Long/Short Global Macro Strategies with Target Beta Using the 3-Factor Model

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ABSTRACT

In this project we construct a Long/Short Global Macro Strategy based on French Fama 3-Factor Model with a Target Beta and evaluate its sensitivity to variation of Beta and its sensitivity to the length of the estimation for covariance matrix and the expected returns under different market scenario. Several comparisons are drawn between different target betas as well as different term structures.

THEORY

FAMA FRENCH 3-FACTOR MODEL

Historically, French Fama 3-Factor Model is regarded as a development of CAPM which explains a relationship between expected returns and risk factors. Sharpe, Lintner, and Black developed an asset pricing model referred as CAPM which illustrates expected returns on the securities are a positive linear function of market beta. The CAPM, developed theoretically, had an empirical success, and became the standard model for describing the cross-sectional structure of expected returns on equity. However, some researchers revealed there were some anomalies that cannot be explained by the CAPM. Banz found the market equity had a relationship between expected returns. Stocks with smaller market equity had higher rates of return, usually referred to as the small cap effect. Bhandari found leverage helps explain the cross-section of average stock returns. Stattman, Rosenberg, Reid and Lanstein found that average returns on U.S stocks were positively related to the ratio of a firm's book value of common equity to its market value.
In response to this criticism, Eugene Farmer, and Kenneth French, in a paper published in 1992, empirically showed that the four representative anomaly factors discovered at the time in the U.S. stock market: market equity, book-to-market ratio, leverage, and E/P (the inverse of P/E ratio), were aggregated into market equity and book-to-market ratio.
They advanced their study and proposed French Fama 3-factor model which describes a cross section of average stock returns with three factors, market risk premium, market equity, and book-to-market ratio.

Under the Farmer-French 3-factor model, the random return of security is given by the following formula

$$r_i - r_f = \alpha_i + \beta_i^{MKT}(r_m - r_f) + \beta_i^{SMB} r_i^{SMB} + \beta_i^{HML} r_i^{HML} + \epsilon_i \quad (1)$$

With $E[\epsilon_i] = 0$, $E[r_i] = R_i$, $E[r_m] = R_m$, $E[r_i^{SMB}] = R_{SMB}$, $E[r_i^{HML}] = R_{HML}$, expected return on a security can be written as

$$R_i - r_f = \alpha_i + \beta_i^{MKT}(R_M - r_f) + \beta_i^{SMB} R_{SMB} + \beta_i^{HML} R_{HML} \quad (2)$$

Where r_i is a random return on a security, r_f is a risk-free rate, r_M is a market return, and three βs, β_i^{MKT}, β_i^{SMB}, β_i^{HML} is a sensitivity measure for risk premium of market portfolio, risk factor of market equity, and risk factor of book-to-market ratio, respectively.

MARKOWITZ PORTFOLIO

Markowitz portfolio theory also known as modern portfolio theory is a theory on how risk-averse investors can construct portfolio to maximize expected return based on a given level of market risk. The theory can also be used to construct a portfolio that minimize risk for a given level of expected return. In mathematical format:

$$\min_{\omega} \omega^T \Sigma \omega \quad (3)$$

Subject to

$$e^T \omega = 1 \quad (4)$$

$$\rho^T \omega = \rho_T$$

Where ω is a vector of weights of securities, Σ is a covariance matrix , ρ is an expected return, ρ_T is a target return.

LINEAR REGRESSION

An approach for predicting a quantitative response Y n the basis of multiple predictor variable X_j that assume an approximately linear relationship between X_j and Y. For a model with p predictors, the linear regression takes the form

$$Y = \beta_0 + \sum_{j=1}^{p} \beta_j X_j + \varepsilon \quad (5)$$

with X_j is the j th predictor and β_j qualifies the relationship between that predictor and the response. Given estimates for $\beta's$, it can make predictors using the model

$$\hat{f}(X) = \hat{\beta}_0 + \sum_{j=1}^{p} \hat{\beta}_j X_j \quad (6)$$

where we estimate these parameters by minimizing the residual sum of squares

$$RSS = \sum_{i=1}^{n} (y_i - \hat{\beta}_0 - \sum_{j=1}^{p} \hat{\beta}_j X_j)^2 \quad (7)$$

INVESTMENT UNIVERSE AND BACKTESTING

DATA

We used the 12 ETFs belowfrom March 1, 2007 to June 30, 2020:

1. CurrencyShares Euro Trust (FXE)
2. iShares MSCI Japan Index (EWJ)
3. SPDR GOLD Trust (GLD)
4. PowerShares NASDAQ-100 Trust (QQQ)
5. SPDR S&P 500 (SPY)
6. iShares Lehman Short Treasury Bond (SHV)
7. PowerShares DB Agriculture Fund (DBA)
8. United States Oil Fund LP (USO)
9. SPDR S&P Biontech (XBI)
10. iShares S&P Latin America 40 Index (ILF)
11. iShares MSCI Pacific ex-Japan Index Fund (EPP)
12. SPDR DJ Euro Stoxx 50 (FEZ)

The S&P 500 (SPY) was chosen to be the analysis benchmark. Lastly, the data used to construct the French Fama 3-Factor Model is quoted from Ken French's website for the factors' historical values.

INVESTMENT HORIZON

The investment horizon was divided into the following sub-periods:

1. Pre-Subprime Crisis : March 22, 2007 – March 3, 2008
2. During Subprime Crisis : March 3, 2008 – September 10, 2010
3. Post-Subprime Crisis : September 10, 2010 – January1, 2015
4. Pre-COVID-19 Pandemic : January 1, 2015 – March 9, 2020
5. During COVID-19 Pandemic : March 9, 2020 – October 30, 2020

BACKTESTING

Individual backtests were executed for each sub-period to compare strategies. We compared with different perspectives.

(1) Impact on Beta Target

Compared our strategy in terms of target beta in the same sub-period. Changed target beta β_T^m ,and compare performance.

(2) Impact of various term structure given Beta

Compare portfolios' performance with different term structures and fixed beta. S_j^i represents a term structure with i days lookback period to estimate the expected return and j days lookback period to estimate the covariance matrix.

We also ran a backtest on whole period from March 1st, 2007 to November 30th, 2020.

INVESTMENT STRATEGY

OBJECTIVE FUNCTION

We considered the following investment strategy:

$$\max_{\omega} \rho^T \omega - \lambda(\omega - \omega_p)^{\mathrm{T}} \Sigma (\omega - \omega_p) \tag{8}$$

with constraints

$$\sum_{i=1}^{n} \beta_i^m \omega_i = \beta_T^m \tag{9}$$

$$\sum_{i=1}^{n} \omega_i = 1$$

where

- ω_i : weight allocated to each security S_i, and ω is a vector of weights.
- ρ : a vector of expected returns of security S_i
- Σ : the covariance matrix between securities returns derived from the Factor model
- ω_p : composition of a reference Portfolio, the previous portfolio when rebalancing the portfolio.
- λ : small regularization parameter to limit turnover.
- $\beta_i^m = \frac{cov(r_i, r_M)}{\sigma^2(r_M)}$: the Beta of security S_i defined in the CAPM model.
- β_T^m : the Portfolio's Target Beta

TERM STRUCTURE

We analyzed the following combinations of term structures and Target Beta

$$\boxed{S_{60}^{60}, \quad S_{120}^{60}, \quad S_{60}^{90}, \quad S_{120}^{90}, \quad S_{60}^{120}, \quad S_{120}^{120}}$$

TARGET BETA

$$\boxed{\beta_T^m = \{-1.0, -0.5, 0.5, 1.0, 1.5, 2.0\}}$$

PERFORMANCE AND RISK METRICS

We introduced the following metrics to compare portfolio performance and the degree of risk. We assumed that each year has 250 trading days in annualizing the metrics.

PERFORMANCE METRICS

- Cumulated Return
- Annual Arithmetic Mean / Geometric Mean Return
- Annual Min Return
- Max 10-days Drawdown
- Sharpe Ratio

RISK METRICS

- Volatility
- Daily VaR
- Annual VaR
- Modified VaR
- Annual CVaR
- Skewness
- Kurtosis

RESULTS & DISCUSSION

1. The evolution the graph of cumulated daily Profit and Loss as summing that investing \$100 at the first allocation date

PRE-SUBPRIME CRISIS

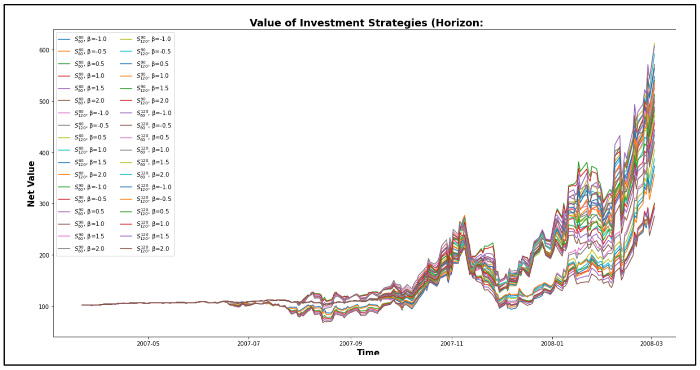

Figure 1: the evolution of cumulated daily profit and loss for several portfolio strategies (Pre-Subprime Crisis)

DURING THE SUBPRIME CRISIS

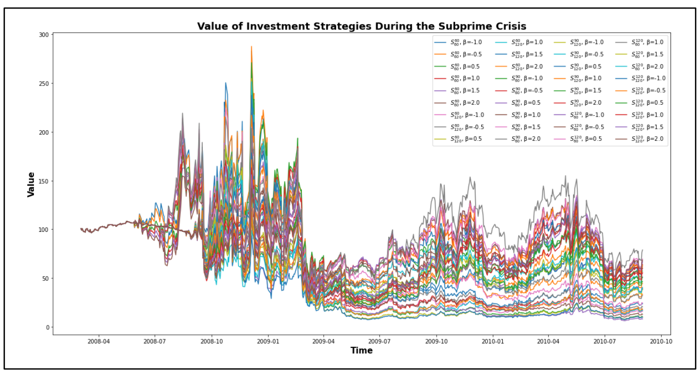

Figure 2: the evolution of cumulated daily profit and loss for several portfolio strategies (During Subprime Crisis)

POST-SUBPRIME CRISIS

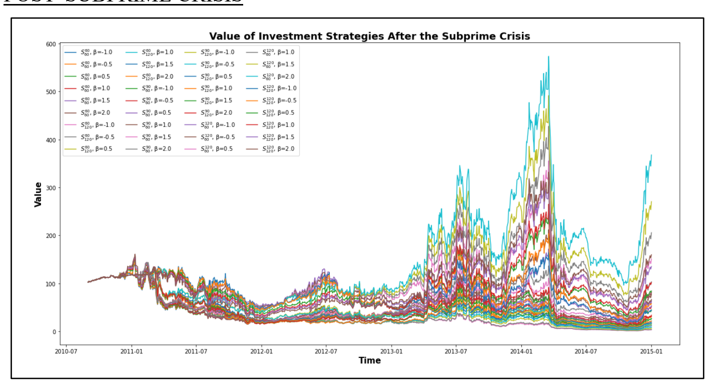

Figure 3: the evolution of cumulated daily profit and loss for several portfolio strategies (Post-Subprime Crisis)

2. The distribution of daily returns

   The following plots shows the distribution of daily returns for different term structures and βs.

PRE-SUBPRIME CRISIS

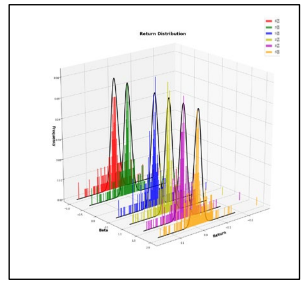

Figure 2: Distribution of daily returns of S_{120}^{60}

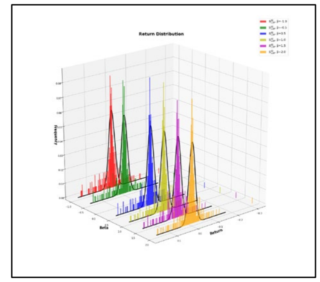

Figure 3: Distribution of daily returns of S_{180}^{120}

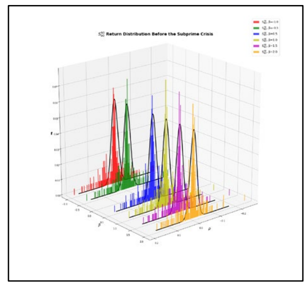

Figure 4: Distribution of daily returns of S_{60}^{90}

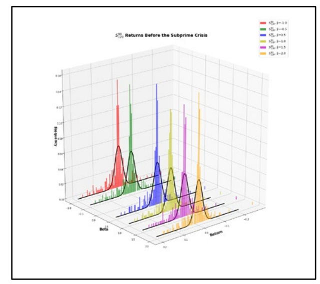

Figure 5: Distribution of daily returns of S_{90}^{120}

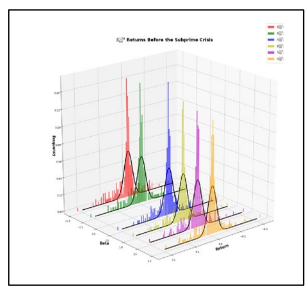

Figure 6: Distribution of daily returns of S_{60}^{120}

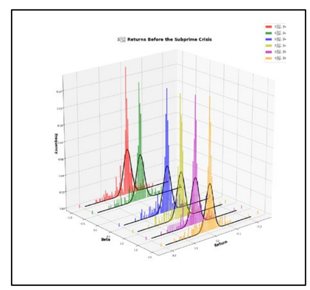

Figure 7: Distribution of daily returns of S_{120}^{120}

DURING THE SUBPRIME CRISIS

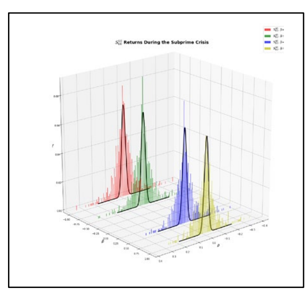

Figure 8: Distribution of daily returns of S_{60}^{60}

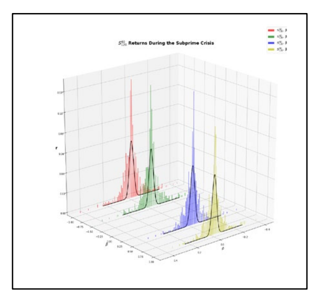

Figure 9: Distribution of daily returns of S_{120}^{60}

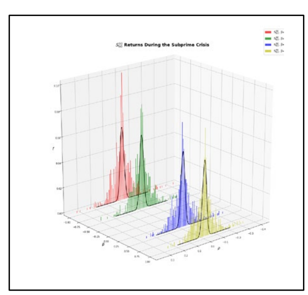

Figure 10: Distribution of daily returns of S_{60}^{90}

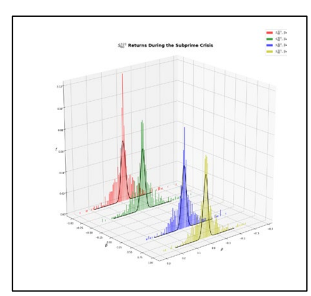

Figure 11: Distribution of daily returns of S_{60}^{120}

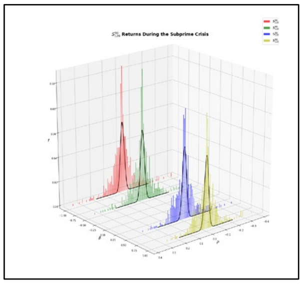

Figure 12: Distribution of daily returns of S_{120}^{90}

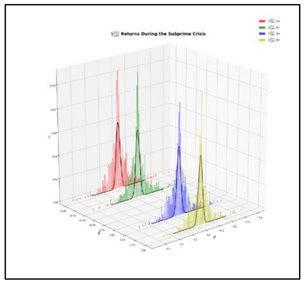

Figure 13: Distribution of daily returns of S_{120}^{120}

POST-SUBPRIME CRISIS

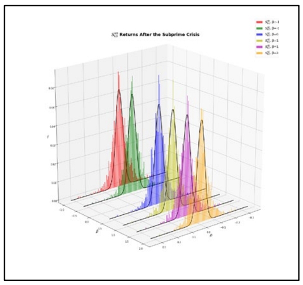

Figure 8: Distribution of daily returns of S_{60}^{60}

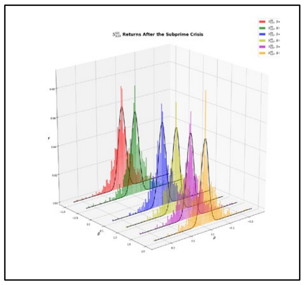

Figure 9: Distribution of daily returns of S_{120}^{60}

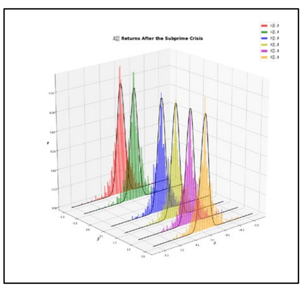

Figure 10: Distribution of daily returns of S_{60}^{90}

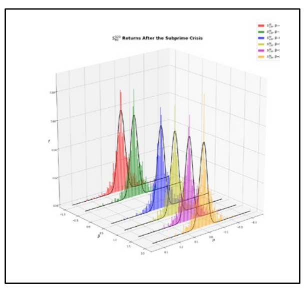

Figure 11: Distribution of daily returns of S_{60}^{120}

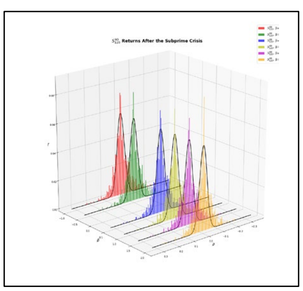

Figure 12: Distribution of daily returns of S_{120}^{90}

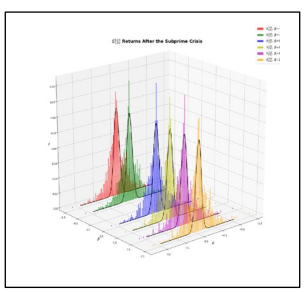

Figure 13: Distribution of daily returns of S_{120}^{120}

3. Comparison of Strategies' Performances and Risks

PRE-SUBPRIME CRISIS

	S^{60}_{60}	S^{60}_{60}	S^{60}_{60}	S^{60}_{60}	S^{60}_{60}
	b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5
Cumulative Retur	3.059205985	3.081321058	3.16764738	3.148573233	3.05535464
Arithmetic Mean	1.430535253	1.428158112	1.456647015	1.458701647	1.440967544
Geometric Mean	1.120659676	1.127895088	1.155652021	1.149584422	1.119394302
Minimum Return	-48.83840363	-51.74100659	-57.66398254	-60.79549784	-63.98607051
Max 10-day Draw	-0.391930965	-0.380802512	-0.388444368	-0.397330812	-0.408050737
Volatility	0.783470291	0.771841236	0.77330038	0.78306201	0.797308992
Sharpe Ratio (An	1.749313624	1.772590072	1.806086033	1.786195256	1.732035581
Kurtosis (Annual)	2.671660638	2.871352927	3.309651591	3.486483111	3.665251128
Skew (Annual)	-0.266302475	-0.217475953	-0.157197155	-0.186647367	-0.265033171
mVaR (Annual)	-121.4241148	-118.1544941	-116.2385365	-118.1703528	-122.036226
VaR (Daily)	-7.578202071	-7.458176245	-7.461960113	-7.562688179	-7.717992723
VaR (Annual)	-119.8218956	-117.9241206	-117.9839488	-119.5765994	-122.0321798
CVaR (Annual)	-185.3463123	-180.0890892	-173.613375	-172.9619153	-174.5969195

S^{60}_{60}	S^{60}_{120}	S^{60}_{120}	S^{60}_{120}	S^{60}_{120}	S^{60}_{120}	S^{60}_{120}
b=2.0	b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5	b=2.0
2.88671202	4.763655869	4.641068117	4.316501371	4.118971066	3.95995084	3.784849721
1.402733898	1.838293468	1.800437066	1.720329603	1.677896642	1.647417965	1.616517311
1.062369026	1.565899111	1.539666305	1.466731051	1.419618832	1.380026599	1.334555634
-66.91239929	-59.14503136	-62.41248699	-68.02648987	-70.81029961	-73.65016449	-76.42408315
-0.420012938	-0.408999286	-0.403340177	-0.432832307	-0.449173715	-0.460061372	-0.469785139
0.818596069	0.736046902	0.719265241	0.706720221	0.711639348	0.722346708	0.73999293
1.64028872	2.416005642	2.419743046	2.349344979	2.273478337	2.19758455	2.103421869
3.731237668	4.659022829	5.619442397	7.586033536	8.419232669	9.051449144	9.340491442
-0.354200361	-0.149465981	-0.202746483	-0.369181242	-0.467388015	-0.573926573	-0.673638248
-127.6605003	-105.6183933	-102.854593	-101.7810788	-103.513833	-106.5391867	-111.0846721
-7.954734955	-6.921754802	-6.762318289	-6.663855833	-6.732002537	-6.855582323	-7.051515663
-125.7754032	-109.4425529	-106.9216403	-105.3648122	-106.4423062	-108.3962741	-111.4942523
-179.5031853	-172.8771152	-163.6015061	-152.9097175	-155.0407518	-160.855593	-168.7887498

S^{90}_{60}	S^{90}_{60}	S^{90}_{60}	S^{90}_{60}	S^{90}_{60}	S^{90}_{60}
b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5	b=2.0
5.834096838	5.794680044	5.523133627	5.243235478	4.949420195	5.065401914
2.076362498	2.057051915	1.996141314	1.943887602	1.893664258	1.935427672
1.769955539	1.763128429	1.714799706	1.662441809	1.604396694	1.627709474
-46.42882951	-48.40894043	-53.83163583	-57.0775576	-59.61845878	-61.36623631
-0.335482173	-0.31127374	-0.269592549	-0.270161892	-0.287010607	-0.299318482
0.782054738	0.766324288	0.749684577	0.748717188	0.75781389	0.780997447
2.578288196	2.606014118	2.582607905	2.516153805	2.419676233	2.401323692
3.047975526	3.23558494	3.449706396	3.703163614	3.870756943	3.833075526
-0.100261157	-0.071056913	-0.067743684	-0.143030641	-0.223163579	-0.255358547
-112.9081229	-109.5759472	-106.9054834	-108.2787619	-111.4894334	-115.753987
-7.305145221	-7.149226097	-7.000487954	-7.01132573	-7.126047757	-7.350520188
-115.5044877	-113.0391899	-110.6874333	-110.8587936	-112.6727081	-116.2219289
-177.7330548	-172.2675424	-165.7228636	-165.4976608	-168.9593156	-172.3898209

S^{90}_{120}	S^{90}_{120}	S^{90}_{120}	S^{90}_{120}	S^{90}_{120}	S^{90}_{120}
b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5	b=2.0
6.653586457	6.415397612	5.915453932	5.669198802	5.528830905	5.377405857
2.185875215	2.135668325	2.043030081	2.002105108	1.982496161	1.963963851
1.902357444	1.865627672	1.783902739	1.741082537	1.715837778	1.687878425
-53.0903808	-55.74351525	-60.8825934	-63.48497224	-66.08957435	-68.6880563
-0.333759522	-0.321362243	-0.295086086	-0.282511673	-0.301971356	-0.318686654
0.755008452	0.736426478	0.719888351	0.721388915	0.727970198	0.73916845
2.815697242	2.818568299	2.754635604	2.692174867	2.640899539	2.575818612
4.011748934	4.629678788	5.864857331	6.368497081	6.690569907	6.982901774
0.13430224	0.121245201	0.039461914	-0.033993729	-0.113247009	-0.219250767
-101.3426673	-98.18534887	-96.1598143	-97.41963829	-99.69882483	-103.2848437
-6.979978492	-6.806753573	-6.671763268	-6.703743584	-6.780052037	-6.903960015
-110.3631503	-107.6242238	-105.4898397	-105.9954929	-107.2020355	-109.1611926
-164.7556352	-157.2458244	-147.8398086	-146.7178872	-148.608987	-153.852109

S^{120}_{60}	S^{120}_{60}	S^{120}_{60}	S^{120}_{60}	S^{120}_{60}	S^{120}_{60}
b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5	b=2.0
6.593016556	6.181021366	5.725363283	5.433898278	5.070811295	4.735962192
2.184269271	2.096665171	2.004819257	1.946144872	1.874604628	1.80853377
1.89314299	1.828135277	1.751009589	1.69839992	1.628783763	1.560032161
-46.4496443	-46.33935516	-48.42707049	-50.23370872	-52.43881076	-54.32456455
-0.323798139	-0.301006577	-0.26772317	-0.254271424	-0.24176717	-0.235686522
0.765958254	0.735850316	0.715493901	0.706830015	0.703172578	0.705820439
2.773348626	2.767771008	2.718149315	2.668456111	2.580596405	2.477306797
3.747228452	4.185084256	5.119768102	5.27548932	5.246680937	5.188328668
0.193009594	0.228596023	0.277290651	0.282788911	0.206150682	0.105290715
-102.1260933	-96.707492	-91.87315826	-90.64153619	-92.18352007	-95.14151935
-7.094531309	-6.816361043	-6.64133228	-6.574671906	-6.565239809	-6.619213758
-112.1743893	-107.7761313	-105.0086835	-103.9546904	-103.8055559	-104.658959
-173.304635	-164.1940538	-157.5045009	-153.4631766	-151.9304986	-155.3029975

S^{120}_{120}	S^{120}_{120}	S^{120}_{120}	S^{120}_{120}	S^{120}_{120}	S^{120}_{120}	SPY
b=-1.0	b=-0.5	b=0.5	b=1.0	b=1.5	b=2.0	
6.0938863	5.800365502	5.176351992	4.892516087	4.744144629	4.485051749	0.964412341
2.096576313	2.027689962	1.891994238	1.836191775	1.813920231	1.768169502	-0.021356888
1.813834358	1.764116017	1.649518563	1.592759023	1.561769172	1.505263562	-0.03623371
-47.72926669	-49.20107634	-52.35153712	-54.72030433	-57.10126549	-59.46562173	-7.408435644
-0.326741916	-0.312174507	-0.284386724	-0.270850117	-0.26270685	-0.260931	-0.074810431
0.754964147	0.728849546	0.698353059	0.698927286	0.71082329	0.724709088	0.172296237
2.697580173	2.699720366	2.623306671	2.541311251	2.467449021	2.357041648	-0.4721919
4.384091045	5.041310821	6.255009432	6.642518352	6.892797617	6.767124314	0.472457853
0.234184878	0.251717726	0.23339572	0.179284696	0.152295173	0.066082901	-0.277512626
-99.13768138	-94.34386968	-89.38283429	-90.37688512	-92.45191576	-96.75683945	-29.64524056
-7.01523715	-6.77112234	-6.50814666	-6.536441309	-6.669103676	-6.831857471	-1.800934954
-110.9206386	-107.0608445	-102.902834	-103.3502116	-105.4477878	-108.0211513	-28.47528186
-166.9619167	-158.1509072	-147.2696124	-148.2404085	-152.2498555	-157.5936754	-40.17965124

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