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Financial Risk Management

Project Part 1 Report

Abstract

In this report for Part 1 of the term project for Financial Risk Management, I will discuss each given question (research topic) by suggesting recommendations about their experimentation (wherever appropriate and applicable), followed by a quick summary of their goals and briefly explain the methodologies applied to analyze them. I will then report and summarily describe the empirical results obtained from each experiment. Lastly in the appendix, I will provide detailed analysis and supporting discussion for each of the research experiments. Finally, wherever applicable, I will compare across the different variants of experiments conducted and how their analyses could be improved from a robust risk management standpoint.

Arbitrage (Q1)

Goal of the research experiment: Calculation of spot and 1-year forward prices for 10 securities (4 currencies, 1 commodity (gold), 4 government bills and 1 equity).

Methodologies Applied:

(a) Spot Price Calculation – Interconvert using given conversion rates across different securities, and using transitive nature of relationship to convert across those securities whose relationships weren't explicitly given. Furthermore, used the fact that there is a unit spot conversion factor between the same securities. Represented the spots as a 10x10 matrix with each index corresponding to one security (e.g. index 0 corresponded to USD, index 9 corresponded to S&P 500, etc.).
E.g. of transitive relation: SecurityA_to_SecurityC = SecurityA_to_SecurityB * SecurityB_to_SecurityC.

(b) Forward Price Calculation – Spot Currency rates were used along with interest rates to calculate currency foreign exchange forward rates. S&P 500 spot price was used along with present liability (via dividends) and combined with USD's interest rate to provide a forward value. Gold spot price was discounted with holding cost for the year to calculate the 1-year forward. Government bills were discounted with their corresponding currencies' risk-free interest rate. Similar to Spot Price calculations, there was a unit forward conversion factor between the same securities. Finally, transitive relationships were used to calculate forwards between the other inexplicitly related securities. Represented the forwards as a 10x10 matrix with each index corresponding to one security (same as Spot Price).

Research Goals:

- Calculate spot price across 10 different securities belonging to different asset classes
- Calculate 1-year forward price across 10 securities belonging to different asset classes
- Apply No Arbitrage Theorem to determine spot and forward values

Empirical Results: The following is the calculated Spot Prices and Forward Prices represented as individual 10x10 matrices.
(*Notation* – Index0: USD, Index1: GBP, Index2: EU, Index3: RMB, Index4: Gold, Index5: U.S. Government Bill, Index6: German Government Bill, Index7: U.K. Government Bill, Index8: Chinese Government Bill, Index9: S&P 500)

Spot Price Matrix -

```
[[ 1.00000000e+00  7.46937556e-01  8.44309355e-01  6.58000000e+00
   7.91765637e-04  1.00000000e+00  8.44309355e-01  7.46937556e-01
   6.58000000e+00  3.74293521e-03]
 [ 1.33880000e+00  1.00000000e+00  1.13036136e+00  8.80930400e+00
   1.06001584e-03  1.33880000e+00  1.13036136e+00  1.00000000e+00
   8.80930400e+00  5.01104166e-03]
 [ 1.18440000e+00  8.84672841e-01  1.00000000e+00  7.79335200e+00
   9.37767221e-04  1.18440000e+00  1.00000000e+00  8.84672841e-01
   7.79335200e+00  4.43313246e-03]
 [ 1.51975684e-01  1.13516346e-01  1.28314492e-01  1.00000000e+00
   1.20329124e-04  1.51975684e-01  1.28314492e-01  1.13516346e-01
   1.00000000e+00  5.68835138e-04]
 [ 1.26300000e+03  9.43382133e+02  1.06636272e+03  8.31054000e+03
   1.00000000e+00  1.26300000e+03  1.06636272e+03  9.43382133e+02
   8.31054000e+03  4.72732717e+00]
 [ 1.00000000e+00  7.46937556e-01  8.44309355e-01  6.58000000e+00
   7.91765637e-04  1.00000000e+00  8.44309355e-01  7.46937556e-01
   6.58000000e+00  3.74293521e-03]
 [ 1.18440000e+00  8.84672841e-01  1.00000000e+00  7.79335200e+00
   9.37767221e-04  1.18440000e+00  1.00000000e+00  8.84672841e-01
   7.79335200e+00  4.43313246e-03]
 [ 1.33880000e+00  1.00000000e+00  1.13036136e+00  8.80930400e+00
   1.06001584e-03  1.33880000e+00  1.13036136e+00  1.00000000e+00
   8.80930400e+00  5.01104166e-03]
 [ 1.51975684e-01  1.13516346e-01  1.28314492e-01  1.00000000e+00
   1.20329124e-04  1.51975684e-01  1.28314492e-01  1.13516346e-01
```

```
   1.00000000e+00   5.68835138e-04]
 [  2.67170000e+02   1.99559307e+02   2.25574130e+02   1.75797860e+03
    2.11536025e-01   2.67170000e+02   2.25574130e+02   1.99559307e+02
    1.75797860e+03   1.00000000e+00]]
```

Forward Price Matrix -

```
[[  1.00000000e+00   7.39788770e-01   8.26315194e-01   6.51702417e+00
    7.54062512e-04   9.86679822e-01   8.33063004e-01   7.36988215e-01
    6.49235323e+00   3.76043292e-03]
 [  1.35173720e+00   1.00000000e+00   1.11696099e+00   8.80930400e+00
    1.01929435e-03   1.33373182e+00   1.12608225e+00   9.96214385e-01
    8.77595537e+00   5.08311706e-03]
 [  1.21019195e+00   8.95286418e-01   1.00000000e+00   7.88685022e+00
    9.12560385e-04   1.19407198e+00   1.00816615e+00   8.91897209e-01
    7.85699365e+00   4.55084567e-03]
 [  1.53444267e-01   1.13516346e-01   1.26793330e-01   1.00000000e+00
    1.15706570e-04   1.51400363e-01   1.27828742e-01   1.13086617e-01
    9.96214385e-01   5.77016875e-04]
 [  1.32615000e+03   9.81070878e+02   1.09581789e+03   8.64255161e+03
    1.00000000e+00   1.30848545e+03   1.10476650e+03   9.77356921e+02
    8.60983424e+03   4.98689812e+00]
 [  1.01350000e+00   7.49775919e-01   8.37470449e-01   6.60500400e+00
    7.64242356e-04   1.00000000e+00   8.44309355e-01   7.46937556e-01
    6.58000000e+00   3.81119877e-03]
 [  1.20038940e+00   8.88034598e-01   9.91900000e-01   7.82296674e+00
    9.05168646e-04   1.18440000e+00   1.00000000e+00   8.84672841e-01
    7.79335200e+00   4.51398382e-03]
 [  1.35687380e+00   1.00380000e+00   1.12120544e+00   8.84277936e+00
    1.02316767e-03   1.33880000e+00   1.13036136e+00   1.00000000e+00
    8.80930400e+00   5.10243291e-03]
 [  1.54027356e-01   1.13947708e-01   1.27275144e-01   1.00380000e+00
    1.16146255e-04   1.51975684e-01   1.28314492e-01   1.13516346e-01
    1.00000000e+00   5.79209539e-04]
 [  2.65926828e+02   1.96729681e+02   2.19739379e+02   1.73305157e+03
    2.00525452e-01   2.62384636e+02   2.21533803e+02   1.95984939e+02
    1.72649090e+03   1.00000000e+00]]
```

Static Strategy Simulation of A Synthetic Bank (Q2)

Recommendations:

- Decision variable must be able to be varied based on spread
- Include more volatile asset classes for investments

Goals of the research experiment:

- Simulate various long/short and investment portfolio of a synthetic bank in different scenarios to calculate risk/rewards for each
- Optimize over decision variable (leverage factor) and/or weighted investments over different securities

Methodologies Applied:

(a) Decision variable y = 2 – For each month long 2 * capital (borrow) and short (2 * capital) in AGG bonds and T-Bills, respectively and invest the rest in T-Bills to calculate capital returns each month, and then calculate risk/reward metrics.

(b) Optimization over only Decision variable ‘y’ – Similar to above except perform a grid search over different values of y over a range (0 to 5 spaced at regular intervals) and brute-forcedly check for CVaR <= $200 Million and no red flags. Finally pick the ‘y’ that yields the best return.

(c) Optimization over only Decision variable ‘y’ and weights over 3 securities – Similar to (b) except introduce 3 weight variables all adding upto 1 spaced at regular intervals, and in conjunction with possible ‘y’ values perform a grid search over red flag constraints and pick the best returning portfolio.

Empirical Results and Observations:

(a) Decision variable y = 2 –

Number of red cards = 0
Number of yellow cards = 152
Number of inverted yields = 134
Annual geometric return (R) = 0.489173
Annualized volatility = 0.069215
Risk Free rate of return = 1.749596
Sharpe Ratio = -4.790879
Annualized downside variance = 0.068448

Sortino Ratio = -4.817674
Maximum DrawDown = 1309164328.331643
VaR = 70511.956637
CVaR = 65382.811719

(b) Optimization over only Decision variable ‘y’ –

Value of optimized decision variable (y) = 1.151151
Number of red cards = 0
Number of yellow cards = 119
Number of inverted yields = 134
Annual geometric return (R) = 0.877546
Annualized volatility = 0.005517
Risk Free rate of return = 1.749596
Sharpe Ratio = -11.740267
Annualized downside variance = 0.005466
Sortino Ratio = -11.795077
Maximum DrawDown = 1173949859.579548
VaR = 199172765.912113
CVaR = 194300775.372668

(c) Optimization over only Decision variable ‘y’ and weights over 3 securities –

Value of optimized decision variable (y) = 0.050505
Value of optimized weight variable for SP500 = 0.100000
Value of optimized weight variable for AGG = 0.100000
Value of optimized weight variable for TBill = 0.800000
Number of red cards = 0
Number of yellow cards = 0
Number of inverted yields = 134
Annual geometric return (R) = 1.555360
Annualized volatility = 0.021274
Risk Free rate of return = 1.749596
Sharpe Ratio = -1.331700

Annualized downside variance = 0.004787
Sortino Ratio = -2.807358
Maximum DrawDown = 4048618922.568420
VaR = 1431918291.274914
CVaR = 1371246808.793591

Observations:

- For highest annualized returns, optimization over weighed securities (S&P 500, AGG, T-Bills) combined with levered long-short portfolio is the best option
- Sharpe Ratio and Sortino Ratio was the highest for the above portfolio (also lowest volatility and downside variance)
- Last portfolio is the best capitalized (no yellow cards) but also very high VaR/CVaR
- Lowest Maximum Draw Down (MDD) for optimization of leverage factor achieved along with moderate annualized returns and Sharpe and Sortino Ratios
- For minimizing VaR/CVar, static leverage factor = 2 is the best portfolio
- Last portfolio produces the best overall returns, lowest volatility but highest MDD
- First portfolio is the worst capitalized, also leading to low VaR/CVaR – meaning it’s not necessarily that helpful from a bank investment point of view
- Diversifying investments and reducing leverage is clearly preferable

Dynamic Strategy Simulation of A Synthetic Bank (Q3)

Recommendations:

- Dynamic decision variable for leverage should be combined with investments over different asset classes instead of stable T-Bill to introduce diversity to investments

Goals of the research experiment:

- Dynamically change the decision variable for leverage based on spread (long returns – short liabilities) and see if a dynamic leverage outperforms the best static portfolio

Methodologies Applied:

- Similar to Static Simulation except that ‘y’ changes each month based on if the spread is positive or negative.
- If spread is positive, then y = 4 (expectation is that it is expected to continue so lever more)
- If spread is negative, change ‘y’ based on the ratio between asset returns and shorted liabilities, and leverage should be < 1.

Empirical Results and Observations:

Number of red cards = 0
Number of yellow cards = 0
Number of inverted yields = 134
Annual geometric return (R) = 1.588064
Annualized volatility = 0.036052
Risk Free rate of return = 1.749596
Sharpe Ratio = -0.850736
Annualized downside variance = 0.010104
Sortino Ratio = -1.606981
Maximum DrawDown = 79653527554.717957
VaR = 1371246808.793591
CVaR = 1309229711.143363

Observations:

- Clearly preferable over static strategy (High Sharpe/Sortino Ratios, high returns but higher volatility)
- Well capitalized to simulate banking liabilities (no yellow cards)
- CVaR decreased compared to best performing static strategy
- Extremely high MDD

Comparison with Commercial Banks (Q4)

Recommendations:

- A significant portion of the period was during the recession, and commercial banks (especially Citi) had very exposure to toxic assets, so the time frame could be properly weighed for normal vs crash vs growth scenarios

Goals of the research experiment:

- Compare returns of two commercial banks (Citi and BOA) over a 14-year span with the best strategy of our simulated bank

Methodologies Applied:

- Calculate monthly returns based on the monthly price information given for each bank – BOA and Citi
- Starting with capital of $1.3 Billion, and with the calculated monthly returns, simulate how much that capital would have yielded each month for both banks
- Calculate usual risk/reward measures and compare with our best static and dynamic strategies

Empirical Results and Observations:

(a) BOA –

Number of red cards = 0
Number of yellow cards = 0
Annual geometric return (R) = 0.997562
Annualized volatility = 0.004707
Risk Free rate of return = 1.749596
Sharpe Ratio = -10.961316
Annualized downside variance = 0.004354
Sortino Ratio = -11.396615
Maximum DrawDown = 515683891.247933
VaR = 990406457.020483
CVaR = 979467126.455483

(b) Citi –

Number of red cards = 0
Number of yellow cards = 122
Annual geometric return (R) = 0.647956
Annualized volatility = 0.288612
Risk Free rate of return = 1.749596
Sharpe Ratio = -2.050609
Annualized downside variance = 0.210363
Sortino Ratio = -2.401901
Maximum DrawDown = 2256595550.869646
VaR = 1961767.656650
CVaR = 1848801.540885

Observations:

- Citi was not very well-capitalized during this period (122 yellow cards) and had higher volatility than BOA (VaR/CVaR numbers high)
- Citi also suffered a high MDD compared to BOA
- BOA performed better on average than Citi, but still lagged behind both best performing static and dynamic strategies of our simulated bank
- BOA was relatively stable with very low volatility during this period

Appendix

Salient Points from Observations:

- Dynamic strategy was clearly the best performing strategy for our bank model
- Both dynamic strategy and best static strategy (diversified investments with static leverage factor) beat out both commercial banks in terms of annualized returns
- Sharpe and Sortino Ratios were negative since none of the strategies (or commercial banks) were able to beat risk-free rate of return
- Dynamicity and diversification led to better capitalization and no yellow cards. On the contrary, static strategies without diversification led to extremely high chances of getting a yellow card
- AGG bonds being stable and less volatile (to cancel out shorted T-Bills which are also stable and less volatile) led to capital growth under the risk-free rate
- With more volatile security to long we would potentially see more capital growth (to beat risk-free rate), therefore to simulate a real bank, we should hold more assets that are more risk-rewarding in nature
- The most volatile security (S&P 500) was only weighed for 10% of the portfolio along with relatively stable T-Bills and AGG bonds, which implied that our annualized returns weren't boosted with high performing stocks as much as we would've liked
- Our simulated bank strategies (dynamic and best static) clearly outperformed both commercial banks – BOA and Citi. This could've been due to the period in time in which those banks' returns were considered, having been during a recession
- Therefore, the we should go short on Citi and go long on our dynamic strategy

Limitations of the Previous Analysis (and steps to provide robust recommendations):

- *Tail Risk Measures Not Considered* – The objective was to maximize returns but we didn't minimize (from portfolio theory) risk measures such as VaR/CVaR/variance. Thus, our CVaRs were high for higher returning strategies. We should take tail risk into consideration while testing out robust strategies.
- *Behavior under different scenarios of different regimes not considered (Modeling Uncertainty)* – We didn't simulate probabilistically determined behavior under multiple regimes, which should be essential to stress test a bank's capital returns and retention.
- *Asset Liability Management not considered* – We did not consider the dynamic cash outflows that occur in each period and the liabilities that accumulate due to them to manage our bank's strategy.