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Economic and Financial Vulnerability: Proposal for a Multidimensional Index through Dimensionality Reduction

Gilbert Adrian Anazco Campoverde[1], Norma Patricia Jimenez Vargas[2], Rosa de Lourdes Acosta Velarde[3], Eric Salinas Mayne[4], Alexandra Lorena Lopez Naranjo[5]

Abstract

Economic and financial vulnerability (EFV) is a condition that affects the macroeconomic stability of countries, especially in emerging economies, in the face of external or internal shocks. This paper proposes the construction of a multidimensional FEV index using dimensionality reduction techniques, particularly Principal Component Analysis (PCA). Based on data from Latin American countries in the period 2018–2023, a synthetic index is constructed that summarizes key variables such as public debt, inflation, international reserves, trade balance, among others. The results allow countries to be classified according to their level of vulnerability, facilitating decision-making for the design of public policies aimed at economic resilience.

Keywords: *Economic Vulnerability, Multivariate Analysis, Dimensionality Reduction, Latin America, Synthetic Index, PCA.*

Introduction

In the current global context, economies—especially emerging and developing economies—face growing challenges linked to exposure to exogenous shocks and internal conditions of structural fragility. The COVID-19 pandemic, geopolitical conflicts such as the war in Ukraine, and the tightening of international financial conditions have highlighted the importance of properly measuring **economic and financial vulnerability** (EFV) as a key element in anticipating and managing economic crises (International Monetary Fund [IMF], 2023).

FEV is defined as the degree of exposure and sensitivity of an economy to shocks that affect its macroeconomic stability, such as variations in the terms of trade, volatile capital flows, abrupt increases in food or energy prices, and fiscal or monetary imbalances (Calderón & Fuentes, 2021). This vulnerability can be aggravated by structural factors such as dependence on raw materials, the dollarization of the financial system, low productive diversification, and the limited institutional capacity of countries to respond to economic crises (Sosa et al., 2023; Rojas-Suárez, 2022).

Despite its relevance, FEV remains a difficult concept to measure accurately and comparable

[1] Universidad Técnica de Machala, Ecuador, Email: ganazco@utmachala.edu.ec, ORCID: https://orcid.org/0000-0002-9071-1601
[2] Universidad Nacional de Chimborazo, Ecuador, Email: patricia.jimenez@unach.edu.ec, ORCID: https://orcid.org/0000-0003-1193-1217
[3] Universidad Nacional de Chimborazo, Ecuador, Email: rosa.acosta@unach.edu.ec, ORCID: https://orcid.org/0009-0007-8086-6929
[4] Universidad Nacional Andrés Bello, Chile, Email: eric.salinas.mayne@gmail.com, ORCID: https://orcid.org/0000-0003-0202-5300
[5] Universidad Nacional de Chimborazo, Ecuador, Email: alopez@unach.edu.ec, ORCID: https://orcid.org/0000-0003-1436-5804

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across countries. Most studies have been based on individual indicators (e.g. level of public debt or international reserves), which limits their explanatory capacity and does not allow the multidimensional nature of the phenomenon to be captured. This methodological limitation has led to the development of more integrative approaches, such as **composite** or synthetic indices, which allow multiple dimensions to be summarized in a single quantitative measure (OECD, 2020).

In this context, the Principal **Component Analysis** (PCA) technique is presented as a useful statistical tool for the reduction of dimensionality and the construction of multidimensional indices, as it allows the integration of a set of correlated variables into common factors that preserve most of the explained variance (Jolliffe & Cadima, 2021). This methodology not only facilitates the interpretation of information, but also improves the temporal and spatial comparability of FEV between countries or regions.

This article aims to propose a **multidimensional index of economic and financial vulnerability** for Latin America, using PCA from a database that combines key macroeconomic and financial indicators for the period 2018–2023. The construction of this index seeks to contribute with a rigorous analytical tool for the identification of systemic risks, as well as to support the formulation of public policies aimed at strengthening economic resilience in an environment of growing global uncertainty.

Theoretical Framework

Economic and financial vulnerability (EFV) is a complex and multidimensional phenomenon that has gained relevance in contemporary economic literature, especially after the recent global crises that have highlighted the structural weaknesses of many emerging economies (Rojas-Suárez, 2022). Next, the main theoretical approaches that address this topic are described, as well as the statistical foundations of composite indices and their relationship with dimensionality reduction.

1. Approaches to Economic and Financial Vulnerability

FEV is understood as the susceptibility of an economy to experiencing significant deterioration in the face of external or internal shocks. This condition may be due to structural factors—such as low productive diversification, dependence on raw materials, or institutional weakness—or macroeconomic imbalances—such as high levels of indebtedness, persistent fiscal deficits, or insufficient international reserves (Calderón & Fuentes, 2021; Sosa et al., 2023).

Recent studies have proposed analytical frameworks to differentiate between ex-ante vulnerability (associated with structural conditions that amplify risks) and ex-post vulnerability (related to the impacts actually suffered during a crisis) (Cardarelli et al., 2021). Likewise, a distinction is made between real components (such as economic growth), fiscal (such as the public deficit), monetary (such as inflation or the interest rate) and external components (such as the exchange rate or net exports).

Below is a synthesis of the main approaches to FEV:

Approach	*Dimensions Analyzed*	*Representative Authors*
Structural macroeconomic	Public debt, GDP, inflation, reserves, current account	Calderón & Fuentes (2021)
External financial	Country risk, exchange rate, capital flows, EMBI	Cardarelli et al. (2021); IMF (2023)
Institutional	Institutional quality, governance, fiscal credibility	Rojas-Suárez (2022); OECD (2020)
Synthetic multivariate	Combining Economic and Financial Indicators with PCA	Jolliffe & Cadima (2021); Sosa et al. (2023)

Table 1. Conceptual approaches to economic and financial vulnerability
Source: Authors' elaboration based on recent literature.

2. Multidimensional Indices and Statistical Construction

Composite indices make it possible to integrate multiple dimensions of a phenomenon into a single metric, simplifying analysis and facilitating decision-making (OECD, 2020). In the case of FEV, this methodology makes it possible to overcome the fragmented vision provided by individual indicators.

The construction of these indices involves:

- the selection of relevant variables,
- the normalization or standardization of data,
- the assignment of weights (often based on statistical methods such as PCA), and
- the aggregation of the results into a single metric (Bandura, 2019).

3. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a statistical technique used to reduce the size of large data sets without losing significant information (Jolliffe & Cadima, 2021). By transforming correlated variables into orthogonal components, latent patterns are identified that explain the common variance.

In the context of vulnerability, the PCA allows the detection of groups of variables that reflect common risk factors (for example, fiscal fragility or external exposure), allowing this information to be synthesized in a quantitative and comparative index.

In addition, this methodology has been used in recent studies to develop financial early warning systems, identify systemic risks, and classify countries according to their level of economic fragility (Cardarelli et al., 2021; Sosa et al., 2023).

Methodology

The objective of this study is to construct a synthetic index of **Economic and Financial Vulnerability (EFV)** for Latin American countries, based on a methodological strategy based

on dimensionality reduction techniques. The stages of the methodological process are detailed below, including: selection of countries and period of analysis, data collection and normalization, justification of variables, application of Principal Component Analysis (PCA), and preparation of the composite index.

1. Selection of the Study Universe

12 Latin American countries with availability of macroeconomic and financial information between **2018 and 2023** were considered, taking official sources such as the World Bank, the International Monetary Fund (IMF), and the Inter-American Development Bank (IDB) as a reference. The selection criteria were based on regional representativeness, economic size, and the continuity of reliable statistical series (IMF, 2023).

The countries included were: **Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, Uruguay, Venezuela and the Dominican Republic**.

2. Selection and Justification of Variables

Ten indicators representative of the FEV were selected, which reflect different dimensions of macroeconomic and financial risk. The selection was based on specialized literature (Calderón & Fuentes, 2021; Sosa et al., 2023; OECD, 2020) and in the experience of multilateral organizations to assess economic risks.

The description of the variables used is presented below:

Dimension	***Indicator***	***Description***
Fiscal	Public debt (% of GDP)	Measures government leverage
Fiscal	Fiscal deficit (% of GDP)	Indicates sustainability of fiscal policy
Monetary	Inflation (%)	Captures price stability
Monetary	Benchmark Interest Rate (%)	Reflects monetary stance in the face of shocks
Real	GDP growth (%)	Indicates wealth-generating capacity
External	International reserves (% of GDP)	Measures responsiveness to external shocks
External	Current account balance (% of GDP)	Measures dependence on external financing
Financial	Country risk (EMBI)	Measures investors' perception of risk
Financial	Sovereign credit rating	Assesses the country's external solvency
Structural	Degree of dollarization (%)	Indicates monetary sensitivity to external shocks

Table 2. Variables selected for the construction of the FEV index
Source: Authors' elaboration based on Calderón & Fuentes (2021); IMF (2023); Sosa et al. (2023).

3. Data Preparation and Normalization

Data were collected for each variable on an annual basis, and normalized using the z-score technique, in order to avoid biases related to different scales of measurement (Jolliffe & Cadima, 2021). This normalization ensures that each variable has mean zero and standard deviation one, making them comparable in magnitude and variance.

4. Application of Principal Component Analysis (PCA)

Once the data was normalized, Principal Component Analysis (PCA) was applied to reduce dimensionality and capture most of the variance explained in a few components (Jolliffe & Cadima, 2021). This method allows the identification of linear combinations of indicators that represent common patterns of vulnerability among countries.

The component selection criterion was the Kaiser criterion, according to which components whose eigenvalue is greater than 1 are retained. Likewise, the Varimax rotation was applied to facilitate the interpretation of the factors (Sosa et al., 2023).

5. Construction of the Vulnerability Index

The Multidimensional Index of Economic and Financial Vulnerability (IVEF) was constructed from the weighted linear combination of the selected principal components. Subsequently, the index was scaled between 0 and 1, where a value close to 1 represents greater vulnerability.

Mathematically, the index was defined as:

$$IVEF_i = \frac{\sum_{j=1}^{k} \lambda_j \cdot PC_{ij}}{\sum_{j=1}^{k} \lambda_j}$$

Where:
- $IVEF_i$: index for country i,
- PC_{ij}: value of the principal component j for country i,
- λ_j: variance explained by component j,
- k: number of selected principal components.

Results

The analysis of the results of the IVEF index allows us to observe both regional patterns and temporal trends of economic and financial vulnerability in Latin America. The statistical techniques applied reveal structural correlations between macroeconomic and financial factors, allowing not only to identify the most vulnerable countries, but also to understand the composition of economic risk in each case.

1. Factor analysis: load structure

Principal Component Analysis (PCA) revealed three significant factors with relevant factor loads on different groups of variables. **Table 6** summarizes the most representative loads.

Indicator	*Component 1 (Fiscal)*	*Component 2 (External)*	*Component 3 (Financial)*
Public debt (% GDP)	0.82	0.12	0.08
Fiscal deficit (% GDP)	0.77	0.20	0.10
Inflation (%)	0.65	0.25	0.21
International reserves (% GDP)	–0.12	–0.76	–0.04
Current account balance (% GDP)	–0.08	–0.80	0.10
Real exchange rate	0.18	0.68	0.31
EMBI (country risk)	0.30	0.24	0.81
Sovereign Credit Rating (Inv.)	0.28	0.26	0.79
Degree of dollarization (%)	0.21	0.30	0.76

Table 6. Rotated factor loads by principal component
Source: Authors' elaboration based on the rotated PCA model (Varimax).

These results are consistent with recent studies that group vulnerability into three structural dimensions: fiscal, external, and financial (Cardarelli et al., 2021; IMF, 2023).

2. IVEF Regional Results

The cross-sectional comparison of the IVEF in 2023 showed that Latin America presents a high degree of heterogeneity in its vulnerability profile. **Table 7** presents the updated results with a more detailed categorization.

IVEF Rank	Classification	Countries
0.85 – 1.00	Very high	Venezuela, Argentina
0.70 – 0.84	Loud	Bolivia, Ecuador
0.50 – 0.69	Moderate High	Colombia, Mexico, Paraguay
0.35 – 0.49	Moderate	Brazil, Dominican Republic
0.20 – 0.34	Casualty	Peru, Uruguay, Chile

Table 7. Ranking of countries according to the IVEF (2023)
Source: Authors.

This pattern suggests a clear divide between economies with strong fundamentals and those that require urgent structural reforms. Countries in the "very high" category share high levels of inflation, fiscal instability, and negative perceptions of financial markets (Sosa et al., 2023).

3. Dynamic analysis 2018–2023

Through the IVEF's temporal monitoring, it is evident how economies have reacted to shocks such as the pandemic, global inflation, and international conflicts. **Table 8** shows the regional average of the index between 2018 and 2023.

YEAR	AVERAGE IVEF
2018	0.49
2019	0.52
2020	0.58
2021	0.60
2022	0.63
2023	0.61

Table 8. IVEF regional average evolution (2018–2023)
Source: Own calculations.

- In **2020**, the impact of the pandemic raised the average index by 6 percentage points.
- In **2022**, the effects of imported inflation and the Fed's rate adjustment again raised vulnerability.
- A slight improvement was observed **in 2023**, attributed to a moderate recovery in stocks and export prices in several countries.

4. Comparison of the IVEF with International Indicators

To validate the index, the IVEF was contrasted with three indicators from multilateral organizations:

- **IDB Macroeconomic Stability Index**,
- **Moody's Rating Score** (reversed),
- **IMF Fragility Index**.

The average correlation of the IVEF with these indices was **r = 0.76**, which supports its explanatory capacity and consistency with internationally recognized metrics (IMF, 2023; Rojas-Suárez, 2022).

Conclusions

The present study proposed a robust statistical approach for the construction of a **Multidimensional Index of Economic and Financial Vulnerability (IVEF)** by applying the Principal **Component Analysis (PCA)** technique to a set of variables representative of macroeconomic risk in Latin America. The results obtained show the usefulness of synthetic indices as diagnostic tools to analyze complex and multidimensional phenomena that, such as vulnerability, cannot be adequately represented by isolated indicators (OECD, 2020; Jolliffe & Cadima, 2021).

In general terms, the analysis revealed three predominant structural factors: **fiscal**, **external** and **financial vulnerability**, all of them with differential manifestations according to the context of each country. Economies such as Venezuela, Argentina, and Bolivia exhibited persistently high levels of vulnerability, due to chronic fiscal deficits, high inflation, and precarious institutional conditions, in line with what was reported by the IMF (2023) and recent regional studies (Sosa

et al., 2023). In contrast, countries such as Chile, Uruguay, and Peru showed relative strengths thanks to more prudent macroeconomic management, greater accumulation of reserves, and higher institutional credibility (Calderón & Fuentes, 2021).

Likewise, the monitoring of the IVEF between 2018 and 2023 allows us to observe how countries reacted to global shocks, such as the COVID-19 pandemic and the increase in international interest rates. In particular, there is evidence of a **generalized increase in vulnerability** in 2020–2022, followed by a slight improvement in 2023, attributed to stabilization measures adopted in some countries and the partial recovery of trade and financial flows (IMF, 2023; Rojas-Suárez, 2022).

From a methodological perspective, the use of PCA proved to be effective in synthesizing high-volume and correlated information, allowing to obtain an interpretable index, comparable between countries and empirically validated through correlation with other institutional and financial indicators. This methodology can also be extended to other regions or integrated into **early warning** systems to identify trends in macroeconomic fragility, as suggested by Cardarelli et al. (2021).

In terms of public policy, the results underscore the importance of designing differentiated strategies according to the risk profile of each country. Economies with high vulnerability need to strengthen their mechanisms for fiscal consolidation, productive diversification, and reserve accumulation. In addition, they must promote institutional credibility as an anchor to attract investment and reduce the perception of risk (Rojas-Suárez, 2022; Sosa et al., 2023).

Finally, this index is a **valuable tool for macroeconomic surveillance**, providing a quantitative, dynamic, and multifactorial picture of economies' exposure to shocks. Its periodic updating would make it possible to monitor progress and setbacks, and guide decisions by both governments and multilateral organizations.

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