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Statistical Insights from Marine Exports in India: An Economic Analysis

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Authors' contributions

This work was carried out in collaboration among all authors. Author SL framed the study, collected the secondary data, conducted the statistical analysis, Author AK wrote the initial draft of the manuscript. Authors HKR and MP assisted with the statistical analysis and provided critical intellectual content and Author SG contributed to drafting the manuscript and performed the literature review. All authors read and approved the final manuscript.

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ABSTRACT

This paper investigates the performance of marine products exported from 1995-2022, in terms of both quantity and value, identify trends, and assess market volatility using metrics *viz.,* CAGR and CDVI. The analysis reveals a substantial overall increase in export volumes, with total quantities

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rising by 485.70 per cent over the period, driven largely by a 642.86 per cent growth in Frozen Shrimp exports. Export values have also seen a dramatic rise, with Frozen Shrimp's value growing by 1730.25 per cent to Rs. 43,135.58 crore. Despite this growth, the market exhibits significant erraticism, particularly in high-value segments *viz.,* Frozen Shrimp, which shows a CDVI of 99.41, indicating instability. Employing multiple models for both quantities and value of exports, the exponential model found to be best in capturing trend with lowest RMSE, AIC, BIC and the highest Adjusted R^2, highlighting it's ability to accurately capture the growth patterns in marine exports. Thus, it indicated the presence of exponential growth pattern in marine exports. In India's marine export sector, particularly segments like dried and chilled items, offers significant potential for further expansion and diversification. These insights are critical to develop strategies to sustain growth while managing the risks associated with market dynamics. Thus, findings give valuable inputs for policymakers and stakeholders in strategic planning to capitalize on growth opportunities while addressing market instability.

Keywords: Marine; exports; growth; instability; trend models.

1. INTRODUCTION

Marine products are among major group of primary agricultural commodities exported from India, constituting 4.1 per cent of the global seafood export and 19 per cent of total agricultural exports in 2019 [1] playing a pivotal role in Indian economy in terms of employment and income generation besides valuable foreign exchange earnings [2]. They have created a huge demand in international trade and are acclaimed to be one of the fastest moving commodities in the world food market [3]. India exports marine products to more than 70 countries of the world, with the key importers being USA, Japan, China, Spain, France and Italy, USA the the largest market [4].

India's rich maritime heritage dates back 5000 years with coastline of 7516.6 kms, an Exclusive Economic Zone (EEZ) in excess of 2.37 million sq. kms, enjoying exclusive legal right to utilise resources. More than 200 million people are dependent on the sea for their sustenance and livelihood [5].

The export of Marine products has achieved highest ever export figures of USD 8.07 billion in the FY 2022-23 touching an all-time high in volume of 17,81,602 MT worth of USD 7.38 billion despite various challenges in significant export markets [6]. During 2022-23 alone, the total export earnings of marine products was Rs. 63,969.14 Cr whereas, the total earnings of marine exports was Rs.5,79,907.86 Cr from 1995- 2022, which signifies its economic importance [7] which is estimated at 3.5 per cent of the total exports from India. The share of marine fisheries in the country's GDP is 1.1%, which is about 5.4% of the total agricultural GDP of India [8]. Marine exports from India are expected to reach US$ 14 billion by 2025 [9]. Government of India (GoI) has declared its intention to increase the fish export earnings to Rs one lakh crore by 2024–25 [1].

Achieving the export targets and the vision of Viksit Bharath by 2047 calls for more focused attention and understanding of entire production, processing and exports etc. In this context, this study examines the performance of marine products from India and discusses the prospects of improving them.

2. METHODOLOGY

Sampling framework and data source: This paper uses a secondary data on marine products exported from India to other countries. The data was collected from MPEDA, an authentic source of information maintained by a government institute.

2.1 Analytical Tools and Techniques Employed

2.1.1 Compound Annual Growth Rate (CAGR)

It is a measure used to determine the annual growth rate over a specified period of time. It provides a smoothed annual rate of growth that can be easily compared across different time periods or investments. It is analysed using the exponential function of the form:

$$Y_t = a\, b^t e^u \quad \text{---------- (1)}$$

where;

Y_t = Dependent variable

a = Intercept

b = trend co-efficient

e = Napierian base

t = Time trend

u = Disturbance or error term

The CAGR is obtained from the linearly transformed estimating form of the above equation (1), as stated below

ln Y_t = ln a + t ln b + u ---------- (2)

The per cent compound annual growth rate (g) was computed by using the relationship

(CAGR) g = (antilog of b - 1) x 100 ------ (3)

2.1.2 Instability analysis using Cuddy-Della Valle Index (CDVI)

Degree of variability in export data was estimated using instability index given by Cuddy and Della (1978). As the usual coefficient of variation (CV) over estimates the variable in time series data due to presence of trend. The CDVI corrects this trend and it is thus more reliable method as compared to CV.

Is obtained through CV which is computed as,

$$CV = \frac{\text{standard deviation}}{\text{mean}} \times 100 \quad \text{--------} \quad (4)$$

CDVI is estimated as follows,

$$CDVI = CV \times \sqrt{1 - \bar{R}^2} \quad \text{----------} \quad (5)$$

Where,

CV: coefficient of variation in percentage

$\bar{R}^2$: adjusted r squared

This index indicates the real direction of the instability and is a better measure to find out the instability in agricultural export. If the index values are below 15 per cent, then it is categorized as low instability, if it lies between 15 to 30 per cent, then it is categorized as medium instability and more than 30 per cent, is categorized as high instability.

2.1.3 Correlation Analysis and Heatmap

Correlation analysis helps to know how variables are related by measuring the strength and direction of relationships between variables, typically using Pearson's correlation coefficient, which ranges from -1 to 1. A value of -1 indicates a perfect negative correlation, 1 a perfect positive correlation, and 0 no correlation. The Pearson's correlation coefficient formula is given by

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2}}$$

A correlation matrix/heatmap is a table showing the correlation coefficients between several variables. To create it we should calculate pairwise correlations for all variable pairs and arrange them in a matrix format. The matrix helps identify patterns and relationships between variables at a glance. This heatmap is a visualisation tool that can further clarify these relationships by using color gradients to represent correlation strengths. The P-values obtained are considered in checking the statistical significance of the relationships between the variables.

2.1.4 Trend Analysis Models

Trend refers to the general tendency of the data to increase or decrease over a long period of time. It measures long-term changes occurring in a time-series without bothering about short-term fluctuations occurring in between.

2.1.5 Linear model

A linear model is one in which all the parameters appear linearly. The average trajectory for the data is a straight line corresponding to increasing or decreasing constant rate of change in time (Nini et al., 2017)

$$Y_t = \beta_0 + \beta_1 X_t + \varepsilon$$

2.1.6 Quadratic model

A quadratic function is one which there is a peak or a trough in the data. (*i.e.,* parabola). The average trajectory for the data contains a curve with variable degrees of steepness and

corresponding to an acceleration or deceleration (Nini et al., 2017).

$$Y_t=\beta_0+\beta_1 X_t+\beta_2 X_t^2+\varepsilon$$

2.1.7 Cubic model

The cubic is one which there are two troughs in the data. The average trajectory for the data behaves quadratically until a further curve occurs, which can correspond to an acceleration or deceleration with variable degrees of steepness (Nini et al., 2017).

$$Y_t=\beta_0+\beta_1 X_t+\beta_2 X_t^2+\beta_3 X_t^3+\varepsilon$$

2.1.8 Quartic model

The quartic model is mainly used when there is a peak or three troughs in the data of past periods. Quartic fit or fourth degree curve is given by the equation:

$$Y_t=\beta_0+\beta_1 X_t+\beta_2 X_t^2+\beta_3 X_t^3+\beta_4 X_t^4+\varepsilon$$

Where,

β_0: Intercept or Average effect

$\beta_1, \beta_2, \beta_3, \beta_4$: Slope or Regression coefficients (β_1: linear effect parameter, β_2: quadratic effect parameter, β_3 : cubic effect parameter, β_4 : quartic effect parameter)

Y_t : Overall marine product exports in time X_t

ε : Error term or disturbance term

2.1.9 Exponential model

If the values of t are arranged in an arithmetic series, the corresponding values of y form a geometric series, the relation is of the exponential type. The function of this type can be given by

$$Y_t = \beta_0 \exp(\beta_1 X_t) +\varepsilon$$

Where,

Y_t: Overall marine product exports in time X_t

β_0 and β_1 are parameters, β_0 is intercept and β_1 represents the exponential rate
exp: exponential term, and

ε: error term.

3. RESULTS AND DISCUSSION

The Table 1 presents a detailed analysis of the growth and instability of marine product exports from 1995-96 to 2022-23, focusing on both quantities (MT) and values (Rs. Cr.). The study employs Compound Annual Growth Rate (CAGR), Cuddy Della Valle Index (CDVI) to get insights on trends and stability of various marine export items.

Table 1. Item-wise growth and instability of marine products export quantities and values from 1995-96 to 2022-23

Item	Quantities (MT)				Values (Rs. Cr.)			
	CAGR (%)	P Value	Adj. R^2	CDVI	CAGR (%)	P Value	Adj. R^2	CDVI
Fr. Shrimp	8.47***	.00	0.88	27.56	5.80^{NS}	.10	0.06	99.41
Fr. Fish	3.22***	.00	0.5	23.78	5.37*	.06	0.09	70.94
Fr. Cuttle fish	3.04***	.00	0.72	14.35	5.58**	.02	0.14	66.47
Fr. Squid	4.09***	.00	0.72	19.88	6.44**	.01	0.18	78.75
Dried item	13.45***	.00	0.89	35.83	13.38***	.00	0.52	76.15
Live items	6.65***	.00	0.86	21.17	9.05***	.00	0.49	60.97
Chilled items	11.27***	.00	0.77	35.91	11.75***	.00	0.52	62.77
Others	10.85***	.00	0.91	20.17	10.17***	.00	0.35	78.93
Total	6.49***	.00	0.96	10.81	5.40 ^{NS}	.14	0.04	92.21

Note: Calculated by author, data source is MPEDA

****, **, *, NS represents the significance levels of P at 1 per cent, 5 per cent, 10 per cent and non-significance, respectively. Standard deviation, CV: coefficient of variation, Adj: Adjusted, Fr: Frozen*

The statistical significance of the results is denoted by P-values, highlighting the robustness of the findings. The results indicate a general strong growth across most categories of marine exports however, in terms of quantity growth, Dried Items gave an highest impressive CAGR of 13.45 per cent, followed by Chilled Items (11.27%) and Others (10.85%). Frozen shrimp being the highest exported marine product in recent years, its historic data analysis gave growth rate of 8.47 per cent. These items have shown consistent and substantial expansion in export quantities, supported by their highly significant P-values, all at the 1 per cent level, confirming the reliability of these growth trends. This underscores the expanding global demand for diverse marine products, reflecting both consumer preference shifts and market diversification strategies.

The growth in export values also demonstrates encouraging trends, particularly for Dried Items (13.38%) and Chilled Items (11.75%), which again exhibit the highest CAGRs among all categories. These items not only grow in terms of quantity but also fetch higher export revenues, indicating their increasing economic importance in global trade. Frozen shrimp though had significant growth in quantities, considering in terms of export values it indicated non-significant.

While growth figures are promising, the CDVI values reveal a more complex narrative regarding market stability. For instance, Frozen Shrimp, despite having a moderate CAGR of 8.47 per cent in quantity, displays a CDVI of 27.56 in quantity and a staggering 99.41 in value. This indicates considerable instability in market dynamics, possibly due to fluctuating global demand, price volatility, or environmental factors impacting shrimp production. Similarly, other categories like Frozen Squid and Frozen Cuttlefish, although showing steady growth, exhibit notable instability in value (CDVI values of 78.75 and 66.47, respectively).

Further, the Adjusted R^2 values provide insights into the predictive power of the regression models used to estimate growth trends. High Adjusted R^2 values, such as those seen in the categories of Others (0.91), Frozen Shrimp (0.88), and Dried Items (0.89), suggest that the models used can effectively explain the variation in the export quantities. Conversely, lower Adjusted R^2 values for export values, such as in Frozen Shrimp (0.06) and Frozen Fish (0.09), suggest that other external factors, possibly including global market conditions or exchange rate fluctuations, might play a significant role in determining export values, which are not fully captured by the models. Study conducted by Das et al., (2016) also indicated that, marine products export from India was highly unstable [10].

Overall, the differential growth and instability across categories indicate the need for targeted policy interventions. For categories like Frozen Shrimp, which exhibit high instability, strategies could focus on market stabilization measures, such as diversifying export destinations. On the other hand, the robust growth of Dried and Chilled Items suggests opportunities to further capitalize on these segments through enhanced production capacities and quality improvements to meet international standards. Thus, the analysis of marine product exports over nearly three decades highlights significant growth potential across various categories, coupled with varying degrees of market instability. The findings underscore the importance of both sustaining growth and addressing the inherent volatilities in marine product markets. Policymakers and stakeholders must balance expansion strategies with risk mitigation to ensure the long-term sustainability and profitability of the marine export sector.

Here, Fig. 1 is an area graph representing the historical trends in the export quantities of various marine products from 1995 to 2022. This visual depiction exposes/highlights the relative contributions of different marine product categories over time, illustrating both growth patterns and fluctuations in the export market.

According to graph, Frozen Shrimp stands out as the dominantly exported item throughout the entire period, with a noticeable increase in export quantities from around 2013 onwards aligning strong CAGR of 8.46 per cent, reflecting its expanding market share and consistent global demand. The Frozen Fish also show significant export quantities, though with more variability over the years exhibiting periods of rapid growth and subsequent declines, possibly due to changing market conditions or resource availability. However, the others category is showing a steady level of increase in the considered period. A similar finding was put forth by Suresh et al., in 2023 who also stated that Frozen shrimp accounted for more than 70% of the export in 2019–20.

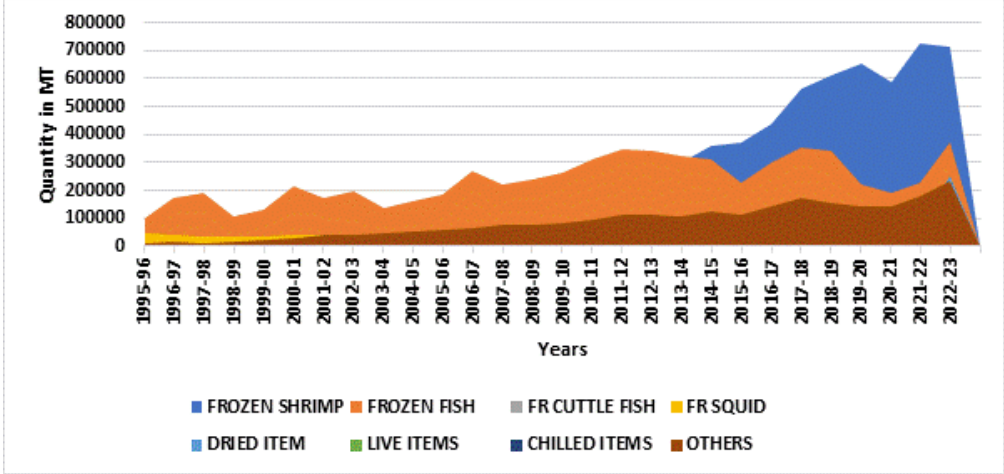

Fig. 1. Area graph depicting historic export quantities of marine products 1995-2022

In a nutshell, the area graph visually highlighted the dynamic nature of marine product exports over the years. The increasing dominance of certain categories like Frozen highlights the shifting focus of the export industry towards high-demand products, while the steady growth in other categories points to a broader diversification strategy. Overall, it gave comprehensive view of the historical trends and future potential in the marine export sector.

The Table 2 presents a comprehensive analysis of the changes in the quantities of various marine export products between 1995-96 and 2022-23 revealing significant shifts in both the scale and composition of India's marine export portfolio over nearly three decades.

According to the data, the Frozen Shrimp has consistently dominated the marine export sector, experiencing an extraordinary net growth of 642.86 per cent from 95,724 MT in 1995-96 to 7,11,099 MT in 2022-23. Its share of total exports rose from 32.31 per cent to 40.98 per cent over the period, indicating its increasing importance as a key export commodity. This category alone contributed to a substantial portion of the total exported quantities, reflecting the growing global for Indian Shrimp.

The Dried Items category recorded the most impressive growth with a net change of 3,269.54 per cent, with an exports of modest 7,506 MT in 1995 to an impressive 2,52,918 MT in 2022-23. This surge elevated its share of total exports from a negligible 2.53 per cent in 1995-96 to a significant 14.58 per cent by 2022-23, highlighting a strategic surge towards global demand. Similarly, the "Others" category, encompassing a range of miscellaneous marine products, exhibited a remarkable increase of 2,324.94 per cent, rising from 9,555 MT to 2,31,703 MT. Its contribution to the total export share expanded from 3.23 per cent to 13.35 per cent, indicating a diversification in the marine export sector and an increased market appetite for varied marine products.

Table 2. Change in quantities of marine exports products between 1995 to 2022-23

Item	1995-96	2022-23	Net change (%)	% of total (1995-96)	% of total (2022-23)	TEQ
Fr. Shrimp	95,724	7,11,099	642.86	32.31	40.98	77,31,248
Fr. Fish	1,00,093	3,68,549	268.21	33.78	21.24	66,17,082
Fr. Cuttle fish	33,845	54,919	62.27	11.42	3.16	14,55,779
Fr. Squid	45,025	83,846	86.22	15.20	4.83	17,30,585
Dried item	7,506	2,52,918	3,269.54	2.53	14.58	13,51,847
Live items	1,756	7,824	345.56	0.59	0.45	1,16,251
Chilled items	2,773	24,428	780.92	0.94	1.41	4,07,575
Others	9,555	2,31,703	2,324.94	3.23	13.35	24,81,938
Total	2,96,277	17,35,286	485.70	100.00	100.00	2,18,92,302

Note: Calculated by author, data source is MPEDA
TEQ is the total quantities of marine products exported from 1995-96 to 2022-23

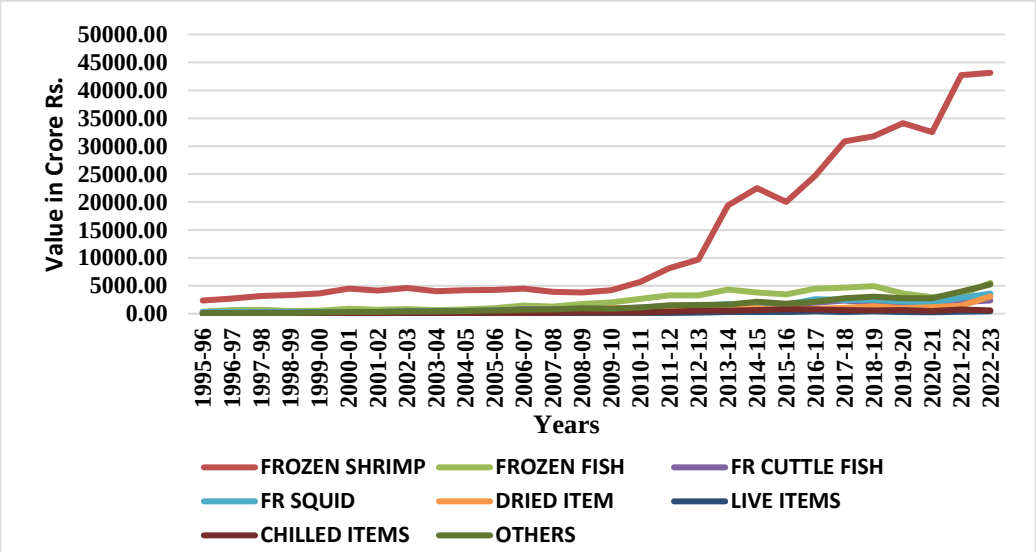

Fig. 2. Line graph depicting historical growth in exports values of marine products 1995-2022

Frozen Fish, traditionally a significant export item, grew by 268.21 per cent, maintaining its importance in the marine export landscape. Whereas, Chilled Items, although representing a smaller portion of the total export volume, recorded a notable growth of 780.92 per cent and us likely driven by advancements in refrigeration and logistics technology.

The line graph in Fig. 2 illustrates the historical growth in the export values of various marine products from 1995 to 2022. Over the years, there is a clear upward trend in frozen shrimp category because of increased exports quantities reflecting in increased export value and also the fact that prices of shrimps exported are also increased. Most categories are reflecting overall growth and increasing economic significance of marine exports.

The Frozen Shrimp stands out with a profound and steady rise, particularly after 2013, indicating its growing dominance in the export market. This product consistently contributes the highest value among all marine products. Frozen Fish, though experiencing some fluctuations, shows significant growth, especially in recent years, demonstrating its resilience and sustained demand. The Dried Items and Others categories also exhibit substantial growth, particularly after 2010, signalling diversification and the rising importance of non-traditional marine products in the export portfolio.

The Table 3 provides a comprehensive overview of the dramatic changes in the export values of various marine products over the nearly three-decade period from 1995-96 to 2022-23. The data reveals not only the significant growth in the value of exports but also shifts in the composition of marine products that dominate the export market.

Table 3. Change in growth of value of exports of marine product between 1995 to 2022-23

Item	1995-96	2022-23	Net change (%)	% of total (1995-96)	% of total (2022-23)	TEV (Rs. Cr.)
Fr. Shrimp	2,356.81	43,135.58	1,730.25	67.32	67.43	3,82,709.71
Fr. Fish	372.26	5,503.18	1,378.32	10.63	8.60	64,406.34
Fr. Cuttle fish	260.86	2,353.34	802.15	7.45	3.68	30,077.93
Fr. Squid	319.58	3,593.75	1,024.52	9.13	5.62	32,511.29
Dried item	44.97	3,080.92	6,751.06	1.28	4.82	17,665.46
Live items	21.31	440.06	1,965.04	0.61	0.69	4,661.56
Chilled items	26.08	616.29	2,263.08	0.74	0.96	8,907.05
Others	99.24	5,246.03	5,186.21	2.83	8.20	38,968.54
Total	**3,501.11**	**63,969.14**	**1,727.11**	**100.00**	**100.00**	**5,79,907.86**

Note: Calculated by author, data source is MPEDA; TEV is the total value of marine products exported from 1995-96 to 2022-23

The total value of marine product exports surged from Rs. 3,501.11 crore in 1995-96 to Rs. 63,969.14 crore in 2022-23, marking an extraordinary net change of 1,727.11 per cent spotlighting the increasing global demand for Indian marine products, driven by expanding markets, rising incomes, and heightened consumer preference for seafood. Among all products, Frozen Shrimp is the flagship exported, with its value shooting up by 1,730.25 per cent from Rs. 2,356.81 crore to Rs. 43,135.58 crore. This product consistently accounted for a dominant share of the total export value, maintaining a stable presence at around 67 per cent of the total export value in both 1995-96 and 2022-23 reflecting its high global demand, superior quality, and strong market positioning.

The data also highlights shifting dynamics in the export values of other marine products. While Frozen Fish experienced substantial growth of 1,378.32 per cent, its share of the total export value declined from 10.63 per cent to 8.60 per cent indicating that while Frozen Fish remains significant, other products are capturing a larger share of the export market. Notably, Dried Items saw an extraordinary increase of 6,751.06 per cent, with their share of total exports rising from a modest 1.28 per cent in 1995-96 to 4.82 per cent in 2022-23 suggesting a growing global appetite for value-added and preserved marine products, positioning Dried Items as a key emerging category within the sector.

The Others category, which include various less prominent marine products, exhibited a remarkable growth of 5,186.21 per cent. The share of this category in total export value jumped from 2.83 per cent to 8.20 per cent, indicating a diversification in export offerings and the successful exploration of niche markets.

The period from 1995-96 to 2022-23 has been one of dynamic growth and transformation for India's marine product exports. The robust increase in export values, coupled with shifts in the composition of exports, reflects the evolving global seafood market and the need for adaptive strategies to maintain competitive advantage. The dominance of Frozen Shrimp suggests that continued investment in this category will be vital for sustaining overall export growth. However, the significant rise of categories like Dried Items and Others highlights opportunities for diversification and value addition in the marine export sector. Strategies to further enhance the quality, sustainability, and market reach of these products could bolster India's position as a global leader in seafood exports.

The correlation analysis presented in the Table 4 reveals the degree of association between different categories of export-oriented marine products. This analysis helps to understand how the performance of one product category influences or correlates with others. This information can inform strategic decisions aimed at optimizing the export portfolio and enhancing the resilience of the marine export sector. Correlation coefficients are used to measure the strength and direction of the linear relationship between two variables. The values range from -1 to 1, where 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation. The significance levels are marked with ***, **, and NS, representing 1per cent, 5per cent, and non-significance, respectively.

The analysis reveals a generally strong positive correlation among most of the marine products, suggesting that the export trends of these items are closely related. This implies that factors influencing the export of one product likely affect others similarly, possibly due to shared market dynamics, common trade partners, or overlapping supply chains.

Frozen Shrimp shows the highest correlation with Others (0.90***), followed closely by Live Items (0.86***) suggesting that trends in the export of Frozen Shrimp are closely linked with the broader category of Other marine products and Live Items. The strong interdependency indicates that market factors influencing Frozen Shrimp are likely to impact these other categories as well. Live Items also exhibit robust correlations with Frozen Squid (0.91***) and Others (0.89***). The Frozen Squid is another category with significant correlations across multiple products, particularly with Live Items (0.91***) and Frozen Cuttlefish (0.81***).

While some correlations are not as strong as those mentioned above, they still provide valuable insights. Frozen Fish has moderate correlations with Frozen Squid (0.79***) and Frozen Cuttlefish (0.73***) sharing significant market characteristics. Chilled Items show a moderate correlation with Frozen Cuttlefish (0.87***) and Frozen Squid (0.81***), indicating a notable, though not overwhelming, degree of interconnection with these categories.

Table 4. Correlation analysis of exported quantities (in MT) of marine products

Item	Fr. Shrimp	Fr. Fish	Fr. Cuttle fish	Fr. Squid	Dried item	Live items	Chilled items	Others
Fr. Shrimp	1.00	0.48*	0.62***	0.73***	0.77***	0.86***	0.57**	0.90***
Fr. Fish	0.48	1.00	0.73***	0.79***	0.70***	0.72***	0.72***	0.75***
Fr. Cuttle fish	0.62	0.73	1.00	0.81***	0.56**	0.77***	0.87***	0.77***
Fr. Squid	0.73	0.79	0.81	1.00	0.69***	0.91***	0.81***	0.84***
Dried item	0.77	0.70	0.56	0.69	1.00	0.77***	0.61***	0.88***
Live items	0.86	0.72	0.77	0.91	0.77	1.00	0.76***	0.89***
Chilled items	0.57	0.72	0.87	0.81	0.61	0.76	1.00	0.76***
Others	0.90	0.75	0.77	0.84	0.88	0.89	0.76	1.00

****, **, * represent significance at 1, 5, 10 per cent levels, respectively*

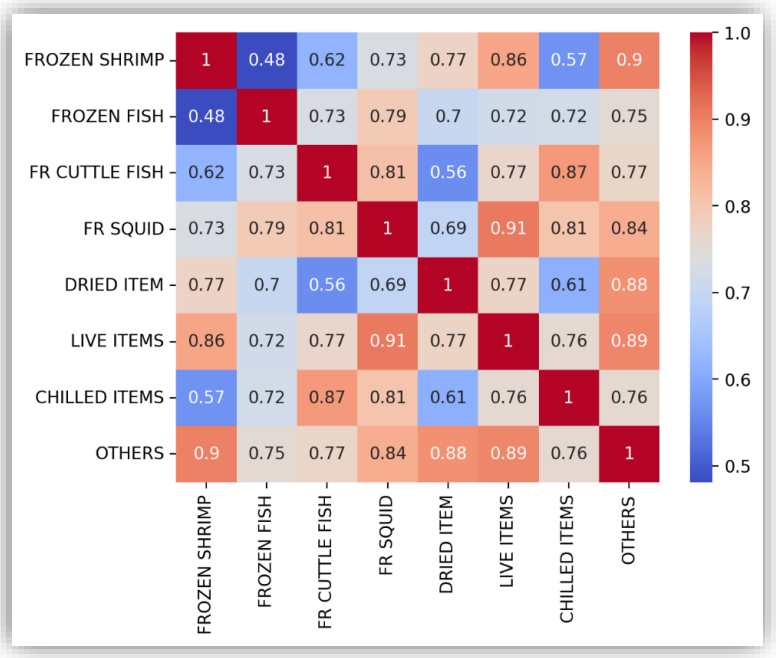

Fig. 3. Heatmap- Correlation of Exported Quantities (in MT) of Marine Products

The weakest correlation observed in the analysis is between Frozen Shrimp and Frozen Fish (0.48*), it could give a sense that the market dynamics influencing Frozen Shrimp may be somewhat distinct from those affecting Frozen Fish.

The values of the same (correlation among the marine products) are represented in a Fig. 3 below which is a heatmap for more appealing visualization. All the diagonal elements represent the correlation of items with itself, thus obtains perfect positive correlation.

The identify the trends in total exports of marine products from 1995 to 2022, various regression models *viz.,* Linear, Quadratic, Cubic, Quartic, and Exponential were employed. Here the best model will be the one that best fits the data, minimizing errors and maximizing the explanatory power as reflected by key metrics such as Root Mean Squared Error (RMSE), Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Adjusted R-squared values. The results are presented in Table 5.

Among the models tested, the Exponential model emerged as the superior fit for the data. This model not only achieved the highest Adjusted R-squared value (0.95646), indicating a strong explanatory power, but also reported the lowest RMSE (0.10622), which signifies the smallest average error between the observed and predicted values. The Exponential model also outperformed the others in terms of AIC and BIC, with values of -40.10731 and -36.11070, respectively, further establishing its robustness and efficiency in fitting the data.

Table 5. Model comparison for trend analysis of marine product exports (1995-2022)

Model	R-squared	Adjusted R-squared	RMSE	AIC	BIC
Linear	0.90784	0.90429	120757.78515	740.74691	744.74353
Quadratic	0.94961	0.94558	89290.65985	725.84108	731.16990
Cubic	0.95130	0.94521	87783.98796	726.88808	733.54911
Quartic	0.95130	0.94283	87783.97135	728.88807	736.88130
Exponential	0.95807	0.95646	0.10622	-40.10731	-36.11070

Note: Authors own computation, data source is MPEDA

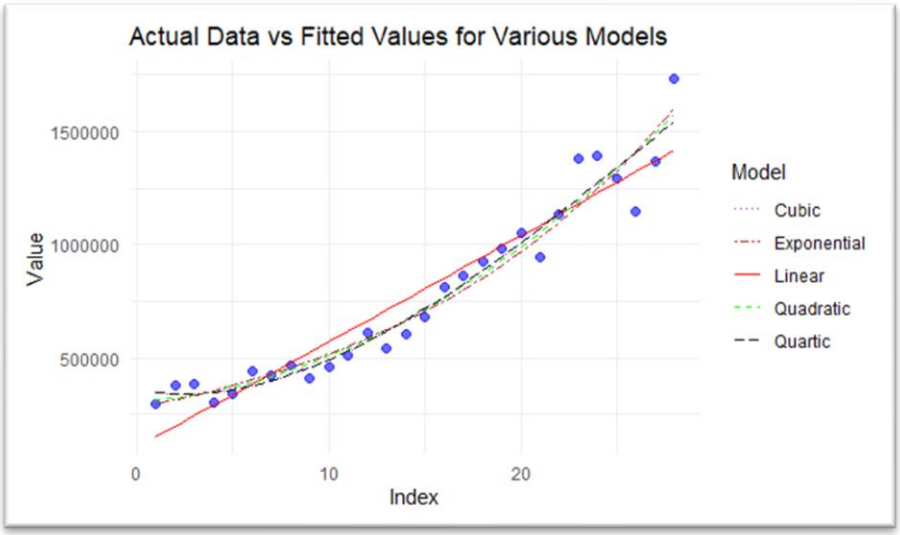

Fig. 4. Actual vs. fitted values for marine product exports (1995-2022) under different models

Table 6. Model comparison for trend analysis of value of marine product exports (1995-2022)

Model	R2	Adj_R2	RMSE	AIC	BIC
Linear	0.8355	0.8292	7487.0447	585.0326	589.0292
Quadratic	0.9704	0.9680	3175.4014	538.9992	544.3280
Cubic	0.9704	0.9667	3175.2610	540.9967	547.6577
Quartic	0.9764	0.9723	2837.5052	536.6987	544.6919
Exponential	0.9508	0.9490	0.2063	-2.9189	1.0777

Note: Authors own computation, data source is MPEDA

The comparison of the models, as depicted in the accompanying graph in Fig. 4 visually supports the conclusion that the Exponential model provides the closest alignment between the actual and fitted values. This suggests that the growth pattern of marine product exports over the period follows an exponential trend, possibly reflecting compounding effects of factors such as increased global demand, advancements in aquaculture, and expanding market access.

In contrast, while the Linear model provided a reasonable fit (Adj. R2 of 0.90429), it was outperformed by the Quadratic, Cubic, and Quartic models in terms of error reduction and goodness-of-fit measures. However, none of these polynomial models could match the precision and lower error margins of the Exponential model, as indicated by their higher RMSE, AIC, and BIC values.

Thus, the Exponential model being superior in capturing the trend of marine product exports suggests its suitability for forecasting and policy analysis in the marine export sector. The findings suggest that future growth in this sector may continue to accelerate, necessitating strategic planning to sustain and manage this growth effectively. The application of the Exponential model offers valuable insights into the dynamics of export expansion, providing a robust tool for stakeholders aiming to optimize export strategies in a globally competitive market.

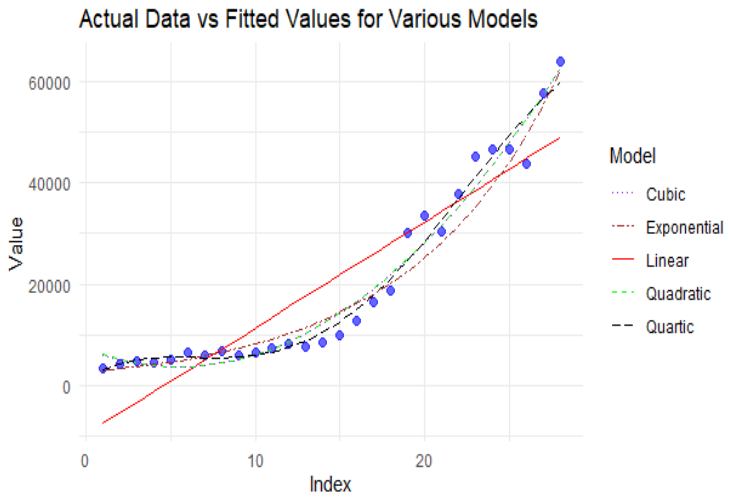

Fig. 5. Actual vs. fitted for total value of marine product exports (1995-2022) under different models

Similarly, the analysis of the total value of exports of marine products from 1995 to 2022 was also conducted and the results are provided in the Table 6.

Here, again the Exponential model demonstrated superior performance across several metrics, achieving the lowest RMSE of 0.2063, indicating minimal discrepancy between the observed and predicted values. Furthermore, the AIC and BIC values were significantly lower for the Exponential model compared to the others, with an AIC of -2.9189 and a BIC of 1.0777. These metrics suggest that the Exponential model not only fits the data well but also avoids overfitting, as indicated by its optimal balance of goodness-of-fit and model simplicity. Adjusted R^2 for this model was 0.9490, reflecting a strong explanatory power.

The graphical comparison of actual versus fitted values as represented in Fig.5 across all models further supports the conclusion that the Exponential model provides the best fit.

Thus, the Exponential model is the most appropriate for capturing the trend in the total value of marine product exports from 1995 to 2022. Its strong statistical performance and alignment with the underlying data trend suggest that it provides the most reliable forecasts for future export values.

4. CONCLUSION

The study conducted on India's marine product exports from 1995-96 to 2022-23 offers a comprehensive analysis of growth patterns, market stability, and the economic significance of various marine products. The findings underscore a robust expansion in export volumes, with the total quantity of marine exports increasing by 485.70 per cent, from 2,96,277 MT in 1995-96 to 17,35,286 MT in 2022-23. This growth is particularly driven by categories such as Frozen Shrimp and Dried Items. Frozen Shrimp, the leading export item, experienced a net growth of 642.86 per cent, with its share of total exports rising from 32.31 per cent to 40.98 per cent highlighting its critical role in the export portfolio, further reflected by its substantial increase in export value, soaring by 1730.25 per cent, from Rs. 2,356.81 crore in 1995-96 to Rs. 43,135.58 crore in 2022-23. However, during covid-19 pandemic, there was a sudden drop in quantity of exports by 7.4 per cent (by 1,02,908 MT) in 2019 as compared to 2018 (13,92,559 MT). Similarly in the concurrent year 2020 also there was a further drop in exported quantity by 2,43,049 MT (-10.87 per cent) compared to the exports during 2019 (12,89,651MT). From 2021 it started a greater recovery and exports became recordingly highest to 17,35,286 MT by 2022-23.

Despite these impressive growth figures, the study reveals significant market instability, particularly in high-value categories. The CDVI values indicate considerable fluctuations, with Frozen Shrimp showing a 27.56 in quantity and a staggering 99.41 in value. Similarly, other categories like Frozen Squid and Frozen Cuttlefish exhibit notable instability in value, with CDVI values of 78.75 and 66.47, respectively.

The Exponential model emerged as the most accurate in predicting trends in both the quantity and value of marine product exports. It achieved the lowest Root Mean Squared Error (RMSE) of 0.2063 and the highest Adjusted R^2 of 0.9490, highlighting its superior fit compared to other models. These metrics underscore the exponential growth pattern in the export sector, driven by increasing global demand, advancements in aquaculture, and enhanced market access.

These findings have important implications for policymakers and industry stakeholders. While the growth trajectory is promising, the notable market instability necessitates targeted strategies to mitigate risks. Diversifying export destinations, stabilizing prices, and enhancing production capabilities, particularly in volatile segments like Frozen Shrimp, are essential to ensure the long-term sustainability and profitability of India's marine export sector.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I have used Quillbot at some point of times to find better wordings for making meaningful sentences. Then, I have also used the Grammarly to find grammatical mistakes in the content and to find synonyms for certain words.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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