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Cointegration-based forecasting of sea bass and sea bream prices in Türkiye: Evidence from monthly wholesale markets

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ABSTRACT

Sea bass and sea bream dominate marine aquaculture production in Türkiye and play a central role in domestic and export markets. Reliable price expectations are therefore essential for producers and traders. This study examines monthly wholesale prices in Türkiye for the period 2016–2025 and evaluates alternative forecasting approaches. Given that both prices are integrated of order one, the Johansen test is applied to assess cointegration. A vector error correction model (VECM) and a robust variant are estimated. Forecast performance is evaluated through rolling-origin backtesting and compared with exponential smoothing, seasonal ARIMA (AutoRegressive Integrated Moving Average), extreme gradient boosting (XGBoost) and a seasonal naïve benchmark using root mean squared error, mean absolute error, mean squared error and mean absolute percentage error. The results show a single cointegrating relationship between sea bass and sea bream prices. Short-run adjustments are asymmetric, with sea bass responding more strongly to disequilibria. In out-of-sample forecasts, VECM-based models produce the lowest error measures. Univariate models perform moderately well, while XGBoost and the seasonal naïve approach yield higher errors. The findings indicate that incorporating long-run equilibrium improves forecast accuracy in integrated seafood markets. Price interdependence between the two species should be considered in applied forecasting and market analysis.

KEYWORDS

Sea bass; sea bream; price forecasting; cointegration; seafood markets

Introduction

Aquaculture has become one of the fastest-growing segments of the global food system (Asche, 2025; Garlock et al., 2020, 2022). It plays a key role in supplying high-quality animal protein while reducing pressure on wild fish stocks. In the Mediterranean region, marine finfish aquaculture is dominated by European sea bass (*Dicentrarchus labrax*) and gilthead sea bream

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(*Sparus aurata*). These two species account for a large share of production, trade and consumption. Their importance extends beyond farming to price formation, market stability and food affordability (Bjørndal et al., 2019; Fernández-Polanco et al., 2023; Garcıa Garcıa et al., 2016; Kallitsis et al., 2020; Llorente et al., 2020; Rad & Köksal, 2000; Ruiz-Chico et al., 2020; Wu et al., 2024).

Over the last three decades, Türkiye has emerged as a central actor in Mediterranean sea bass and sea bream markets. Rapid expansion of farming capacity since the mid-1990s has positioned Türkiye as the largest producer and a major exporter of both species (FAO, 2024, 2026; TURKSTAT, 2023). Turkish producers are highly integrated into European Union markets (Fernández-Polanco et al., 2021). As a result, domestic prices in Türkiye are influenced not only by local supply and demand but also by international trade conditions, exchange-rate movements and export competition (Bjørndal et al., 2019; Rad & Köksal, 2000).

The Turkish sea bass and sea bream sector is characterized by an export-oriented value chain, where production is largely concentrated in coastal farming regions and closely linked to processing and international distribution networks. Domestic consumption remains limited relative to production, while a substantial share of output is exported, primarily to European Union markets. The market structure is dominated by vertically coordinated firms that integrate farming, processing and export activities. This structure strengthens price linkages across stages of the value chain and across countries. In recent years, producers have also expanded into alternative markets beyond the EU, reflecting diversification strategies and changing trade conditions (Asche et al., 2022).

From a market perspective, sea bass and sea bream prices are shaped within integrated value chains. In European sea bass and sea bream markets, prices are transmitted vertically across production, wholesale and retail stages, and horizontally across countries through trade flows (Fernández-Polanco et al., 2023). Empirical evidence from European aquaculture markets demonstrates strong price integration and significant information transmission between exporting and importing countries (Fernández-Polanco et al., 2023; Fernández-Polanco & Llorente, 2019). In particular, Turkish export prices have been shown to affect price formation in European Union markets, especially for sea bass. This finding suggests that Türkiye acts as a price-relevant supplier rather than a passive price taker (Bayramoğlu, 2019; Bjørndal et al., 2019; Landazuri-Tveteraas et al., 2018).

Another defining feature of Mediterranean finfish markets is substitution between sea bass and sea bream. The two species are often produced by the same firms. They are marketed through similar channels and consumed as close substitutes. Because of this structure, shocks affecting one species

may spill over to the other. These spillovers may arise through demand substitution, joint production decisions or inventory adjustments. Recent empirical studies confirm statistically significant substitution relationships between sea bass and sea bream prices in Mediterranean markets (Fernández-Polanco et al., 2024). Evidence from Türkiye also shows strong co-movement between retail prices of the two species, even at the local level (García García et al., 2016).

Price dynamics in aquaculture markets are further influenced by production costs and biological constraints (Fernández-Sánchez et al., 2022). Feed represents one of the largest cost components in sea bass and sea bream farming. Changes in feeding strategies, pellet size and delivery rates have direct implications for production costs and profitability (Luna et al., 2022; Wu et al., 2024). Life cycle assessment studies show that feed and on-farm operations are key drivers of both environmental and economic performance in Mediterranean sea bass and sea bream production (García García et al., 2016; Kallitsis et al., 2020; Luna et al., 2019). These cost structures contribute to price volatility and reinforce the need for reliable price expectations.

At the consumer end of the value chain, price remains a key determinant of seafood purchasing behavior. Studies highlight that consumer acceptance of aquaculture products is closely linked to price perceptions, trust and sustainability claims (Ruiz-Chico et al., 2020; Sun et al., 2023). There is also some evidence that ecolabeled aquaculture products may command a premium in the marketplace as some consumers are willing to pay a higher price for products that offer certain sustainability attributes (Hammarlund et al., 2025). Supply chain innovations, including processing and packaging strategies, further affect market value and price differentiation for sea bass and sea bream products (Rosati et al., 2025). Together, these findings indicate that price dynamics in sea bass and sea bream markets are embedded in a broader food-system context that connects production decisions, sustainability concerns and consumer behavior.

Despite this extensive literature, most existing studies remain retrospective. They focus on market integration, price transmission or substitution using historical data. Much less attention has been paid to price forecasting, especially at high (monthly) frequency. Recent contributions demonstrate the potential of advanced forecasting approaches for marine fish prices and food markets more generally (García et al., 2022; Wu et al., 2024). However, these studies often abstract from the specific structural characteristics of aquaculture markets, such as species substitution and export-driven price leadership.

This gap is particularly relevant in the case of Türkiye. Firstly, Türkiye's dominant production scale and export orientation imply that domestic

prices are closely linked to regional market conditions. Secondly, sea bass and sea bream are cornerstone species for Turkish aquaculture, making price volatility highly relevant for income stability and production planning. Thirdly, Türkiye offers a long and consistent monthly price series that allows for rigorous empirical analysis. Official statistics confirm that sea bass and sea bream remain the leading species in Turkish marine aquaculture (FAO, 2026; TAGEM & TEPGE, 2023; TURKSTAT, 2023). Academic syntheses further emphasize Türkiye's competitive cost structure and growing influence in Mediterranean finfish markets (Aydın et al., 2025; WWF, 2021). Against this background, the present study develops and evaluates forecasting models for monthly sea bass and sea bream prices in Türkiye over the period 2016–2025.

Materials and methods

Data description

This study analyzes monthly market prices of two economically important aquaculture species in Türkiye: sea bream (*S. aurata*) and sea bass (*D. labrax*). The dataset includes data which runs from January 2016 until December 2025 with 120 observations for each series. The market uses Turkish Lira per kilogram (TRY/kg) to measure prices which stem from the interactions between producers and wholesalers in the wholesale market. The price series consist of ex-farm (producer) prices collected as primary data through direct communication with municipal authorities across Türkiye.

The natural logarithm transformation was applied to both price series to address scale effects and heteroskedasticity which typically affect price data while enabling elasticity measurement through the transformed values. In the production of these two series, same domestic factors and uncertainties such as inflation and exchange rate affect in the same way, in addition to international factors. Thus, time series are presented in relative terms. Both time series are in TRY. The log-transformed series (Kwas & Rubaszek, 2021) shows through visual inspection that both species demonstrate rising patterns from start to finish of the observation period which indicates their measurement levels could be non-stationary (Figure 1).

Descriptive statistics for the log-transformed prices are presented in Table 1. The price data for sea bass shows higher mean values and standard deviations than sea bream which indicates that sea bass prices fluctuate more widely. The two series show positive skewness together with negative kurtosis which indicates they experience rare large price fluctuations while showing different responses to market changes. The presence of positive skewness and negative kurtosis suggests that extreme price movements

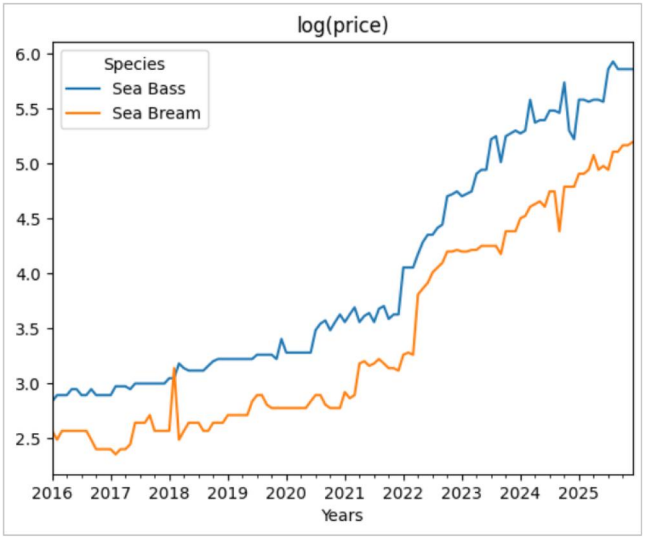


Figure 1. Log price series over time (sea bass vs sea bream) (2016–2025).

Table 1. Descriptive statistics of log-transformed prices (2016–2025).

Species	*N*	Mean	Median	Std. dev.	Min	Max	Skewness	Kurtosis
Sea bream	120	3.413	2.890	0.918	2.351	5.193	0.593	−1.231
Sea bass	120	3.981	3.555	1.023	2.833	5.927	0.592	−1.235

Table 2. ADF test results.

Series	Level/diff.	*n*	Regression	ADF stat.	*p*-Value	Selected lag
Sea bream	Level	120	c	1.2366	0.996	2
Sea bass	Level	120	c	1.4618	0.997	2
Sea bream	1st diff.	119	c	−10.3477	<0.001	1
Sea bass	1st diff.	119	c	−2.9509	0.039	6

occur occasionally, which may bias standard least-squares-based vector error correction model (VECM) estimates. For this reason, we also consider a robust VECM based on Huber weighting (Hao et al., 2020).

The stationarity of the log-transformed series was tested using the augmented Dickey–Fuller (ADF) test (Hall, 1994). As shown in Table 2, both series are non-stationary in levels but become stationary after first differencing, indicating that they are integrated of order one, I(1) (Hall, 1994). The ADF test is based on the following regression:

$$\Delta y_t = \propto + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-1} + \varepsilon_{t-1} \quad (1)$$

The test examines non-stationarity through unit root detection by testing $H_0 : \gamma = 0$ while stationarity is proven through $H_1 : \gamma < 0$. Optimal lag length was selected using the Akaike Information Criterion (AIC) (Liew, 2004).

The ADF test results, reported in Table 2, indicate that both sea bream and sea bass prices are non-stationary in levels but become stationary after first differencing, consistent with an integrated process of order one, I(1). The research finding shows cointegration analysis requirements which prove that these two-time series follow a single long-term stochastic pattern. The results find support through visual analysis of Figure 1 which shows the log price series following a clear trend throughout time while their first differences show random movements that stay within zero.

Given the absence of a clear deterministic trend beyond stochastic trending behavior, we included only a constant term in the ADF regression. The addition of a deterministic trend would have decreased statistical power while making it more likely to apply too many differences to the data.

Cointegration analysis (Johansen test)

Given that both series are I(1), we applied the Johansen cointegration test (Johansen, 2014) to assess whether a stable long-run relationship exists between sea bream and sea bass prices. Before conducting the test, the appropriate lag length for the underlying VAR (Vector Autoregression) model was determined. The model selection criteria (AIC, BIC (Bayesian Information Criterion), HQIC (Hannan–Quinn Information Criterion) and FPE (Final Prediction Error)) indicated that the best model results from using $p = 1$ as the lag order, which achieves a proper balance between model complexity and predictive ability. BIC was prioritized due to the relatively small sample size (Liew, 2004).

Although AIC suggested a lag length of 3, we selected a more parsimonious lag of 1 based on BIC, which is generally preferred in small samples and avoids overfitting (Liew, 2004).

The Johansen procedure tests the number of cointegrating vectors r using the trace and maximum eigenvalue statistics. As shown in Table 3, both tests reject the null hypothesis of no cointegration ($r = 0$) but fail to reject $r \leq 1$, indicating the presence of a single cointegrating relationship. This implies that although both prices are individually non-stationary, a linear combination of them is stationary, consistent with economic theory of price co-movement in substitute goods.

Table 3. Johansen cointegration test results.

r	Trace stat.	5% crit.	Max-eigen stat.	5% crit.
0	23.16*	15.49	21.22*	14.26
1	1.94	3.84	1.94	3.84

*Indicates statistical significance at the 5% level.

The normalized long-run equilibrium equation can be expressed as:

$$ECT_y = \beta' y_t = \log(\text{Sea Bream}_t) - 0.8979 \log(\text{Sea Bass}_t) = \text{ECT} \quad (2)$$

where $\beta_2 \approx -0.90$. This coefficient implies a strong negative association between the two prices in the long run, consistent with their role as close substitutes in consumer markets.

VECM

Given the presence of cointegration, we estimated a VECM (Hoffman & Rasche, 1996), which captures both short-run dynamics and long-run equilibrium adjustment. The general VECM specification is given by:

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-1} + c + \varepsilon_t \quad (3)$$

where $\Pi = \alpha\beta'$ contains the adjustment coefficients (α) and the cointegration vector (β). Alternatively, this can be written in error correction form as:

$$\Delta y_t = \propto ECT_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-1} + c + \varepsilon_t \quad (4)$$

where $ECT_{t-1} = \beta' y_{t-1}$. The model was estimated with one lag in differences ($k_{ar_diff} = 1$), cointegration rank $r = 1$ and a deterministic term restricted to the cointegration equation ("co" specification).

Monthly price series can show some seasonal variation over the year. However, in this study, the model is kept relatively simple in order to focus on the underlying stochastic trends and long-run relationship between the series. Given the sample size, seasonal dummy variables and additional deterministic trend terms were not included, as they would add complexity without a clear improvement in explanatory power.

The estimated short-run coefficients are summarized in Table 4. The sea bass model shows a negative adjustment coefficient but sea bream model shows a positive coefficient which indicates that these systems react differently to changes from their equilibrium state. The absolute value of the adjustment coefficient shows greater magnitude for sea bass which indicates

Table 4. Short-run VECM coefficients.

Equation	Term	Coef.	Std. err.	*z*	*p*-Value
Δ Sea Bream	Const	−0.0129	0.017	−0.771	0.441
Δ Sea Bream	L1. Sea Bream	−0.2224	0.092	−2.410	0.016
Δ Sea Bream	L1. Sea Bass	−0.0539	0.105	−0.514	0.607
Δ Sea Bass	Const	0.0629	0.015	4.204	0.000
Δ Sea Bass	L1. Sea Bream	−0.1337	0.082	−1.621	0.105
Δ Sea Bass	L1. Sea Bass	−0.1452	0.094	−1.551	0.121

that sea bass prices exhibit stronger reactions to market imbalances than sea bream.

Forecasting and rolling-origin backtesting

To evaluate out-of-sample predictive performance, we adopted a rolling-origin backtesting framework (Mahkya et al., 2022). The first estimation period spanned 60 months before the model started producing forecasts through a sequential process which added one month to the sample at each step. The design structure allowed model re-estimation with new data while keeping all methods under the same evaluation duration.

We evaluated six forecasting models which included the VECM and its robust version with Huber-weighted re-estimation and exponential smoothing (ETS) and seasonal ARIMA (SARIMA) and extreme gradient boosting (XGBoost) and a seasonal naïve benchmark (Bloznelis, 2018; Jainonthee et al., 2025; Michinaka et al., 2016; Wu et al., 2024). The selected models use structural time-series methods together with machine-learning techniques and they also include fundamental forecasting systems.

We evaluated forecast accuracy through multiple error metrics which evaluated different elements of predictive performance. Specifically, we considered the mean squared error (MSE), root mean squared error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE) (Hyndman & Koehler, 2006). MSE and RMSE emphasize larger forecast errors and are particularly informative when avoiding occasional large misses is important. MAE provides a more robust measure of typical forecast error, as it is less sensitive to outliers. The MAPE system enables users to compare different series and models through relative percentage error measurements which help users understand their performance differences. The metrics used for evaluation were calculated from log-scale data because they needed to match the modeling structure. The collection of metrics allows researchers to assess their prediction accuracy while they can evaluate their results against different forecasting approaches.

The rolling-origin protocol served to estimate and evaluate all models, producing equivalent results for comparison purposes. The resulting performance measures are reported in Table 5, which summarizes MSE, RMSE, MAE and MAPE for each model and species. The system allows researchers to perform an open and organized evaluation between structural econometric models (VECM and robust VECM), traditional time-series models (ETS and SARIMA) and the machine-learning method (XGBoost) against the basic seasonal naïve model (Hewamalage et al., 2023; Hyndman & Koehler, 2006).

Table 5. Forecast performance comparison (rolling-origin backtesting).

	Sea bass				Sea bream			
Model	MAE	RMSE	MSE	MAPE	MAE	RMSE	MSE	MAPE
VECM	0.0937	0.1372	0.0188	1.925	0.0859	0.1252	0.0157	2.155
RobustVECM	0.0936	0.1373	0.0189	1.923	0.0863	0.1251	0.0156	2.165
ETS	0.0979	0.1383	0.0191	2.039	0.0914	0.1336	0.0178	2.260
SARIMA	0.0977	0.1420	0.0202	2.055	0.0863	0.1287	0.0166	2.138
XGBoost	0.1423	0.1932	0.0373	2.909	0.1136	0.1624	0.0264	2.876
Seasonal naïve	0.4656	0.5400	0.2916	9.712	0.4471	0.5134	0.2636	10.851

Forecasting performance

The descriptive statistics in Table 1 reveal that sea bass prices exhibit higher volatility than sea bream. The non-stationarity of both series in levels and stationarity in first differences (Table 2) justify the use of cointegration-based modeling.

Forecast performance results are summarized in Table 5, which reports MSE, RMSE, MAE and MAPE for each model under the rolling-origin backtesting scheme. The seasonal naïve model produced the worst results for all evaluation criteria when tested on both species which proved that basic seasonal pattern repetition fails to explain the actual price behavior in these markets.

The seasonal naïve benchmark shows the worst performance across both species because it generates the highest values for all error metrics which include MSE and RMSE and MAE and MAPE. The data shows that using only historical seasonal patterns will not work to predict price changes for sea bream and sea bass because their market behavior has become more complex during times of market transformation and price instability. The poor results of the naïve benchmark confirm that better modeling methods than the current approach need to be developed.

Among the econometric and statistical models, VECM and Robust VECM consistently rank at or near the top. For sea bass, the standard VECM yields the lowest RMSE (0.1372) and among the lowest MSE and MAE values, while Robust VECM produces nearly identical results. For sea bream, Robust VECM slightly outperforms the standard VECM in terms of MSE and RMSE, although the differences are marginal. The two specifications show similar performance results which indicate that rare extreme data points exist in the data but they do not affect the core cointegration relationships or prediction results.

The percentage-based metrics show that the current ranking order remains unchanged. The VECM and Robust VECM models produce the most accurate price predictions for both species because they achieve the lowest MAPE value which amounts to approximately 2 percent. The models generate the most accurate forecasts because they achieve both high absolute precision and high precision relative to the price level. The results

from MSE, RMSE, MAE and MAPE measurements confirm that VECM-based methods produce the most reliable forecasting results in this specific context.

ETS and SARIMA models form a competitive second tier. Their RMSE and MAE values are slightly higher than those of VECM, but still considerably lower than those of XGBoost and the naïve benchmark. This suggests that classical univariate time-series models are able to capture much of the temporal structure in each series, yet they fall short of fully exploiting the long-run interdependence between the two prices.

The XGBoost model produces results that are inferior to the econometric benchmarks because it generates higher values for MSE and RMSE and MAE and MAPE for both species. While flexible in modeling nonlinear patterns, XGBoost does not explicitly incorporate the cointegration relationship between sea bream and sea bass prices. Given the relatively small sample size and the strong long-run linkage between the two series, this structural information appears to be more valuable than purely data-driven feature engineering.

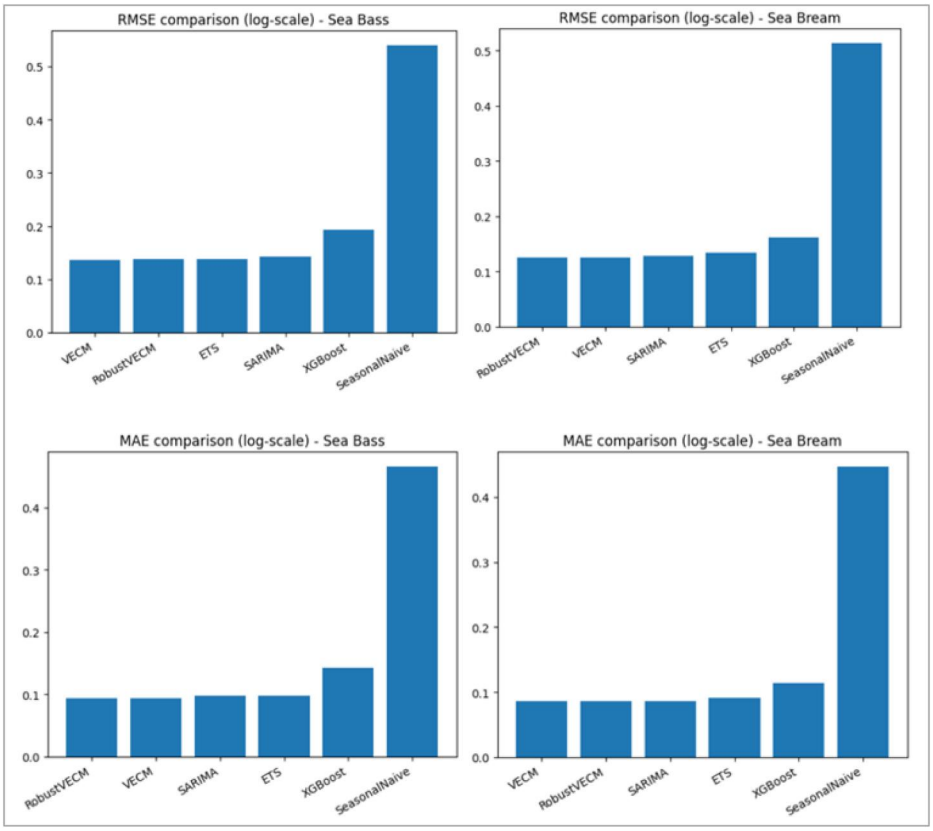


Figure 2. RMSE and MAE comparison across models (sea bass and sea bream).

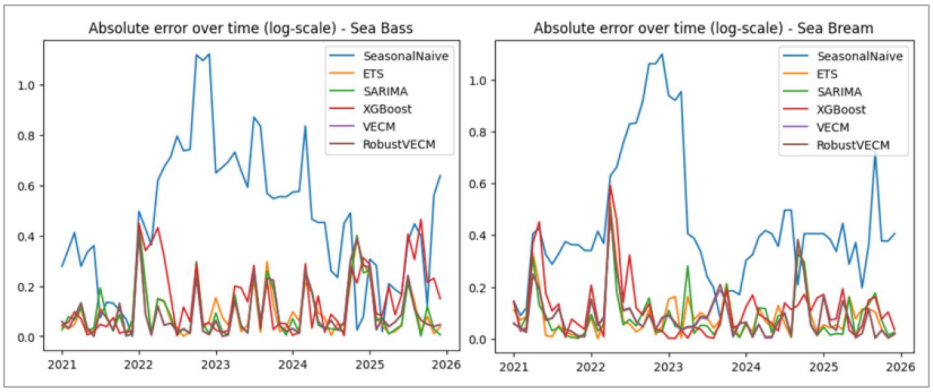


Figure 3. Absolute forecast error over time (sea bass and sea bream).

The model comparisons are visually summarized in Figure 2, which display RMSE and MAE values across all methods. These bar charts clearly illustrate that VECM and Robust VECM cluster at the lower end of the error spectrum, while seasonal naïve stands out as a clear outlier with much larger errors.

The forecast error development pattern appears in Figure 3. The models in these plots show that market price volatility leads to higher forecasting errors but VECM-based forecasting maintains its accuracy best throughout the entire period. The naïve benchmark shows extended periods of big errors which become more severe when market conditions change between different regimes.

The forecasting results show that VECM and RobustVECM models which study the expanded price connection between sea bream and sea bass produce better predictions than univariate models and current machine-learning methods. This finding is consistent with the view that these two species function as close substitutes in the Turkish market, and that their prices are jointly determined by underlying economic forces.

Discussion and conclusions

Sea bass and sea bream prices move together in the long run. The Johansen test confirms one cointegrating vector (Johansen, 2014). This result is consistent with substitution between the two species in Mediterranean markets (Bayramoğlu, 2019; Fernández-Polanco et al., 2024). In Türkiye, the two products share production systems and marketing channels. They are often consumed as close alternatives (Ruiz-Chico et al., 2020; Sun et al., 2023). Although prices are affected inflation and exchange-rate movements, the link between the two series remains stable over time, allowing for a meaningful cointegration analysis.

The long-run coefficient indicates a strong equilibrium linkage. Relative price gaps do not persist. This finding aligns with earlier evidence on market integration in European aquaculture (Fernández-Polanco et al., 2023; Fernández-Polanco & Llorente, 2019). Türkiye is not a passive supplier. Export activity affects regional price formation (Bjørndal et al., 2019; Landazuri-Tveteraas et al., 2018). Domestic wholesale prices therefore reflect broader Mediterranean conditions.

Short-run dynamics differ across species. Sea bass adjusts more rapidly to disequilibria. sea bream reacts more slowly. This asymmetry may reflect differences in export intensity and market positioning (Bjørndal et al., 2019; Rad & Köksal, 2000). Cost structures also matter. Feed and on-farm operations are central components of production costs (García García et al., 2016; Kallitsis et al., 2020). Such structural features influence price responses to shocks.

Forecast results reinforce the importance of economic structure. VECM and RobustVECM outperform alternative models. These specifications explicitly incorporate the long-run relationship (Hoffman & Rasche, 1996). Univariate models such as ETS and SARIMA perform reasonably well, but they ignore cross-species dependence. Their errors remain higher.

XGBoost does not improve accuracy in this setting. Flexible algorithms can perform well in food price prediction (García et al., 2022; Wu et al., 2024). Here, the sample is limited and the equilibrium link is strong. Models that embed cointegration capture this structure more effectively. The results echo the view that model choice should reflect economic context, not only predictive flexibility (Hao et al., 2020; Oztornaci et al., 2024).

Small samples limit the learning capacity of flexible algorithms. With only 120 monthly observations, feature extraction remains constrained. XGBoost relies on repeated partitioning of the data space. In short time series, this may lead to unstable splits and overfitting. In contrast, VECM imposes an economically meaningful long-run structure. When prices share a common stochastic trend, restricting the model space can improve out-of-sample performance. The results therefore reflect data characteristics rather than a general weakness of machine-learning methods (Xia et al., 2024).

The seasonal naïve benchmark performs poorly. Simple repetition of seasonal patterns is insufficient (Bloznelis, 2018). Price dynamics are shaped by integration, substitution and trade exposure (Fernández-Polanco et al., 2023; 2024). Ignoring these elements leads to large forecast errors.

The findings contribute to the literature on seafood price formation. Most previous studies focus on transmission and integration ex post (Fernández-Polanco et al., 2023; 2024; Fernández-Polanco & Llorente, 2019). This study links those structural insights to out-of-sample forecasting. For Türkiye, this is particularly relevant. Official statistics confirm the

dominant role of sea bass and sea bream in national aquaculture (FAO, 2026; TAGEM & TEPGE, 2023; TURKSTAT, 2023). Sectoral reviews underline the country's competitive position and regional influence (Aydın et al., 2025; WWF, 2021). In such a system, joint modeling of prices is necessary.

Price forecasting in this context is not a purely technical exercise. It relates to farm planning, export contracts and income stability. In integrated seafood markets, equilibrium relationships matter. Models that respect these relationships perform better (Asche et al., 1999, 2007; Gordon & Hannesson, 1996).

Overall, the results point to a clear conclusion. Sea bass and sea bream prices are jointly determined through a stable long-run equilibrium, and this structure is central for both interpretation and prediction. Models that incorporate this relationship provide consistently lower forecast errors, while approaches that ignore cross-species dependence remain limited. This has direct relevance for an export-oriented and integrated market such as Türkiye, where reliable price signals depend on capturing interdependence rather than treating species in isolation.

The results should, however, be interpreted with caution. The analysis relies on a single wholesale market and does not explicitly account for cost-side drivers. Future research can extend the framework by incorporating additional markets, input prices and potential nonlinear dynamics. Such extensions would contribute to the literature by improving the understanding of price formation in integrated aquaculture markets and by enhancing the robustness of forecasting models under different market conditions. Despite these limitations, the evidence shows that economically grounded models provide a more consistent basis for seafood price forecasting in integrated systems.

Additional information

No additional information is available for this paper.

Author contributions

CRediT: **Burak Öztornacı**: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Data availability statement

All the datasets are publicly available.

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