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DYNAMIC LINKAGES BETWEEN REGIONAL AND ARMENIAN AQUACULTURE: EVIDENCE FROM PCA AND ARDL ERROR CORRECTION ANALYSIS

Nairuhi Jrbashyan*
Yerevan State University, Ph.D. in Economics, Associate professor
n.jrbashyan@ysu.am
ORCID ID: https://orcid.org/0000-0002-8844-7514

Gayane Ghukasyan
Yerevan State University, Ph.D. in Math-Phys., Associate professor
gayaneghukasyan@ysu.am
ORCID ID: https://orcid.org/0000-0003-4169-7687

Abstract: Aquaculture is the fastest-growing food production sector globally and guarantees food security and nutrition. Aquaculture production in Armenia increased significantly over the past three decades, increasing approximately tenfold. In this context, it is important to study the dynamics of aquaculture production in the region and the impact of regional market pressures on Armenian production, considering the country's right to start exporting aquaculture to the EU.

This study examines the impact of regional aquaculture expansion on Armenian aquaculture. Using Principal Component Analysis, regional growth and divergence factors were extracted and

incorporated into an ARDL Error Correction framework. Results reveal a long-run cointegration with regional growth trend and negative short-run effects. Nevertheless, the system rapidly corrects disequilibria through cointegration.

Keywords: capture fisheries, aquaculture production, PCA, ADRL model, cointegration

JEL codes: Q22, O13, C22

Research objectives: Assess whether global aquaculture's rapid growth appears in the neighboring economies, and analyze Armenia's aquaculture production within the regional context.

Research novelty: Considering the scarcity of quantitative studies on Armenian aquaculture, this research provides econometric analysis of Armenia's aquaculture, linking national production to regional dynamics, and generates evidence-based insights for policy formulation.

Introduction

Production of aquatic foods has emerged as a cornerstone of global food security and sustainability. Global policy frameworks increasingly emphasize the role of aquatic foods in sustainable development, with Food and Agriculture Organization (FAO) Blue Transformation agenda calling for sustainable aquaculture expansion, effective fisheries management, and upgraded value chains aligned with the SDGs (FAO, 2024; FAO, 2021). Empirical evidence shows that while capture fisheries have plateaued near ecological limits, aquaculture has become the fastest-growing food sector, surpassing capture production since 2020 and now

providing more than half of global aquatic animal output (FAO, 2024).

Although aquaculture has rapidly emerged as a dominant source of seafood, its precise impact on capture fisheries remains contested. Scholars argue that aquaculture's rise often complements, rather than substitutes, wild fisheries (Longo & York, 2024), some studies find limited evidence of direct substitution or displacement (Cottrell et al., 2021). Racionero et al. (2020) noted that aquaculture expansion generates dynamic interactions with capture fisheries that can be interdependent, synergistic, or competitive.

Against this backdrop, Armenia's aquaculture sector has expanded more than tenfold since 1990s, achieving self-sufficiency levels above 130% and exporting nearly 44% of production. This trajectory offers a distinctive case of a landlocked transition economy increasingly tied to regional aquaculture dynamics and trade competitiveness.

In this context, it is important to investigate the dynamics of aquaculture production in the region and the impact of regional market pressures on Armenian production, considering entitlement of the country to start exporting aquaculture products to EU since March 2025.

Research methodology and data

This study draws on the FAO FishStat dataset *Global aquaculture production 1950–2023* (accessed 28 March 2025) and Armenia's Food Balances published by ArmStat. These sources

provide consistent time-series data on aquaculture and capture fisheries production at global, regional, and national levels.

To analyze the interdependencies between Armenia's aquaculture and regional dynamics, the production trajectories of seven neighboring economies bordering the Mediterranean, Black, and Caspian seas (Türkiye, Albania, Romania, Bulgaria, Ukraine, Georgia, and Azerbaijan) were examined alongside Armenia.

Descriptive analysis revealed marked heterogeneity: while some economies experienced rapid aquaculture growth, others stagnated or declined.

This heterogeneity justified the application of Principal Component Analysis (PCA) to extract diverse trajectories in the countries neighboring Armenia into two interpretable factors: a regional growth component and a divergence component. The PCA results confirmed the coexistence of shared regional dynamics and country-specific deviations, providing a parsimonious framework for econometric modeling.

In the final step, an Autoregressive Distributed Lag (ARDL) Error Correction Model incorporating the PCA-derived factors was estimated. This approach allowed identification of both long-run cointegration between Armenia's aquaculture and regional aquaculture growth, and short-run effects of divergence and volatility in the regional aquaculture production.

The PCA and ARDL modeling was performed using EViews v.13.

Research results

1. Descriptive analysis of global, regional, and Armenian aquaculture and capture fisheries trends.

Over the past six decades, global aquatic animal production has increased more than fivefold, with significant structural changes. Descriptive analysis confirms the divergence between aquaculture and capture fisheries: since 1990, aquaculture output expanded by 652%, while capture fisheries grew by only 8.6%. As a result, aquaculture surpassed capture fisheries in 2020, now accounting for more than half of global aquatic animal production (FAO, 2024).

This global transformation is strongly shaped by income levels. In 2023, 92% of aquaculture production originated in low- and upper-middle income countries (the World Bank's country classification), with 67% produced in the upper-middle income countries. In 1990-2023, the annual growth rate of aquaculture production in upper-middle income countries comprised 7%, while in the rest of the World – 5.5%.

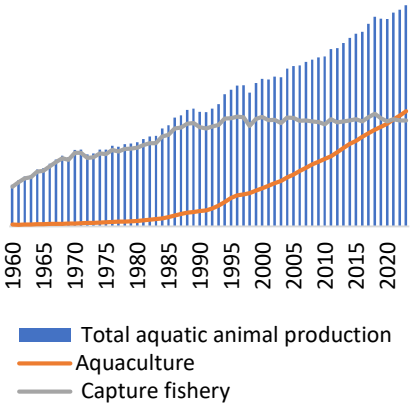


Figure 1. Global aquatic animal, aquaculture and capture fisheries production in 1960-2023, metric tons. Source: [2]

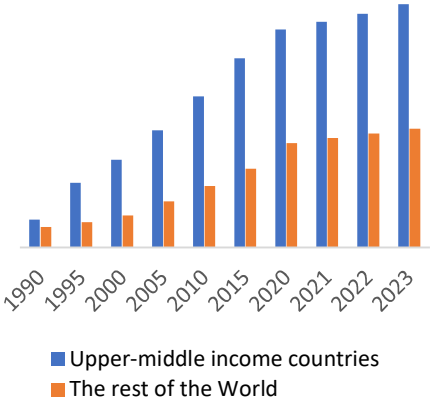


Figure 2. Dynamics of aquaculture production in 1990-2023 in the upper-middle income countries and in the rest of the World, metric tons. Source: [2]

Among 52 upper-middle income countries Armenia ranked 14th in 2023, with 24,800 metric tons of aquaculture production and being a landlocked country surpassed by maritime countries only.

Since 2007, aquatic animal production in Armenia increased fivefold and reached 25,900 tons in 2023, with aquaculture being the driver of this growth and accounting for 95.8% of total output.

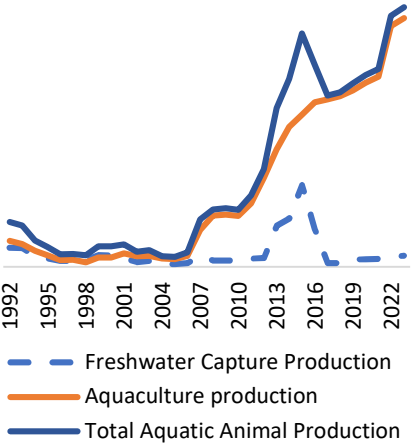


Figure 3. Aquatic animal, aquaculture and capture fisheries production in Armenia in 1992-2023, metric tons. Source: [2]

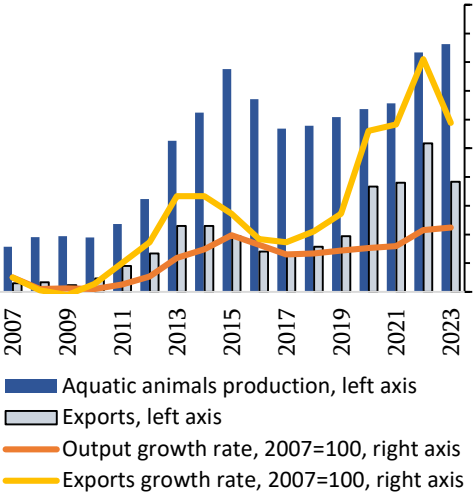


Figure 4. Aquatic animal production and exports in Armenia in 2007-2023, metric tons. Source: [7]

By 2012, Armenia had surpassed the threshold of 100% self-sufficiency in aquatic food products, and since 2013, the level of self-sufficiency has remained consistently above 100%, reaching

137% in 2023. Exports of aquatic animals have grown nearly 13 times in the same period, reaching 11,500 tons and accounting for 44.4% of the total output. This indicates a transition from subsistence-level production to a market-oriented, export-capable industry.

To understand Armenia's aquaculture competitiveness, regional aquatic animal production trends is reasonable to consider.

The analysis shows that economies in the region show divergent trajectories in aquaculture and capture fishery production. Table 1 illustrates these divergent patterns. Türkiye and Albania experienced rapid aquaculture growth, Bulgaria and Georgia show moderate growth, Romania and Ukraine - stagnation. In Georgia and Azerbaijan, the production remains dominated by capture fisheries, whereas Türkiye and Bulgaria demonstrate aquaculture production surpassed capture fisheries.

This heterogeneity underscores that the region cannot be characterized by a single trajectory of aquaculture. Instead, countries follow divergent paths shaped by geography, resource endowments, policy frameworks, and market integration. To capture these complex dynamics in a parsimonious way, Principal Component Analysis (PCA) was applied in the next step of the research. PCA enables the extraction of common regional growth factors while simultaneously accounting for divergence across countries, thereby providing a structured basis for subsequent econometric modeling.

Table 1. Aquaculture (AQ) and capture fisheries (CF) production dynamics in the region

Country	Country location	AQ average annual growth rate in 1992-2023, %	CF average annual growth rate in 1992-2023, %	Dynamics of AQ and CF	Dominant production mode (2023)
Türkiye	Mediterranean & Black seas	15.0	1.7	Rapid growth of AQ and stagnated CF	AQ, surpasses CF since 2020
Albania	Mediterranean & Adriatic seas	18.6	9.3	Rapid growth of AQ and gradual growth of CF	Neither dominant. Equal levels of AQ and CF
Bulgaria	Black sea	5.9	0.7	Moderate growth of AQ and stagnated CF	AQ, surpasses CF since 2012
Georgia	Maritime, Black sea	9.1	23.2	Rapid growth of CF and moderate growth of AQ	CF constantly dominates
Azer-baijan	Caspian sea/lake	8.5	11.1	Rapid growth of CF and moderate growth of AQ	CF constantly dominates
Romania	Black sea	-1.6	1.2	Decreased, then stagnated AQ and CF	Neither dominant. Equal levels of AQ and CF
Ukraine	Black sea	-3.7	-5.9	Decreased, then stagnated AQ and CF	Neither dominant. Equal levels of AQ and CF

Source: *Authors' analysis*

2. Principal Component Analysis results.

The PCA was conducted on the aquaculture production series of seven regional economies (Türkiye, Albania, Romania, Bulgaria, Ukraine, Georgia, and Azerbaijan), excluding Armenia to avoid endogeneity in subsequent econometric modeling. Table 2 reports the eigenvalues, proportions of variance, and cumulative variance explained by each principal component derived from aquaculture production. According to the Kaiser criterion, the results identified two dominant components with eigenvalues greater than one, jointly explaining 91.1% of the total variance - PC1 and PC2.

Table 2. Eigenvalues and variance explained by principal components

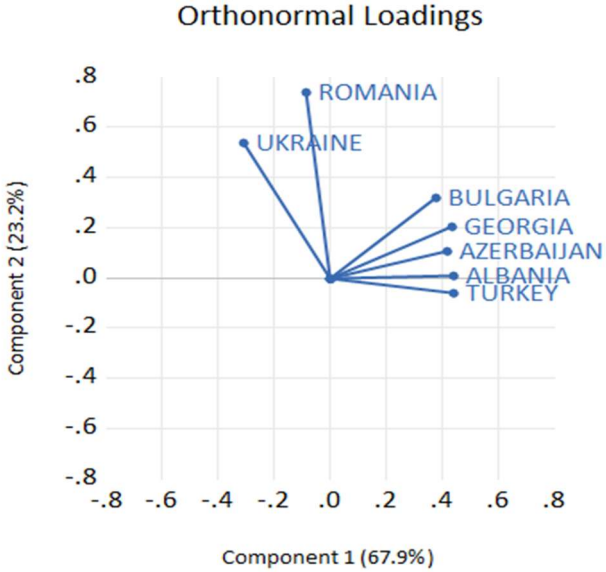
Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	4.752	3.125	0.679	4.752	0.679
2	1.627	1.345	0.232	6.379	0.911
3	0.282	0.108	0.040	6.661	0.952
4	0.174	0.051	0.025	6.834	0.976
5	0.123	0.089	0.018	6.957	0.994
6	0.034	0.025	0.005	6.991	0.999
7	0.009	---	0.001	7.000	1.000

Source: *Authors' analysis*

According to the loadings of each country on the first two principal components, the first component (PC1) captured the common regional *growth trend*, with strong positive loadings for Türkiye, Albania, Georgia, and Azerbaijan, reflecting their rapid or moderate aquaculture expansion. The second component (PC2)

represented *structural divergence*, driven primarily by Romania and Ukraine, where aquaculture growth has stagnated or declined. Bulgaria showed mixed contributions across both components.

Figure 5. PCA biplot of regional aquaculture trajectories



Source: *Authors' analysis*

These findings confirm that regional aquaculture dynamics are shaped by both a shared growth factor and country-specific deviations. By summarizing complex multi-country trajectories into two interpretable indices, PCA provides a parsimonious representation of regional dynamics. These indices are incorporated into the ARDL Error Correction framework to assess how Armenia's aquaculture production responds to long-run regional growth pressures and short-run divergence shocks.

3. ARDL Error Correction Model estimation results.

Following the extraction of regional growth and divergence factors through PCA, an ARDL Error Correction Model was estimated with Armenia's aquaculture production as the dependent variable and PC1 and PC2 – as the explanatory variables.

Unit root tests indicated a mixture of integration orders - Armenia's production and PC1 (regional growth factor) were integrated of order one, while PC2 (divergence factor) was stationary at level. This justified the use of the ARDL bounds testing approach. The Pesaran–Shin–Smith cointegration test confirmed the existence of a long-run relationship between Armenia's aquaculture production and the regional factors (F-statistic = 8.92, 1% upper bound I (1)=6.3).

The ARD (3,3,3) specification selected using the Akaike Information Criterion provided the best fit among alternative models. Residual diagnostics confirmed absence of serial correlation, homoskedasticity, stability of parameters (CUSUM test), and normally distributed errors, indicating that the model is robust and suitable for inference.

Long-run effects. The estimated cointegrating equation revealed that Armenia's aquaculture is structurally tied to the regional growth factor (PC1). A one-unit increase in PC1 is associated with an additional 4,170 tons of aquaculture output in Armenia, underscoring integration into the dominant regional expansion. By contrast, the divergence factor (PC2) carried a negative coefficient, but its long-run effect was weaker and less robust, suggesting that structural heterogeneity across regional economies does not exert a persistent drag on Armenia's trajectory.

Table 3. Cointegrating equation and error correction model

CE = ARMENIA(-1) - (4170.370716*PC1(-1) - 85.148912*PC2(-1) + 9196.809915)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ*	-0.55	0.09	-5.91	0.00
D(ARMENIA(-1))	0.06	0.15	0.41	0.68
D(ARMENIA(-2))	1.06	0.27	3.87	0.00
D(PC1)	-1,564.41	522.45	-2.99	0.01
D(PC1(-1))	-1,917.84	701.56	-2.73	0.01
D(PC1(-2))	-1,452.97	619.20	-2.35	0.03
D(PC2)	768.03	394.96	1.94	0.07
D(PC2(-1))	-212.25	314.16	-0.68	0.51
D(PC2(-2))	-1,473.62	399.76	-3.69	0.00
R-squared	0.76	Mean dependent var		801.03
Adjusted R-squared	0.66	S.D. dependent var		1244.40
S.E. of regression	722.16	Akaike info criterion		16.25
Sum squared resid	10,430,226.00	Schwarz criterion		16.68
Log likelihood	-226.65	Hannan-Quinn criter.		16.38
F-statistic	7.89	Durbin-Watson stat		2.18
Prob(F-statistic)	0.00			

Source: *Authors' analysis*

Short-run dynamics. In contrast to the long-run effect, the short-run coefficients of PC1 are consistently negative and statistically significant. This indicates that in the short-run regional growth shocks reduce Armenia's aquaculture output, likely reflecting competitive pressures, market crowding, or adjustment costs in the short term. While a change in PC2 has no immediate effect on Armenia's aquaculture, a shock from two periods ago has a significant negative impact. This suggests a delayed, but strong,

negative short-run relationship. These findings highlight a dual dynamic: Armenia's aquaculture ultimately benefits from regional growth in the long run, but in the short run, it is vulnerable to adverse spillovers from regional aquaculture production.

Error correction mechanism. The error correction term is negative and highly significant (–0.55), implying that approximately 55% of any deviation from the long-run equilibrium is corrected within a year. This relatively fast speed of adjustment confirms that Armenia's aquaculture production is anchored to the regional growth path, with disequilibria resolved smoothly over time.

Conclusion

Econometric modeling confirmed a long-run cointegrating relationship between Armenia's aquaculture and the regional sectoral dynamics. Armenia's production is strongly and positively associated with the regional growth of aquaculture, underscoring structural integration into the broader expansion of aquaculture in the Mediterranean–Black Sea–Caspian region. In the short run, however, both regional aquaculture growth and divergence shocks transmit negatively into Armenia's production, reflecting exposure to volatility and competitive pressures. Nevertheless, more than half of any disequilibrium is corrected annually.

Importantly, as of 16 March 2025, Armenia is officially entitled to export high-quality aquaculture products to EU Member States. This new market access amplifies the relevance of the findings: Armenia stands to benefit from long-run regional integration, but resilience-oriented policies are essential to mitigate short-run instability and fully capitalize on emerging export opportunities.

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ՏԱՐԱԾԱՇՐՋԱՆԻ և ՀԱՅԱՍՏԱՆԻ ՋՐԱՅԻՆ ԿՈՒԼՏՈՒՐԱՆԵՐԻ ԱՐՏԱԴՐՈՒԹՅԱՆ ԴԻՆԱՄԻԿ ՓՈԽԿԱՊԱԿՑՎԱԾՈՒԹՅՈՒՆՆԵՐԸ՝ ԳԼԽԱՎՈՐ ԲԱՂԱԴՐԻՉՆԵՐԻ ՎԵՐԼՈՒԾՈՒԹՅԱՆ և ՍԽԱԼՆԵՐԻ ՈՒՂՂՄԱՄԲ ԲԱՇԽՎԱԾ ԼԱԳԵՐՈՎ ԱՎՏՈՌԵԳՐԵՍԻԱՅԻ ՄՈԴԵԼԻ ԱՐԴՅՈՒՆՔՆԵՐՈՎ

Նաիրուհի Ջրբաշյան
Երևանի պետական համալսարան, տ.գ.թ., դոցենտ

Գայանե Ղուկասյան
Երևանի պետական համալսարան, ֆիզ.-մաթ. գ. թ., դոցենտ

Բանալի բառեր - ձկնորսություն, ջրային կուլտուրաների արտադրություն, PCA, ADRL մոդել, կոինտեգրացվածություն

Ջրային կուլտուրաների արտադրությունը պարենի արտադրության աշխարհում ամենաարագ աճող ոլորտն է և պարենային ապահովության և սնուցման գրավականներից մեկը: Հայաստանում ջրային կուլտուրաների արտադրությունը վերջին երեք տասնամյակներին աճել է շուրջ տասն անգամ: Այս համատեքստում կարևոր է ուսումնասիրել տարածաշրջանում ջրային կուլտուրաների արտադրության դինամիկան և տարածաշրջանային շուկայի ճնշումների ազդեցությունը հայկական արտադրության վրա՝ հաշվի առնելով երկրի իրավունքը՝ սկսել ջրային կուլտուրաների արտահանումը ԵՄ:

Այս հետազոտությունը վերաբերում է տարածաշրջանում ջրային կուլտուրաների արտադրության ազդեցությանը՝ հայկական արտադրության վրա: Գլխավոր բաղադրիչների վերլուծության միջոցով առանձնացվել են ջրային կուլտուրաների արտադրության տարածաշրջանային աճի և տարամիտման գործոնները, որոնք այնուհետև ներառվել են սխալների ուղղմամբ բաշխված լագերով ավտոռեգրեսիայի մոդելի շրջանակում: Արդյունքները բացահայտել են տարածաշրջանային աճի միտման հետ Հայաստանի արտադրության երկարաժամկետ կոինտեգրացվածություն և կարճաժամկետ բացասական ազդեցություն:

Այնուամենայնիվ, համակարգը արագորեն շտկում է շեղումները և նույն տարվա ընթացքում վերադառնում երկարաժամկետ հավասարակշռությանը:

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