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EXPLORATORY STATISTICAL ANALYSIS OF STOCK PRICES OF MAJOR ENERGY FIRMS OF INDIA AND APPLICATION TO SIMULATION-BASED EQUITY PORTFOLIO OPTIMIZATION

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Abstract: India's energy sector comprises several large public enterprises working with different primary energy forms like coal, crude oil and natural gas as well as involved in thermal and renewable technology development and electricity production. This study looks at the equity market performance of 10 Indian firms with 5 equity market indices as the benchmarks, over the last one decade, using their weekly stock prices or index values as the primary input data set. Depending on choice of market index, the cost of capital for the chosen energy firms is seen to lie between 7.55% to 19.02% p.a. for the studied firms, while the market indices have shown returns between 13.4-15.6% p.a. Using security level data and estimated risk-free rates, portfolio optimization studies are performed to identify the best combinations of these 10 securities to minimize portfolio performance metrics like risk to return ratio and maximize indicators like Sharpe, Treynor ratios and Jensen alpha value. It is seen that 3 to 4 securities make up the largest share of these portfolios while the rest get very small allocations. The optimal portfolios have returns between 24-38% p.a. with risk lying between 15-31% p.a.

Keywords: Cost of equity; energy firms; equity portfolio; optimization; stock prices;

JEL Classification: C4, C8, G1

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1. INTRODUCTION

1.1. Infrastructure Finance and Equity Capital Markets

Energy consumption is a key indicator of a nation's state of welfare and development **(Tiwari et al, 2021)**. India's energy consumption landscape is evolving in response to her clean energy transition commitments, for mitigation of climate change. India targets to achieve net zero emissions by 2070 for which the energy sector must be restructured extensively. This massive reshaping of the energy system naturally entails huge capital investment on energy demand and supply sides, energy transmission infrastructure and in new technologies like energy storage, EV charging, water electrolysers and carbon capture **(EY, 2025)**.

One notable feature is that many of the clean energy technologies are front loaded when it comes to capital investment, which means that a very significant part of the cash flows associated with such energy projects will occur in the very initial phases of the projects. The running costs of most of them will make up a much smaller part of their life cycle cash flows. Thus, the profitability and feasibility of such projects will be very sensitive to the cost of capital employed for the project.

Typically, most infrastructure projects including energy projects use a mixture of debt and equity capital deployed in a suitable ratio. The weighted average cost of capital or *WACC* for a project is defined as

$$WACC = \frac{D}{D+E} \times (1-t) \times k_D + \frac{E}{D+E} \times k_E \tag{1}$$

where, D and E refer to market values of debt and equity finance components used in the project, t is the prevailing tax rate, and k_D and k_E are the costs of debt finance and equity finance used for the project, respectively **(Damodaran, 2015)**. While in the financing of most energy infrastructure projects, the share of debt capital remains high and thus governs the overall *WACC* for the project, the role of equity cannot be undermined as the cost of equity is much higher than the cost of debt. In addition, for projects in sectors with substantial encouragement to private sector participation and for those involving emerging companies and novel technologies, it may not be possible to secure debt at low cost due risk perception; thus, equity from project developers or venture capitalists may be required to deploy them. Cost of equity capital is also used as one of the inputs to evaluate tariffs from various public sector projects, such as power tariffs from electricity generation projects.

This study therefore focuses on equity cost trends based on equity or stock price characteristics of major Indian energy sector firms (which are mostly large cap firms based on their current market capitalization). These are firms which have already created many significant energy infrastructure projects in the nation. Their performance and expectations of equity returns are analysed vis-à-vis the performance of the equity markets in general, for which the values of the market indices are used as the proxies. The estimated equity returns characteristics are further used in portfolio optimization case studies. Thus, this work addresses security analysis and portfolio analysis in an integrated manner, with specific reference to Indian equity markets and the energy sector companies to assess cost of equity characteristics of energy projects in the country.

1.2. Literature Review and Motivation for the Study

A limited number of studies on equity characteristics of Indian energy firms and energy infrastructure projects have been reported in literature. For example, the general trends in infrastructure finance in India have been elucidated and compared with other economies in the Asia-Pacific region; the cost of debt is seen to be around 9% p.a. and for equity it is about 15.5% p.a. **(Srivastava, 2021)**. Using firm level stock price data (from 2019 to 2024)and 3 equity pricing models, the cost of equity for regulated infrastructure projects, including energy sector projects in India has been estimated to be 10.1%-12.1% by CAPM, 9.9-18.5% p.a. by Fama-French 3-factor model and 7.025-19.03% by Fama-French 5-factor model, against returns on equity of 12-16% p.a. **(Singh et al, 2022)**. Sectoral average costs of equity and debt capital have been summarized in a research report which finds that for the power sector, weighted average cost of equity has been about 14-14.3% p.a. (based on analysis of 10 listed companies) and for general infrastructure sector, it has been about 15.8-15.9% p.a. (using data from 10 listed firms) **(RBSA Advisors, 2023)**. The differences in equity returns estimation using different models like CAPM, Fama-French 3 factor model and Carhart 4-factor model have been evaluated with respect to 489 Indian firms across all major sectors using monthly data from January 2012 to December 2019 **(Unni and Santhosh Kumar, 2023)**.

They find that CAPM gives the highest average cost of equity but with smallest standard deviation in the estimates. For the energy sector (in which 27 firms were considered), the three models find that the cost of equity lies between 9.07-18.55% p.a., 4.06-18.27% p.a. and 1.06-24.61% p.a. respectively, with the mean cost being about 13-13.5% from all models. A more recent cost of capital assessment for Indian firms to help initial studies on infrastructure project valuation has been performed for the period 2014 to 2024 and it finds that for power and utilities sector, the cost of equity has been in the range of 12.5-15.6% p.a., while for the infrastructure sector, it has been 13-16.8% p.a. **(EY and NSE, 2024)**.

This current work is motivated by the extending the previous studies for the following main objectives:

(i) Understanding the nature of equity returns distributions of major energy firms operating in India across various segments of the energy business landscape over a reasonably long time-horizon of about a decade, including the most recently available data points (i.e., covering various kinds of business cycles and economic shocks),

(ii) Evaluating cost of equity for these firms using individual security level data and studying the impact of choice of market portfolio on the results, thus helping to provide related inputs for forward looking analyses of energy project feasibility in India, where the cost of capital needs to be calculated as part of life cycle costing and valuation of energy projects

(iii) Assessing the cumulative risk-return performance of a portfolio of energy company stocks with respect to various objective functions based on measures of risk-adjusted financial performance

2. DATA AND MATHEMATICAL MODELLING

2.1. Description of Data Sets

In this study, 10 major Indian energy companies are selected for stock price analysis based on their market capitalization and to cover major sectors of the energy industry such as coal, petroleum products, natural gas, and renewable energy (hydel power, wind energy, etc). The list of selected firms is provided in Table 1. Five equity market indices, comprising of generic and sectoral indices relevant to energy are also selected to be used as proxies for the market portfolio and market returns estimation, for stock performance comparison and cost of equity estimation. This list is provided in Table 2. The weekly stock price/market index value data from January 2016 to September 2025 (which translates into approximately 509 data points on prices/values per stock or index) are used for analysis in this work. The weekly returns are converted to annualized returns for the purpose of reporting and portfolio optimization studies.

The stocks of the energy companies in Table 1 are serially identified using the symbols S1 to S10 in all subsequent analyses. The market indices in Table 2 are sequentially identified using the symbols M1 to M5 in all subsequent analyses.

Table 1: List of Indian energy companies chosen for analysis

Serial No	*Name of firm*	*Symbol used in this study*
1	Adani Industries	S1
2	Adani Green Energy	S2
3	Coal India Limited	S3
4	Gas Authority of India Ltd	S4
5	Indian Oil Corporation	S5
6	JSW Energy	S6
7	National Hydro Power Corporation	S7
8	Reliance Industries	S8
9	Suzlon India	S9
10	Tata Power	S10

Table 2: Indian equity market indices chosen for analysis

Serial No	*Name of market index*	*Symbol used in this study*
1	NIFTY 50	M1
2	NIFTY COMMODITIES	M2
3	NIFTY ENERGY	M3
4	BSE OIL AND GAS	M4
5	BSE POWER	M5

2.2. Assessment of cost of equity for the energy companies

The following evaluations are first performed for each of the 10 energy firms to determine their respective costs of equity using 5 different market indices as proxy for the market portfolio for comparison:

(i) Weekly stock price data collection from open platforms like Yahoo Finance and/or Investing.com for the period January 2016 to September 2025

(ii) Calculation of log returns based on the collected sample of weekly stock prices

Log returns for any given stock are defined as in Eqn. 2, based on the two consecutive price data points **(Bodie et al, 2014)**

$$r_t = \ln \frac{P_t}{P_{t-1}} \tag{2}$$

(iii) Determination of the distributional characteristics of the log returns from stock price or index values using the mean and variance

The mean of the log returns or expected returns over *n* time periods for a given stock or index is calculated as

$$\overline{r} = \frac{1}{n} \Sigma_{t=1}^{n} r_t \tag{3}$$

The variance of returns of the stock or index is calculated as

$$\sigma^2 = \frac{1}{n-1} \Sigma_{t=1}^{n} (r_t - \overline{r})^2 \tag{4}$$

The stock's risk is calculated as the standard deviation of the log returns, i.e., as the square root of the value obtained in Eqn. 4.

(iv) Evaluation of pair-wise stock price correlations with respect to each of the chosen firms

The linear correlation coefficient between the log returns of two stocks *S1* and *S2* over *n* time periods is calculated as **(Bodie et al, 2014)**

$$\rho_{S1,S2} = \frac{Cov(S1, S2)}{\sigma_{S1}\sigma_{S2}} \tag{5}$$

The beta of a stock *S1* relative to a market index or portfolio *M* is calculated as the slope of the regression line between stock returns and market returns using Eqn. 6 **(Bodie et al, 2014)**

$$\beta_{S1,M} = \frac{Cov(S1, M)}{\sigma_M^2} \tag{6}$$

With 10 securities and 5 market indices considered in this work, the 10 X 10 correlation coefficient matrix of the 10 stocks with 100 elements in it and the 10 X 1 vector of beta values for each index-stock combination (i.e., a total of 50 values of beta for 10 stocks and 5 indices) have been evaluated.

(v) Estimation of cost of equity for each firm using the Capital Asset Pricing Model (CAPM)

According to this model, the cost of equity k_e from stock *S1* based on the market index *M* and the risk-free rate r_F is calculated as **(Bodie et al, 2014)**

$$k_e = r_F + \beta_{S1,M}[E(r_M) - r_F] \quad (7)$$

Thus, with 10 stocks and 5 indices, a total of 50 cost of equity data points are derived in this study.

2.3. Equity portfolio optimization studies based on multiple metrics

When the cost of equity has been determined for each of the firms using each of the given indices, the equity portfolio optimization studies are carried out next. This involves:

(vi) Simulation based identification of optimal portfolio composition using the chosen 10 firms, using the mean-variance portfolio optimization framework of Markowitz (**Bodie et al, 2014**). This is a quadratic optimization problem which generally requires a complex algorithm for solution. However, this work uses a much simpler and faster simulation-based approach towards the solution. The portfolio optimization problem and the simulation algorithm to identify the optimal equity portfolios comprising 10 Indian energy firm stocks is described below.

For a portfolio of *N* equity assets (*N* = 10 in this study as the portfolio consists of 10 stocks of major Indian energy firms), with each asset making up w_1, w_2....w_N fraction of the total portfolio and each asset's log returns being r_1, r_2....r_N, the expected portfolio return is given by **(Elton et al, 2014)**

$$r_P = \Sigma_{i=1}^{N} W_i r_i \quad (8)$$

For this portfolio, the portfolio risk is measured in terms of the variance of its log returns and it is given by **(Elton et al, 2014)**

$$\sigma_P^2 = \Sigma_{i=1}^{N} w_i^2 + \Sigma_{i=1}^{N} \Sigma_{j=1}^{N} \quad w_i w \sigma_i \sigma_j \rho_{ij} \quad (9)$$

The portfolio beta is calculated as a weighted average sum of the individual stock betas (which are in turn defined with respect to a given market portfolio as the benchmark) as follows **(Bodie et al, 2014)**:

$$\beta_P = \Sigma_{i=1}^{N} \beta_i w_i \tag{10}$$

The portfolio optimization problem therefore is to determine the optimal set of values of w_1, w_2....w_N needed to attain a given objective regarding portfolio performance, such as minimization of the performance indicators like the portfolio risk to return ratio, and maximization of indicators like portfolio Sharpe ratio, Treynor ratio or Jensen's alpha ((**Bodie et al, 2014**)). These ratios are defined as follows:

$$Risk\,to\,return = \frac{\sigma_P}{r_P} \tag{11}$$

$$Share = \frac{r_P - r_F}{\sigma_P} \tag{12}$$

$$Treynor = \frac{r_P - r_F}{\beta_P} \tag{13}$$

$$Jensen\,alpha = r_P - [r_F + (E(r_M) - r_F)\beta_P] \tag{14}$$

The significance of these ratios in the evaluation of investment portfolios has been discussed extensively in literature (**Bodie et al, 2014; Elton et al, 2014**).

For portfolio optimization, a vector of values of w_1 to w_{10} is first generated using a random sampling process, since N = 10 in this work (i.e., 10 energy companies are taken as part of the equity portfolio). This is done by calling the random number generator 10 times, to get ten random numbers, RV_1 to RV_{10}. The portfolio weights to be given to each of the ten stocks are then calculated as in Eqn. 15:

$$w_i = RV_k / \Sigma_k{}^{10} RV_i, for\, k = 1\ to\ 10 \tag{15}$$

Each such vector of values of w_1 to w_{10} represents one portfolio of stocks. The individual stock characteristics like annualized log returns and returns variance are used to determine the values of the corresponding portfolio returns, risk and beta (using Eqns. 8, 9 and 10) based on the sampled values of w_1 to w_{10}. This process is repeated multiple times to simulate the creation of various equity portfolios. Once the portfolios are constructed, the corresponding performance indicators like risk, returns and beta values are estimated and the values of the objective functions are calculated for each of them from Eqns. 11-14. In this study, 50000 equity portfolios are simulated at once, and for each of them, the values of all four performance metrics are calculated. Out of this collection of 50000 simulated portfolios, the one(s) with the lowest risk to return ratio or the highest Sharpe, or highest Treynor ratio or highest Jensen alpha are then identified in turn. It is evident that the optimal portfolios can be different, depending on the analyst's choice of the objective function, though it is also possible that the same portfolio out of the simulated collection will turn out to be the optimal one on more than one metric at a time. To implement this optimization algorithm, an in-house code has been developed and all results are generated using it.

The additional assumptions made for the equity portfolio optimization studies are as follows:

(i) The risk-free interest rate (for calculation of expected equity returns using CAPM, for example) is based on analysis of data on the annualized yield of 10-year government bonds issued in India over the same time horizon as has been used for the stock price data. This value (i.e., value of r_F is taken as 7.25% per annum throughout this study, based on analysis of the bond yield data available at Investing.com portal.

(ii) No short selling is allowed as part of portfolio creation, hence the portfolio weights w_1, $w_2 \ldots w_N$ are all positive, with each value lying between 0 and 1, and their summation is equal to unity. Thus, the constraints on w_i may be written as

$$0 \leq w_i \leq 1 \ and \ \Sigma_{i=1}^{N} w_i = 1 \tag{16}$$

(iii) Considering 52 weeks per annum, the weekly log returns on the stock prices or market indices are annualized using the expression

$$r_{ann} = \left(1 + r_{weekly}\right)^{52} - 1 \tag{17}$$

(iv) Similarly, the variance of the weekly log returns is annualized using the expression

$$\sigma_{aan} = \sigma_{weekly} \times \sqrt{52} \tag{18}$$

3. RESULTS AND ANALYSES

3.1. Stock Price and Returns Analysis

The main results of the individual stock price analysis are presented in this section. Figs. 1 to 5 and Table 3 present these quantitative findings and inferences drawn from each of them is discussed next. Figs. 1a and 1b are the raw data sets about energy company stock prices and equity market index values respectively. Figs. 2a and 2b show the calculated values of the log returns on the stock prices and market indices for the 10 firms and 5 indices studied in this work, using Eqn. 2. The log return data sets are seen to be much closer approximations to a stationary time series than the raw price data for the stocks or indices. Fig. A1 in the Appendix section also presents the data in Fig. 2a in the form of histograms of stock returns to enable better visualization of their statistical distributional properties. Fig. A2 of the Appendix also presents the corresponding histograms of market returns data for the 5 indices.

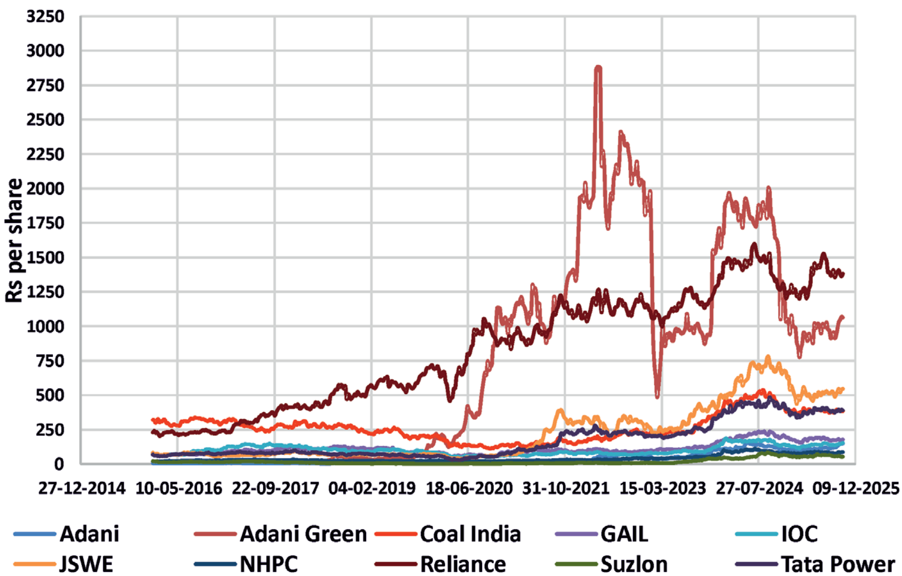

Fig. 1a: Weekly stock prices from January 2016 to September 2025

Table 3 presents the calculated key statistics from the log returns data in Fig. 2. It is seen that the typical market returns have been between 11.3 to 15.6% p.a., with volatilities varying from 15.7 to 22.7% p.a. These figures are therefore taken as benchmark performance indicators of the equity markets in India during the study period in this work. With reference to the firm-specific performance, there is a much wider range of log returns (1.86% to 65.1% p.a.) and returns volatility (26% to 65.3% p.a.) seen in the values. Firm S2 shows the highest returns and highest volatility out of all 10 firms considered, whereas firm S3 shows lowest returns and highest volatility to returns or risk to return ratios. Volatilities of the returns of all firms has naturally been much higher than that of the market indices, showing that the indices are indeed quite well diversified compared to the individual energy sector stocks themselves.

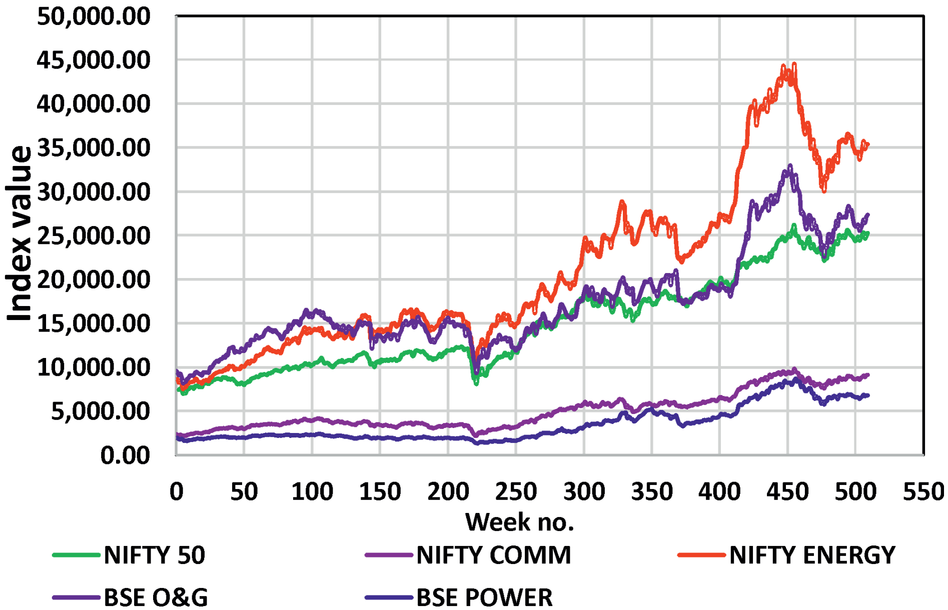

Fig. 1b: Weekly market index values of major equity indices in India from January 2016 to September 2025

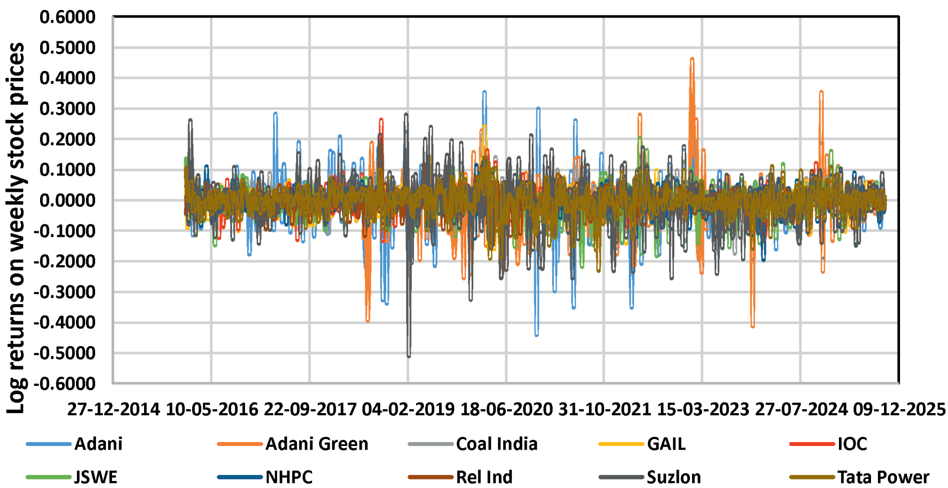

Fig. 2a: Weekly log stock returns from January 2016 to September 2025

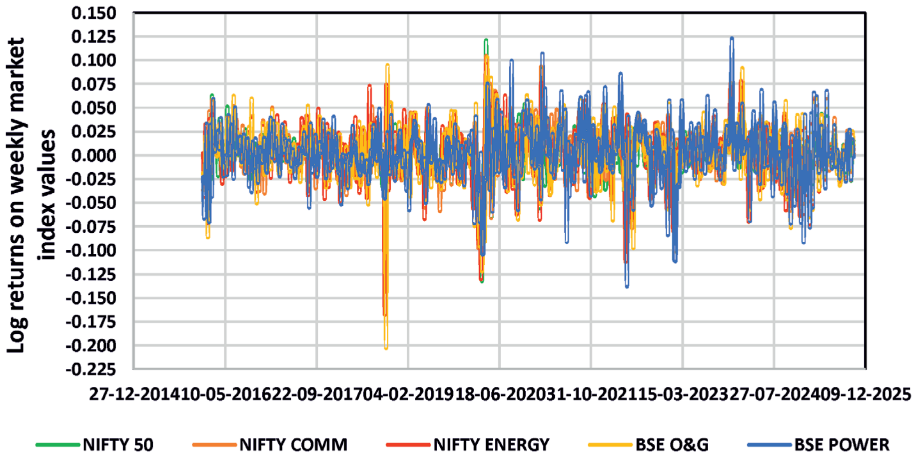

Fig. 2b: Weekly log market returns on major equity market indices from January 2016 to September 2025

Table 3: Annualized stock price and market returns for selected firms and indices in India

Stock	*Annualized returns (%)*	*Volatility (%)*	*Market index*	*Annualized returns (%)*	*Volatility (%)*
S1	37.24	58.78	M1	13.38	15.67
S2	65.10	65.29			
S3	1.86	29.53	M2	14.66	19.63
S4	10.07	31.89			
S5	7.71	29.61	M3	15.55	20.56
S6	21.19	39.48			
S7	15.54	28.87	M4	11.32	21.96
S8	20.03	25.97			
S9	9.87	60.10	M5	13.44	22.56
S10	19.38	33.65			

Fig. 3 is a correlogram of the pair-wise linear correlation coefficients of the stock returns of the 10 firms. All correlation coefficients are found to be positive, with values ranging from 0.145 to 0.460. This shows low to moderate correlations in the firm performances in the equity markets. The data from Table 3, Fig. 3 and Eqn. 6 are further used to determine the values of beta in Fig. 4, which show how much more or less volatile the individual energy stock returns have been corresponding to the market index chosen as the reference value. The values range from 0.048 to 1.455. The values of beta derived with respect to indices M4 and M5 are consistently lower than that from any of the other three indices, for all the energy firm stocks. Firms S3, S5, S6, S7 and S8 show beta less than 1.00 for all choices of market indices/portfolios, showing that their stock price performance has consistently shown lower than market volatility over the study period, irrespective pf market benchmark chosen. The estimated cost of equity for these 10 firms as reported in Fig. 5 is seen to lie in the broad range of 7.55% to 19.02% p.a., depending on choice of market portfolio and for the risk-free rate of 7.25% in each case. These results are also validated by the previous estimates of the range of cost of equity for energy companies in India over different time frames, as discussed in Section 1.2. Therefore, these historical data-driven insights can be used as reliable inputs for valuation and feasibility studies involving large-scale energy projects in India in the near term.

	Adani	Adani Green	Coal India	GAIL	IOC	JSWE	NHPC	Rel Ind	Suzlon	Tata Power
Adani	1.0000	0.4604	0.2653	0.3386	0.2698	0.4193	0.3360	0.2888	0.2216	0.4500
Adani Green	0.4604	1.0000	0.1641	0.2297	0.2766	0.2249	0.2422	0.2343	0.1449	0.2531
Coal India	0.2653	0.1641	1.0000	0.4373	0.4613	0.3542	0.3564	0.2551	0.2344	0.4391
GAIL	0.3386	0.2297	0.4373	1.0000	0.5296	0.2879	0.3502	0.3141	0.2762	0.4582
IOC	0.2698	0.2766	0.4613	0.5296	1.0000	0.2471	0.3310	0.3375	0.2509	0.4387
JSWE	0.4193	0.2249	0.3542	0.2879	0.2471	1.0000	0.3256	0.2563	0.2630	0.4325
NHPC	0.3360	0.2422	0.3564	0.3502	0.3310	0.3256	1.0000	0.2096	0.2140	0.4307
Rel Ind	0.2888	0.2343	0.2551	0.3141	0.3375	0.2563	0.2096	1.0000	0.1554	0.2784
Suzlon	0.2216	0.1449	0.2344	0.2762	0.2509	0.2630	0.2140	0.1554	1.0000	0.3164
Tata Power	0.4500	0.2531	0.4391	0.4582	0.4387	0.4325	0.4307	0.2784	0.3164	1.0000

Fig. 3: Pair wise correlation coefficients of weekly log returns on stock prices of 10 Indian firms

3.2. Optimal equity portfolio composition analysis

Many objective functions can be defined to determine an optimal equity portfolio consisting of a mixture of stocks. This section presents the results of the optimization study for a combination of 10 Indian energy company stocks for 4 objective functions defined in Eqns. 11-14 in Section 2.

Fig. 6 shows the general risk return landscape for simulated portfolios of the 10 energy companies, with respect to NIFTY 50 as the market index or portfolio. The mean-variance frontier of the collection of portfolios can be

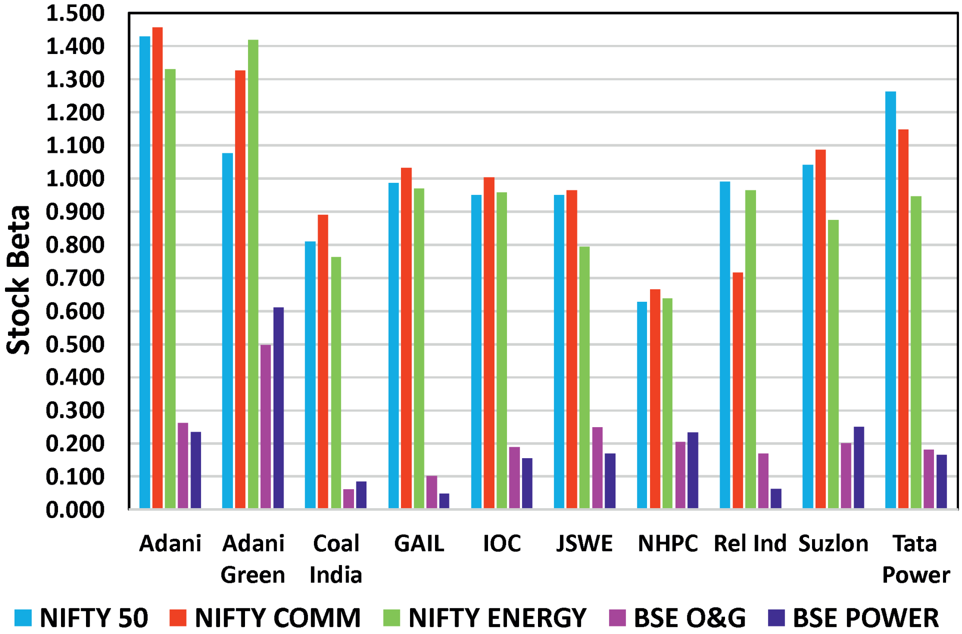

Fig. 4: Estimated betas of the stock prices of 10 energy firms in India with respect to 5 equity market indices

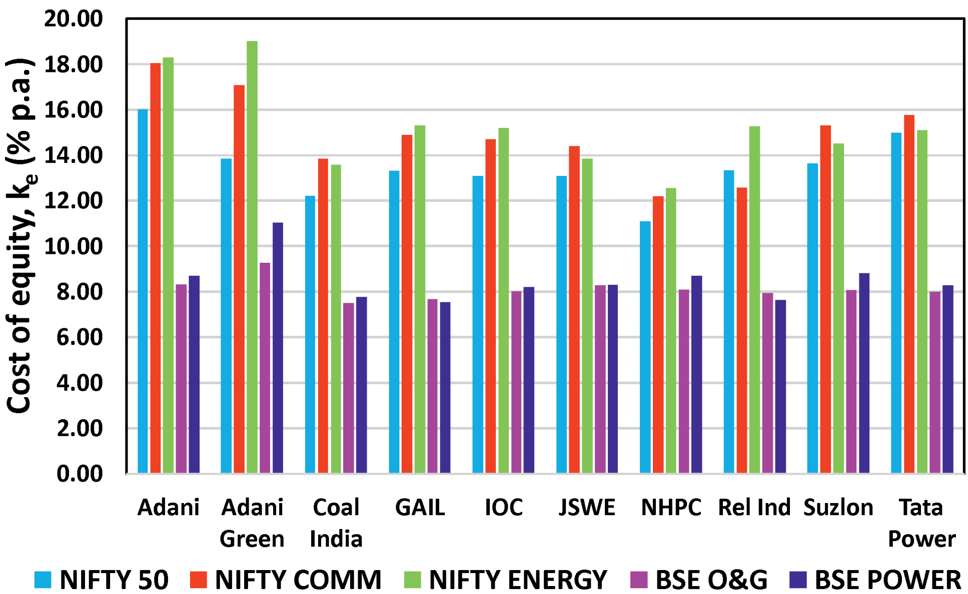

Fig. 5: Calculated expected cost of equity of 10 energy firms in India with respect to 5 equity market indices

reasonably delineated from this figure, which encompasses and enveloped all the possible risk-return combinations that can be generated using the portfolios of the 10 stocks analyzed here.

Fig. 7 shows the spread of Sharpe ratio values seen for 1000 representative simulated portfolios; it is evident that highest Sharpe ratios achievable using combinations of the 10 stocks considered here is ~1.2, while for very infeasible portfolios, the value could drop down to ~0.3. This is seen to be true irrespective of the chosen benchmark market portfolio (i.e., the value of r_M). Table 4 presents the optimal portfolio compositions when the target is to maximize the portfolio Sharpe Ratio, without placing any additional constraints on minimum acceptable return or maximum acceptable risk. The maximum Sharpe ratio values for the optimal portfolios are 1.1936, 1.1933, 1.1884, 1.2015 and 1.1973 respectively for the market indices M1 to M5. For every market index, it is observed that stocks S1, S2, S7 and S8 are the top 4 contributors to the composition of the Sharpe ratio maximizing portfolios.

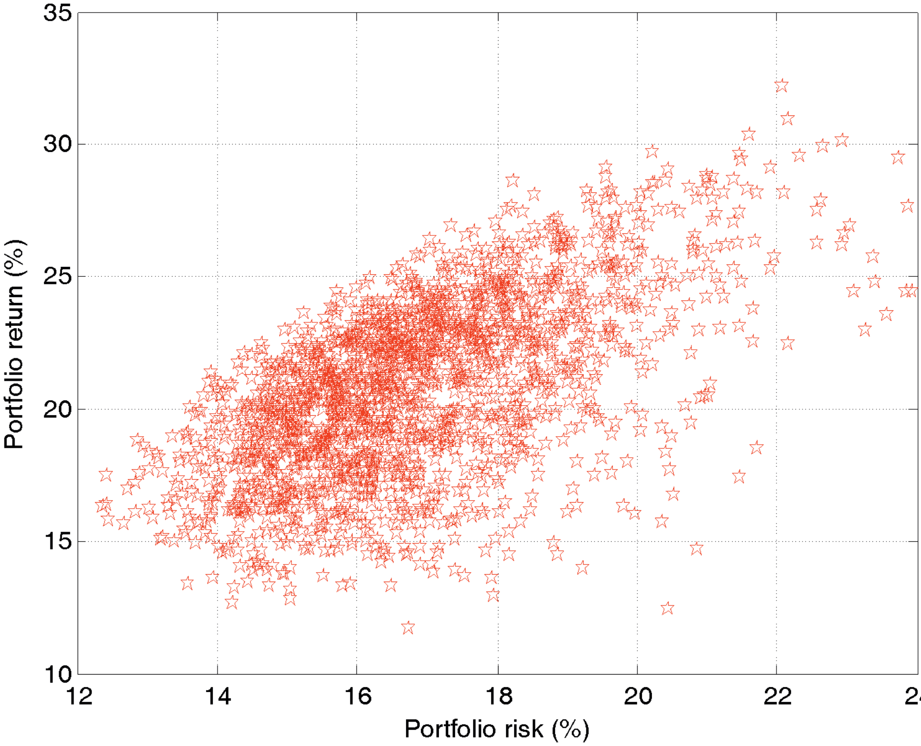

Fig. 6: Representative risk-return plane of 1000 randomly generated equity portfolios of 10 Indian energy firms (for market index = M1 = NIFTY 50)

Fig. 8 shows the spread in Treynor ratios for typical simulated portfolios. Table 5 presents the results when the portfolio's Treynor ratio is maximized, without placing any constraints on minimum acceptable return or maximum acceptable risk. For the optimal portfolios, the stock S2 makes a substantial contribution in every case towards maximizing Treynor ratio, followed by stocks S1, S6 and S8. The corresponding optimal Treynor ratios obtained are 0.2961, 0.2650, 0.2586, 0.9841, and 1.0316 respectively, for each of the market indices used as the benchmark.

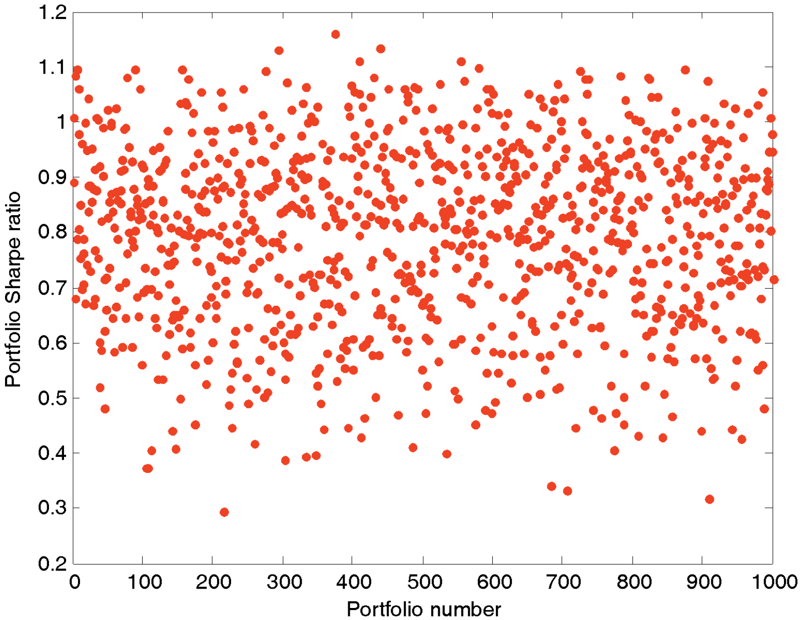

Fig. 7: Representative Sharpe ratios based on 1000 randomly generated portfolios of 10 Indian energy firms (for market index = M1 = NIFTY 50)

Table 4: Optimal portfolio compositions for maximum Sharpe ratio, based on different market indices

Stock	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Weight	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10
Index										
M1	0.136	0.221	0.030	0.004	0.022	0.107	0.201	0.228	0.009	0.042
M2	0.195	0.222	0.000	0.049	0.039	0.136	0.084	0.238	0.011	0.026
M3	0.121	0.217	0.003	0.063	0.040	0.192	0.091	0.207	0.045	0.021
M4	0.137	0.218	0.012	0.072	0.001	0.160	0.127	0.218	0.012	0.043
M5	0.144	0.192	0.012	0.077	0.039	0.145	0.142	0.202	0.015	0.034

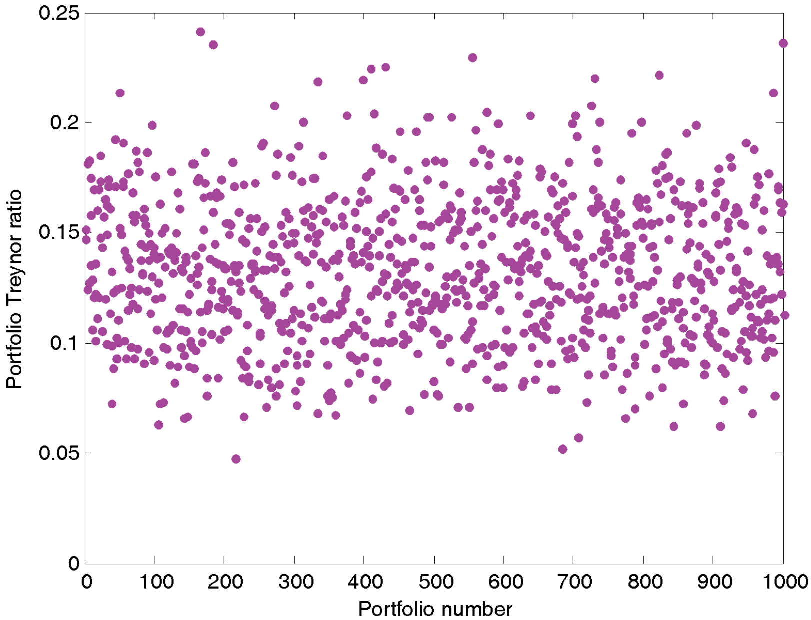

Fig. 8: Representative Treynor ratios based on 1000 randomly generated portfolios of 10 Indian energy firms (for market index = M1 = NIFTY 50)

Table 5: Optimal portfolio compositions for maximum Treynor ratio, based on different market indices

Stock	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Weight	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10
Index										
M1	0.078	0.363	0.004	0.001	0.004	0.026	0.201	0.277	0.019	0.027
M2	0.072	0.406	0.015	0.003	0.044	0.039	0.001	0.111	0.019	0.289
M3	0.154	0.297	0.028	0.017	0.003	0.227	0.099	0.166	0.001	0.006
M4	0.261	0.373	0.050	0.033	0.102	0.059	0.023	0.029	0.036	0.034
M5	0.257	0.224	0.025	0.016	0.020	0.127	0.017	0.251	0.014	0.049

Fig. 9 shows a sample of Jensen alpha ratios from different portfolios of the energy firm stocks. Table 6 presents the results when the portfolio's Jensen alpha ratio is maximized, without placing any constraints on minimum acceptable return or maximum acceptable risk. Stock S2 appears to have a dominant role in all the optimal portfolios in this case (given that it has indeed generated the maximum excess returns (but with maximum volatility) over its expected cost of equity out of all 10 stocks studied here), with S1 and S10 having greater contributions than the other remaining stocks in most cases. The optimal portfolios have Jensen's alpha values of 0.2425, 0.2241, 0.1895, 0.2988 and 0.2626 respectively.

Fig. 10 shows the values of risk to return ratios for various portfolios. Table 7 presents the results when the portfolio's risk to return ratio is minimized, without placing any constraints on minimum acceptable return or maximum acceptable risk. Here, stocks S2, S6, S7 and S8 make up most of the optimal portfolios that have highest risk to return ratios. The corresponding ratio values are 0.6182, 0.6146, 0.6164, 0.6162 and 0.6205 respectively, depending on market index chosen.

Table 8 consolidates the return and risk characteristics for the optimal portfolios under each optimization metric and for each considered market index. The choice of market index is not very significant in influencing the risk-return profile, for a given objective function. However, it is also quite clearly seen that the portfolios which minimize metrics like risk to return ratio (i.e., which are constructed without considering the factors like risk free rates or market portfolios) also offer substantially smaller expected returns (~24-26%) than those which maximize the Sharpe or Treynor ratio or Jensen alpha values (~29-38%). The difference in portfolio risks for a given optimization metric is also not very high across the choice of the benchmark market portfolio, but it does differ substantially across the optimization objectives to be met.

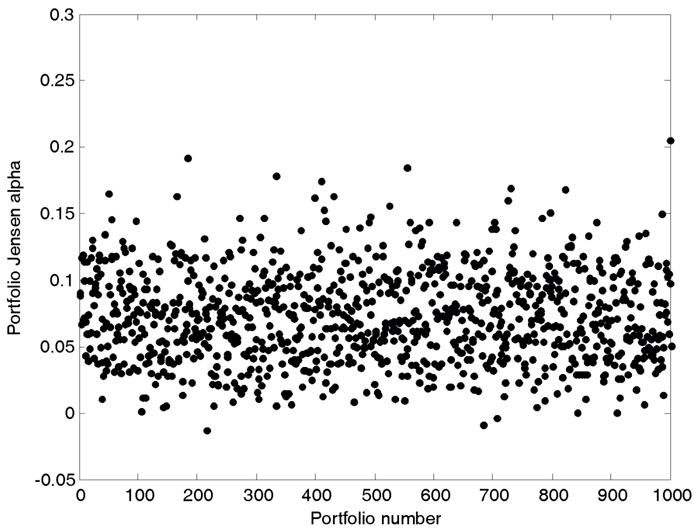

Fig. 9: Representative Jensen alpha ratios based on 1000 randomly generated portfolios of 10 Indian energy firms (for market index = M1 = NIFTY 50)

Table 6: Optimal portfolio compositions for maximum Jensen's alpha ratio, based on different market indices

Stock	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Weight	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}
Index										
M1	0.286	0.339	0.059	0.023	0.008	0.068	0.097	0.039	0.006	0.075
M2	0.072	0.406	0.015	0.003	0.044	0.039	0.001	0.111	0.019	0.289
M3	0.154	0.297	0.028	0.017	0.003	0.227	0.099	0.166	0.001	0.006
M4	0.261	0.373	0.050	0.033	0.102	0.059	0.023	0.029	0.036	0.034
M5	0.294	0.258	0.037	0.015	0.003	0.138	0.017	0.108	0.059	0.071

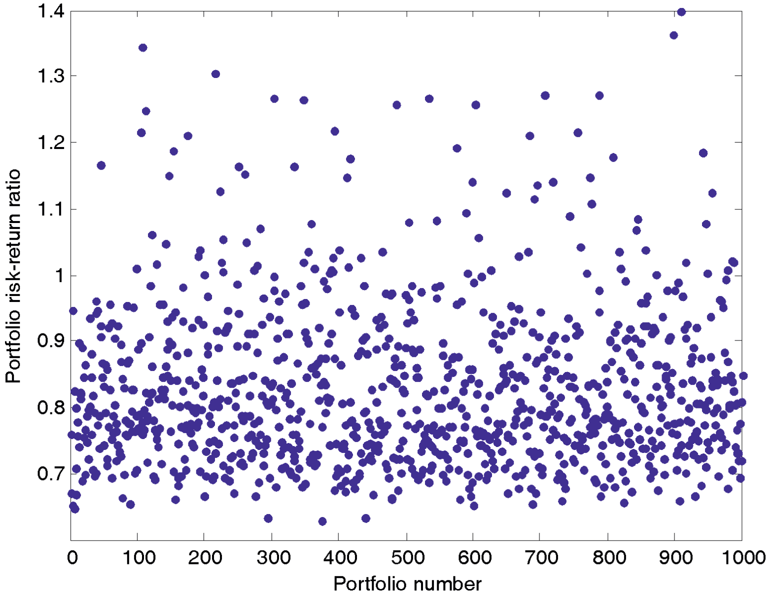

Fig. 10: Representative risk to return ratios based on 1000 randomly generated portfolios of 10 Indian energy firms (for market index = M1 = NIFTY 50)

Table 7: Optimal portfolio compositions for minimum risk to return ratio, based on different market indices

Stock	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
Weight	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}
Index										
M1	0.098	0.136	0.070	0.114	0.088	0.147	0.131	0.199	0.002	0.015
M2	0.078	0.133	0.011	0.108	0.107	0.126	0.150	0.218	0.037	0.032
M3	0.083	0.166	0.021	0.087	0.119	0.154	0.143	0.191	0.035	0.001
M4	0.125	0.156	0.024	0.091	0.055	0.139	0.154	0.216	0.006	0.033
M5	0.083	0.187	0.044	0.083	0.057	0.124	0.152	0.213	0.037	0.021

Table 8: Return and risk characteristics of the optimal portfolios based on various objective functions and market indices

Optimization objective function	*Maximum Sharpe ratio of portfolio*		*Maximum Treynor ratio of portfolio*		*Maximum Jensen alpha of portfolio*		*Minimum risk-return ratio of portfolio*	
Market index	*Return*	*Risk*	*Return*	*Risk*	*Return*	*Risk*	*Return*	*Risk*
M1	30.61%	19.57%	36.52%	26.15%	38.34%	29.00%	23.92%	14.79%
M2	32.09%	20.82%	38.37%	30.63%	38.37%	30.63%	23.84%	14.65%
M3	30.06%	19.19%	35.14%	23.87%	35.14%	23.87%	25.44%	15.68%
M4	30.71%	19.53%	38.42%	29.55%	38.42%	29.55%	26.60%	16.39%
M5	29.05%	18.20%	33.57%	23.25%	35.31%	26.11%	26.63%	16.52%

4. CONCLUSIONS AND FUTURE WORK

The present study has estimated the cost of equity for 10 major publicly listed energy firms of India (large cap firms) based on statistical analysis of weekly stock price data from their last 10 years' performance. Values of 5 general and sectoral equity market indices are used to represent the benchmark market portfolios over the same time horizon. It also develops and employs a simulation-based approach towards identification of optimal equity portfolios, using combinations of stock from these energy firms, with respect to different objective functions like attaining minimum portfolio risk to return ratio or achieving maximum Sharpe, Treynor or Jensen alpha values of the portfolios. The objective of this work is to provide a ready set of inputs towards estimating the cost of equity capital for future energy projects with comparable techno-financial project characteristics to be deployed in India and to understand the risk-return behaviour of equity portfolios made up of these stocks.

The major findings and inferences drawn from this study are as follows:

(i) Over the study period from January 2016 to September 2025, the weekly stock returns, their volatility data and equity market index performance show that the expected cost of equity for the large energy sector firms in India lie between 7.55% to 19.02% p.a., which is a substantially wide range. However, they lie in the range of historic cost of equity data for energy projects in India over last 2 decades. There is no clear sectoral trend identified in this study with respect to the cost of equity, i.e., it cannot be generically stated that any on type of energy firm consistently has a lower cost of equity than another sector.

(ii) The energy firm stock prices are seen to be weakly or moderately strongly and positively correlated to each other over the time frame considered in this study. Thus, even when constructing equity portfolios using stocks from various kinds of energy firms, the extent of diversification possible is not very high.

(iii) The optimal portfolio composition determined through the simulation-based approach naturally depends on the objective of optimization. In an optimal portfolio of 10 stocks, about 3 to 4 stocks are seen to make the dominant contributions in each case. The optimal returns range from ~24% to 38% p.a. and volatility lies between 14 and 31% p.a.

(iv) Another characteristic observed is that the expected returns and risks from the optimal equity portfolios are much more sensitive to the type of objective function used in the optimization problem than the choice of the benchmark market portfolio or index used to calculate factors like beta and evaluate the objective functions. Objective functions which do not consider the market characteristics like risk free rates and market portfolio returns create optimal portfolios which have lower returns than those which build in market characteristics in the analysis.

This study has considered the equity performance of only a limited cross section of energy companies in India over a decade long time frame and has studied the characteristics of portfolios constructed out of them. Future work on expanding this theme can be performed to address the following aspects:

(i) The stock performance of other public energy firms in the mid cap and small cap segments can be analyzed to understand how costs of equity (and hence risk perceptions) in India for newer or innovative technologies are evolving. More than 10 energy firm stocks can be added to the portfolio to see if there is a substantial benefit of diversification (in terms of obtaining increased return at lower risk) achieved by this process.

(ii) Alternative measures of portfolio performance (e.g., value at risk measures, expected shortfall, etc.) beyond the 4 metrics considered in this study may be used as the objective function for the optimization. Other distributional characteristics beyond risk and return of each stock such as skewness and kurtosis can also be incorporated into the portfolio optimization studies.

(iii) Additional constraints (like minimum acceptable portfolio return, maximum allowed portfolio loss over a given time horizon, i.e., value-at-risk (VaR)) may also be defined for the optimization problems in addition to using a diverse nature of objective function forms.

(iv) Comparative analysis of the performance of Indian energy companies with similar energy companies of other major developed or developing economies may be carried out to understand differences in cost of equity characteristics.

(v) Multi-criteria portfolio optimization problems may also be formulated and solved (e.g., identification of the portfolio with highest Sharpe ratio and Treynor ratio) using combined objective functions, with different weights given to the different objectives. Alternate portfolio optimization philosophies such as the use of hierarchical risk parity (HRP) models can be used to decide optimal asset allocations to selected equities **(Dekovic and Simovich, 2025)**.

(vi) The estimates of cost of equity using models like CAPM which are based on market data can be validated against returns on equity obtained by the respective firms as per their reported financial statements. More advanced models of equity cost prediction such as factor models (e.g., the Fama-French model) may also be used.

Disclaimer

This work is an academic study only and none of its contents, results and statements are to be interpreted or taken as financial or investment advice.

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Appendix – Additional Figures

Fig. A2: Histograms of log returns on 5 equity market index values in India (Symbols M1 to M5 are defined in Table 2)

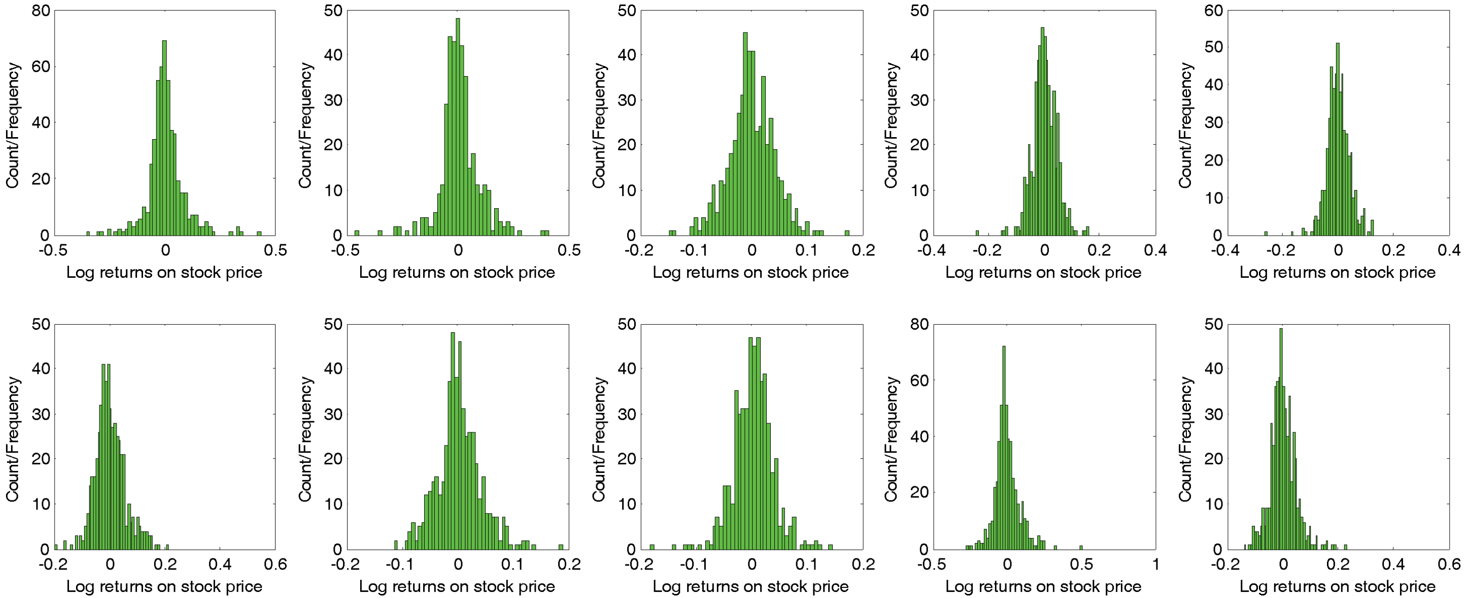

Fig. A1: Histograms of log returns on stock prices of 10 major energy firms of India (Symbols S1 to S10 are defined in Table 1)