	1.00E-05
1013	1.00E-05
1016	1.00E-05
1018	1.00E-05
1019	1.00E-05
1023	1.00E-05
1024	1.00E-05
1026	1.00E-05
1028	1.00E-05
1029	1.00E-05
1031	1.00E-05
1034	1.00E-05

1035	1.00E-05
1036	1.00E-05
1037	1.00E-05
1039	1.00E-05
1040	1.00E-05
1047	1.00E-05
1052	1.00E-05
1056	1.00E-05
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3258	1.00E-05
3260	1.00E-05
3263	1.00E-05
3264	1.00E-05
3266	1.00E-05
3275	1.00E-05
3280	1.00E-05
3281	1.00E-05
3282	1.00E-05
3284	1.00E-05
3290	1.00E-05
3294	1.00E-05
3295	1.00E-05

3296	1.00E-05
3297	1.00E-05
3304	1.00E-05
3317	1.00E-05
3325	1.00E-05
3333	1.00E-05
3334	1.00E-05
3335	1.00E-05
3340	1.00E-05
3343	1.00E-05
3345	1.00E-05
3346	1.00E-05
3347	1.00E-05
3348	1.00E-05
3349	1.00E-05
3350	1.00E-05
3354	1.00E-05
3356	1.00E-05
3359	1.00E-05
3361	1.00E-05
3364	1.00E-05
3366	1.00E-05
3369	1.00E-05
3371	1.00E-05
3376	1.00E-05
3377	1.00E-05
3378	1.00E-05
3379	1.00E-05
3385	1.00E-05
3387	1.00E-05
3393	1.00E-05
3394	1.00E-05
3396	1.00E-05
3399	1.00E-05
3400	1.00E-05
3403	1.00E-05
3405	1.00E-05
3407	687904
3414	1.00E-05
3422	1.00E-05
3425	1.00E-05
3427	1.00E-05
3428	1.00E-05

3429	1.00E-05
3430	1.00E-05
3433	381100
3434	1.00E-05
3438	1.00E-05
3439	228680.3
3445	1.00E-05
3447	490176
3448	1.00E-05
3452	1.00E-05
3453	1.00E-05
3455	1100604
3456	1.00E-05
3463	1.00E-05
3464	1.00E-05
3466	1.00E-05
3469	1.00E-05
3473	1.00E-05
3476	1.00E-05
3477	1.00E-05
3483	1.00E-05
3484	1.00E-05
3485	1.00E-05
3486	1.00E-05
3492	1.00E-05
3493	1.00E-05
3494	1.00E-05
3499	1.00E-05
3502	1.00E-05
3503	1.00E-05
3505	1.00E-05
3506	1.00E-05
3508	1.00E-05
3510	1.00E-05
3513	1.00E-05
3515	1.00E-05
3517	1.00E-05
3519	1.00E-05
3524	1.00E-05
3525	1.00E-05
3526	1.00E-05
3529	1.00E-05
3530	1.00E-05

3531	1.00E-05
3532	1.00E-05
3534	1.00E-05
3538	1.00E-05
3539	1.00E-05
3546	1.00E-05
3556	1.00E-05
3567	1.00E-05
3568	1.00E-05
3573	1.00E-05
3577	1.00E-05
3584	1.00E-05

Code for extra credit problem 2

```
# Steve CVXR

## include libraries

library(tidyverse)

library(CVXR)

library(Matrix)

library(glpkAPI)


## set folders and files

workingFolder <- "C:\\Users\\rohan\\Documents\\UW\\CFRM-507\\2022\\project1"

#benchmarkDataFileName <- "BenchmarkData_Small.csv"

#portfolioDataFileName <- "PortfolioHoldings_Small.csv"

benchmarkDataFileName <- "BenchmarkData.csv"

portfolioDataFileName <- "PortfolioHoldings.csv"


#######

##

##  Rework the data to calculate all the necessary values

##

#######
```

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```
## Read in raw data

benchmark_df <- read.csv(file.path(workingFolder,benchmarkDataFileName))

portfolio_df <- read.csv(file.path(workingFolder,portfolioDataFileName))


## parameters

redemptionAmount <- 15000000

#redemptionAmount <-  1.40428e+07

#redemptionAmount <- 1000

DevMkts <- c("Australia","Austria", "Belgium", "Denmark", "Finland",

        "France", "Germany", "Italy", "Netherlands", "Norway",

        "Spain", "Sweden", "Switzerland",  "United Kingdom", "Canada",

        "Japan")


######

## Parse benchmark data and add new values to benchmark_df data frame

######

benchmark_df$SecurityIndex <- 1:dim(benchmark_df)[1]

benchmark_df$Market <- ifelse(benchmark_df$Country %in% DevMkts,"Developed","EM")

uniqueMarkets <- unique(benchmark_df$Market)

uniqueMarkets <- data.frame(Market = uniqueMarkets) %>%

  arrange(Market) %>%

  mutate(MarketIndex = row_number())


uniqueCountries <- unique(benchmark_df$Country)

uniqueCountries <- data.frame(Country = uniqueCountries) %>%

  arrange(Country) %>%

  mutate(CountryIndex = row_number())
```

```
uniqueCapTiers <- unique(benchmark_df$Cap.Tier)

uniqueCapTiers <- data.frame(Cap.Tier = uniqueCapTiers) %>%

  arrange(Cap.Tier) %>%

  mutate(CapTierIndex = row_number())


uniqueSectors <- unique(benchmark_df$Sector)

uniqueSectors <- data.frame(Sector = uniqueSectors) %>%

  arrange(Sector) %>%

  mutate(SectorIndex = row_number())


benchmark_df <- left_join(benchmark_df, uniqueMarkets, by = c("Market"))

benchmark_df <- left_join(benchmark_df, uniqueCountries, by = c("Country"))

benchmark_df <- left_join(benchmark_df, uniqueCapTiers, by = c("Cap.Tier"))

benchmark_df <- left_join(benchmark_df, uniqueSectors, by = c("Sector"))


benchmark_df$MarketCap <- as.numeric(gsub(",","",benchmark_df$Market.Cap..US))

totalMarketCap <- sum(benchmark_df$MarketCap)


benchmark_df$Weight <- benchmark_df$MarketCap / totalMarketCap


#####

## Calculate weights for sectors, cap tiers, markets, countries

#####


SectorWeight_df <- benchmark_df %>%

  group_by(Sector) %>%

  summarize(Weight = sum(Weight)) %>%

  ungroup()

SectorWeight_df <- left_join(SectorWeight_df,uniqueSectors)
```

```
CapTierWeight_df <- benchmark_df %>%
  group_by(Cap.Tier) %>%
  summarize(Weight = sum(Weight)) %>%
  ungroup()
CapTierWeight_df <- left_join(CapTierWeight_df, uniqueCapTiers)

MarketWeight_df <- benchmark_df %>%
  group_by(Market) %>%
  summarize(Weight = sum(Weight)) %>%
  ungroup()
MarketWeight_df <- left_join(MarketWeight_df, uniqueMarkets)

CountryWeight_df <- benchmark_df %>%
  group_by(Country) %>%
  summarize(Weight = sum(Weight)) %>%
  ungroup()
CountryWeight_df <- left_join(CountryWeight_df, uniqueCountries)

benchmark_df <- left_join(benchmark_df, CountryWeight_df, by = c("Country","CountryIndex"))

colnames(benchmark_df)[which(colnames(benchmark_df) == "Weight.x")] = "Weight"
colnames(benchmark_df)[which(colnames(benchmark_df) == "Weight.y")] = "CountryWeight"

## Set transaction costs
benchmark_df$tcost <- ifelse(benchmark_df$CountryWeight > 0.02,0.0008, 0.002)

######
```

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```
## Parse portfolio data and add new values to portfolio_df data frame

######


portfolio_df$InvestmentIndex <- 1:dim(portfolio_df)[1]


uniqueInvestments <- unique(portfolio_df$Identifier)


portfolio_df <- left_join(portfolio_df, benchmark_df %>%
select("Identifier","Current.Price","SecurityIndex","tcost"))


portfolio_df$Value <- portfolio_df$Current.Price * portfolio_df$Number.of.Shares


portfolio_df$GainLossCoef <- ((1 - portfolio_df$tcost) * portfolio_df$Current.Price -
portfolio_df$Purchase.Price) /
  ((1- portfolio_df$tcost) * portfolio_df$Current.Price)


totalPortfolioValue <- sum(portfolio_df$Value)


#######
##
##  Build matrices needed to specify optimization problem in CVXR
##
#######


# create variables to hold dimensions of matrices
numSecurity <- dim(benchmark_df)[1]
numSector <- dim(SectorWeight_df)[1]
numInvestment <- dim(portfolio_df)[1]
numCapTier <- dim(CapTierWeight_df)[1]
```

```
numCountry <- dim(CountryWeight_df)[1]

numMarket <- dim(MarketWeight_df)[1]


##  Create indicator matrices


Sector <- as.matrix(sparseMatrix(as.vector(benchmark_df$SecurityIndex),
                     as.vector(benchmark_df$SectorIndex),
                     x=rep(1,numSecurity)))


CapTier <- as.matrix(sparseMatrix(as.vector(benchmark_df$SecurityIndex),
                      as.vector(benchmark_df$CapTierIndex),
                      x = rep(1,numSecurity)))


Market <- as.matrix(sparseMatrix(as.vector(benchmark_df$SecurityIndex),
                     as.vector(benchmark_df$MarketIndex),
                     x = rep(1,numSecurity)))


Country <- as.matrix(sparseMatrix(as.vector(benchmark_df$SecurityIndex),
                      as.vector(benchmark_df$CountryIndex),
                      x = rep(1,numSecurity)))


Stock <- as.matrix(sparseMatrix(as.vector(c(portfolio_df$SecurityIndex,numSecurity)),
                    as.vector(c(portfolio_df$InvestmentIndex,numInvestment)),
                    x = c(rep(1,numInvestment),0)),
            nrow = numSecurity, ncol = numInvestment)


## Construct matrices to hold other model data


Value <- as.matrix(portfolio_df$Value, ncol = 1)
```

```
SectorWeight <- as.matrix(SectorWeight_df$Weight, ncol = 1)

CapTierWeight <- as.matrix(CapTierWeight_df$Weight, ncol = 1)

MarketWeight <- as.matrix(MarketWeight_df$Weight, ncol = 1)

CountryWeight <- as.matrix(CountryWeight_df$Weight, ncol = 1)

Cost <- as.matrix(portfolio_df$Purchase.Price, ncol = 1)

investmentPrice <- as.matrix(portfolio_df$Current.Price, ncol = 1)

securityPrice <- as.matrix(benchmark_df$Current.Price, ncol = 1)

investmenttcost <- as.matrix(portfolio_df$tcost, ncol = 1)

securitytcost <- as.matrix(benchmark_df$tcost, ncol = 1)

gain_loss_coef <- as.matrix(portfolio_df$GainLossCoef, ncol = 1)

#CVXR constraints
X <- Variable(numSecurity)
P <- Variable(numSecurity)
S <- Variable(numInvestment)
W <- Variable(1)
NG <- Variable(1)
NL <- Variable(1)
isHeld = Variable(numSecurity, boolean=TRUE)
```

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```
sector_range <- 0.05

market_range <- 0.08

captier_range <- 0.1


# W Definition constraint

constraint_W_defn <- W == sum(X)


# Budget constraint

constraint_budget <- redemptionAmount + t(1+securitytcost) %*% P ==

  t(1-investmenttcost) %*% S


# Loss limit constraint

constraint_loss_limit <- NL <= 0.1 * W


# Gain loss constraint

constraint_gain_loss <- t(gain_loss_coef) %*% S == NG - NL


# Sector weights

constraint_sector_weight_lower <- (1 - sector_range) * SectorWeight * W <= t(Sector) %*% X

constraint_sector_weight_upper <- (1 + sector_range) * SectorWeight * W >= t(Sector) %*% X


# Market weights

constraint_market_weight_lower <- (1 - market_range) * MarketWeight * W <= t(Market) %*% X

constraint_market_weight_upper <- (1 + market_range) * MarketWeight * W >= t(Market) %*% X


# Cap Tier weights

constraint_captier_weight_lower <- (1 - captier_range) * CapTierWeight * W <= t(CapTier) %*% X

constraint_captier_weight_upper <- (1 + captier_range) * CapTierWeight * W >= t(CapTier) %*% X
```

```
# Security inventory

constraint_security_inventory <- Stock %*% Value + P - Stock %*% S == X


constraint_non_negative_X <- X >= 0


constraint_non_negative_P <- P >= 0


constraint_non_negative_S <- S >= 0


constraint_limit_sales <- S <= Value


constraint_non_negative_gains <- NG >= 0


constraint_non_negative_losses <- NL >= 0


#new constraints

BigM <- sum(portfolio_df$Value * 10)

ct_4 = isHeld >= (1/BigM) * X

ct_5 = isHeld <= BigM * X


#construct constraints list

constraints <- list(constraint_W_defn,

                    #constraint_budget,

                    #constraint_loss_limit,

                    #constraint_gain_loss,

                    constraint_sector_weight_lower,

                    constraint_sector_weight_upper,

                    constraint_market_weight_lower,
```

```
            constraint_market_weight_upper,
            constraint_captier_weight_lower,
            constraint_captier_weight_upper,
            constraint_non_negative_X,
            constraint_non_negative_P,
            constraint_non_negative_S,
            constraint_limit_sales,
            constraint_non_negative_gains,
            constraint_non_negative_losses,
            constraint_security_inventory,
            ct_4, ct_5)

#####
##
##  Solve with CVXR
##
#####
#objective <- t(securitytcost) %*% P + t(investmenttcost) %*% S + 0.15 * NG
objective = sum(isHeld)
prob <- Problem(Minimize(objective), constraints)

CVXR::installed_solvers()
#result <- solve(prob)
result <- solve(prob, verbose = TRUE, solver = "GLPK")
#result <- solve(prob, solver = "SCS")
#result <- solve(prob, num_iter = 1000, solver = "ECOS_BB")

result$status
result$value
```

```
# extract solution values

X_cvxr <- result$getValue(X)

P_cvxr <- result$getValue(P)

S_cvxr <- result$getValue(S)

W_cvxr <- result$getValue(W)

#NG_cvxr <- result$getValue(NG)

#NL_cvxr <- result$getValue(NL)
```