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**Research Article**
Human Talent

# Analysis of the relative efficiency in the trade balance of the departments of Colombia

Análisis de la eficiencia relativa en la balanza comercial de los departamentos de Colombia

Análise da eficiência relativa na balança comercial dos departamentos da Colômbia

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## Abstract

**Introduction:** This study analyzed indicators from Colombian departments to establish the inputs and outputs necessary for Data Envelopment Analysis (DEA). The trade balance served as the basis for this study, as it is a key indicator of regional economic performance. **Objective:** Key trade balance indicators were identified and analyzed, as well as other relevant factors influencing departmental economic efficiency. **Methodology:** A quantitative and descriptive approach was used to collect and organize data from the last five years, aimed at understanding logistics infrastructure and trade flows. **Results:** The findings revealed a high concentration of efficiency in the central and western departments of the country, revealing marked structural differences between regions. **Discussion:** The quality and inconsistency of the different official database sources represented the main obstacle to the study. This indicated that the greatest challenge was collecting and constructing a reliable database prior to the application of the analytical model. **Conclusion:** A structured and comprehensive database was successfully developed, which was essential for the subsequent stages of the study and for the analysis of the commercial efficiency of Colombian departments, with Bogotá emerging as the most efficient city.

**Keywords:** international trade; exports; imports; transportation infrastructure; data processing.
**JEL:** C67; F10; M21; O11; O18; R40.

## Resumen

**Introducción:** Este estudio analizó indicadores de los departamentos colombianos para establecer los inputs (entradas) y outputs (salidas) necesarias para el Análisis Envolvente de Datos (DEA). La balanza comercial fue la base de este estudio, siendo un indicador clave del desempeño económico regional. **Objetivo:** Se identificaron y analizaron los indicadores clave de la balanza comercial, así como otros factores relevantes que influyeron en la eficiencia económica departamental. **Metodología:** Se utilizó un enfoque cuantitativo y descriptivo para recolectar y organizar datos de los últimos cinco años, con el objetivo de comprender la infraestructura logística y los flujos comerciales. **Resultados:** Los hallazgos demostraron una alta concentración de eficiencia en los departamentos del centro y occidente del país, evidenciando marcadas diferencias estructurales entre las regiones. **Discusión:** La calidad e inconsistencia de las diferentes fuentes de bases de datos oficiales representaron el principal obstáculo del estudio. Esto mostró que el mayor desafío fue la recopilación y construcción de una base de datos confiable antes de la aplicación del modelo analítico. **Conclusión:** Se logró desarrollar una base de datos estructurada y completa, esencial para las etapas posteriores del estudio y para el análisis de la eficiencia comercial de los departamentos colombianos, dando como resultado a la ciudad de Bogotá como la más eficiente.

**Palabras clave:** comercio internacional; exportaciones; importaciones; infraestructura de trasportes; procesamiento de datos.

**JEL:** C67; F10; M21; O11; O18; R40.

## Resumo

**Introdução**: Este estudo analisou indicadores dos departamentos colombianos para estabelecer os inputs (entradas) e outputs (saídas) necessários para a Análise Envolvente de Dados (DEA). A balança comercial foi a base deste estudo, sendo um indicador-chave do desempenho económico regional. **Objetivo**: Foram identificados e analisados os indicadores-chave da balança comercial, bem como outros fatores relevantes que influenciaram a eficiência económica departamental. **Metodologia**: Foi utilizada uma abordagem quantitativa e descritiva para recolher e organizar dados dos últimos cinco anos, com o objetivo de compreender a infraestrutura logística e os fluxos comerciais. **Resultados**: As conclusões demonstraram uma elevada concentração de eficiência nos departamentos do centro e oeste do país, evidenciando diferenças estruturais marcantes entre as regiões. **Discussão**: A qualidade e a inconsistência das diferentes fontes de bases de dados oficiais representaram o principal obstáculo do estudo.

Isto mostrou que o maior desafio foi a recolha e construção de uma base de dados fiável antes da aplicação do modelo analítico. **Conclusão**: Conseguiu-se desenvolver uma base de dados estruturada e completa, essencial para as etapas posteriores do estudo e para a análise da eficiência comercial dos departamentos colombianos, resultando na cidade de Bogotá como a mais eficiente.

**Palavras-chave:** comércio internacional; exportações; importações; infraestrutura de transportes; processamento de dados.
**JEL:** C67; F10; M21; O11; O18; R40.

# Introduction

Analyzing resource utilization in Colombian departments is crucial for effectively managing the trade balance and thereby enhance regional economic development. Disparities in resource efficiency, as reflected in their capacity to manage exports and imports, directly affect the competitiveness of each region. It is essential to measure indicators such as infrastructure, economic resources, and human capital, evaluating the results they generate to design public policies that promote growth (Abreo et al., 2021).

The Outlook for Colombian foreign trade, especially as reflected in the figures for 2024, shows persistent structural vulnerability. Although there was a slight contraction in the total value of exports (0.4%), which amounted to approximately 49.552 billion USD FOB (Free On Board), this decline was mainly associated with the mining and energy sector. This underscores the historical dependence on commodities of the country, a reality that international organizations have urged to reduce in order to mitigate exposure to volatile markets (OECD, 2024). However, this complex context also showed signs of diversification, with an increase in the total export volume and a notable upturn in the performance of non-traditional sectors, particularly agroindustry and manufacturing.

This economic situation highlights the critical importance of analyzing regional capacities to take advantage of trade opportunities, and overcoming structural limitations that affect resource efficiency and national competitiveness. The context of this problem is framed by the economic and logistical disparities that exist between Colombian departments, where some have more developed infrastructure and greater capacity to generate exports, whereas

others face limitations that reduce their competitiveness. These factors are reflected in the trade balance, which, depending on the efficient use of resources, can be positive or negative.

The social, economic, and cultural dimensions of the problem are reflected in the impact that regional inequalities in efficiency have on living conditions, their access to economic opportunities, and the capacity for sustainable growth. A proper analysis of efficiency indicators will enable better resource management and contribute to more balanced and competitive economic development at the national level.

Therefore, this research contributes to the understanding of commercial efficiency at the departmental level by applying DEA (Data Envelopment Analysis) to identify and measure structural disparities in the relative performance of regions. The DEA model is a non-parametric methodology used to evaluate the relative efficiency of homogeneous Decision-Making Units (DMUs) that transform multiple inputs into outputs. The study identifies which departments make the most efficient use of their available resources to generate commercial results. In addition, the analysis of these inequalities serves as a basis for identifying best practices and the design of policies that promote more competitive territorial development in terms of foreign trade.

Therefore, the central question of this research is: Which departments in Colombia demonstrate greater or lesser relative efficiency in the use of their inputs to generate outputs according to the DEA model?

**Logistics infrastructure: National and International Perspective**

The Ministry of Transportation defines logistics infrastructure as the set of facilities, services, and networks that enable the efficient transport, storage, and distribution of goods. Its quality and development are decisive factors in international trade, directly affecting the costs and times of exports and imports. (Ministerio de Transporte [Ministry of Transportation], 2024).

In terms of international logistics infrastructure, the 2023 Logistics Performance Index of the World Bank report highlights that in emerging countries, the digitization of supply chains can significantly reduce port delays by up to 70% compared to developed countries (Banco

Mundial [World Bank], 2023). This reflects the importance of implementing advanced technologies to streamline processes and improve competitiveness. Regarding information on logistics costs in Colombia, according to the National Planning Department (DNP), national logistics costs have been a major challenge. At the national level, logistics costs stand at 17.9% of gross domestic product (GDP), which is above the 12.9% target established in the National Logistics Policy. This level of costs reflects barriers and deficiencies in infrastructure, such as road, rail, and port connectivity, which continue to affect the efficiency of the logistics sector in the country (Departamento Nacional de Planeación [National Planning Department], 2021).

The International Monetary Fund has warned that logistics costs in Colombia, measured as a percentage of business sales, average 12.6%. This proportion, largely driven by domestic transport, becomes a critical factor that limits the competitiveness of exports and generates cost overruns in supply chains of the Fondo Monetario Internacional (2023). In this regard, reducing these costs is key to expanding the diversification and scope of national exports.

**CCR Methodology of the DEA Model**

The DEA model was first introduced by Charnes, Cooper, and Rhodes in 1978, in what is known as the CCR model, named after their surnames. This model assumes constant returns to scale, which implies that a proportional increase in inputs will generate a proportional increase in outputs. In other words, the CCR model is based on linear programming to construct an efficient frontier and calculate the relative efficiency of each DMU in comparison to that frontier (Charnes et al., 1978).

In the context of logistics infrastructure and international trade, the application of DEA allows us to identify region (e.g., Colombian departments) that make the most efficient use of their available resources to generate positive trade results, such as export value. In this particular case, the use of three inputs (the level of logistics infrastructure, economically active population, and territorial area), and three outputs (exporting companies, competitiveness index, and exports in 2024) is proposed.

The CCR approach has proven particularly suitable when the units analyzed operate under a constant production scale and an objective tool is required to evaluate relative performance without the need to know a priori the functional form of the relationship between inputs and outputs (Cooper et al., 2011).

Applying the CCR model at the departmental level in Colombia allows us to explore how logistical resources (such as roads, dry ports, free trade zones, and logistics platforms) and business resources (export companies) translate into tangible results in the trade balance. This analysis is crucial for identifying regional inequalities, guiding strategic investments, and designing policies that promote more balanced and competitive territorial development.

**Super-efficiency of the DEA model**

The super-efficiency technique in the context of the DEA model emerges as an extension of the classical model, designed to differentiate among units that have been classified as efficient under the traditional approach. In the CCR model, DMUs located on the efficient frontier obtain an efficiency score equal to 1, which prevents the establishment of a hierarchy among them. Super-efficiency overcomes this limitation by excluding the evaluated DMU from the construction of the efficient frontier, making it possible to assign it an efficiency value greater than 1 (Andersen & Petersen, 1993).

This methodology is particularly advantageous in comparative studies where it is necessary to establish an efficiency ranking among the best units, as is the case in institutional performance evaluations, benchmarking among regions, or processes for allocating limited resources. Super-efficiency provides a more discriminating perspective, identifying not only which units are efficient, but also how efficient they are in relation to their equally efficient peers. Along the same lines of research, the application of DEA models with super-efficiency has proven to be a useful tool for evaluating and classifying units of analysis in contexts of regional competitiveness (Camargo y Quintero, 2018).

In the case of analyzing logistics infrastructure and the trade balance at the departmental level in Colombia, the application of the super-efficiency model is particularly relevant. Given that several departments may achieve optimal efficiency levels under the CCR approach, super-efficiency allows for a more accurate assessment of which of these departments make exceptional use of their resources. This differentiation is key to prioritizing public policies, identifying best practices, and directing strategic investments toward areas with greater logistical and commercial returns.

# Methodology

The research was conducted using a quantitative approach, characterized by the collection and analysis of objective and measurable data, which ensured accuracy in the processing of information. This approach focused on identifying key indicators related to the logistics infrastructure and trade balance of Colombian departments. To this end, reliable sources were used, such as official databases, national statistics, and specialized reports.

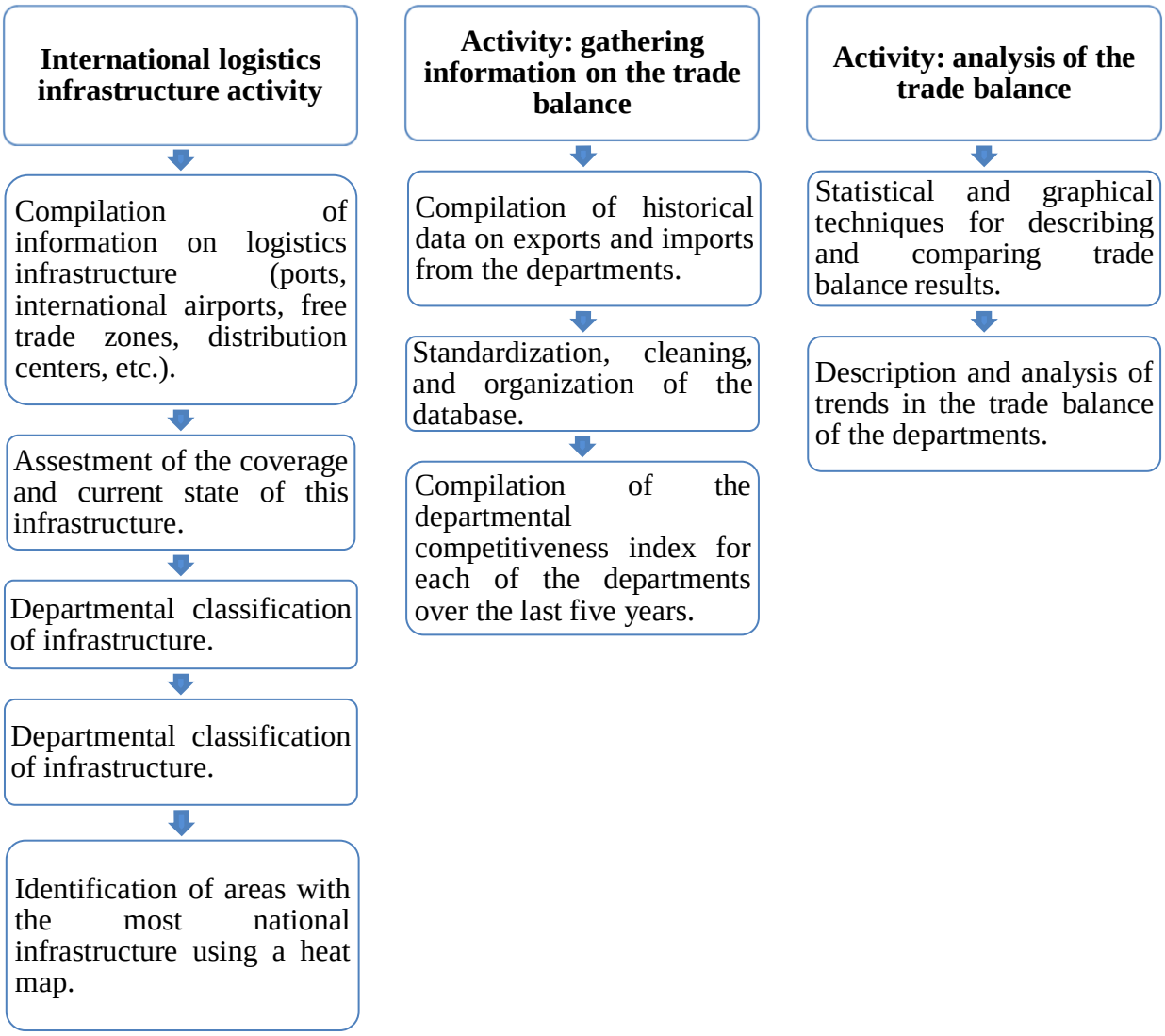
The descriptive scope of the research made it possible to characterize the current conditions of the logistics infrastructure and international trade dynamics in each department. This included analyzing data from the last five years, identifying patterns, trends, and possible inequalities between departments.

**Components and activities**

Three main components were carried out in the methodological development of the research, each consisting of specific activities aimed at meeting the proposed objectives. Figure 1 schematically presents the stages of the research process. These include the collection of information on logistics infrastructure, the compilation and cleaning of data related to the trade balance, and the statistical analysis of the results obtained. Each phase is articulated sequentially, allowing progress from the identification of resources to the interpretation of the commercial efficiency of departments of Colombia.

**Figure 1**

*Diagram of conducted activities*




*Source*: Prepared by the authors.

**Procedures**

The procedures developed in the research allowed for the orderly structuring of the stages of data collection, organization, and analysis, ensuring the methodological consistency of the study and the reliability of the results. Each procedure followed a logical sequence aimed at achieving the objectives.

- **Data collection:** Numerical and statistical information related to the logistics infrastructure and trade balance of the departments was compiled.
- **Organization of information:** The data were classified and structured into categories relevant for effective analysis.

- **Analysis of results:** Analytical techniques were applied to interpret the data and draw meaningful conclusions that would enable the research objectives to be achieved.

### Setting and population

The study population included the 32 departments of Colombia, and the capital district. The setting focused on economic and logistical data obtained at the national and regional levels over the past five years.

### Analysis and interpretation of results

The results were analyzed in relation to specific objectives. The analysis made it possible to interpret the factors that influenced the efficiency of each department. To this end, the RStudio tool, integrated with the R programming language, was used to optimize statistical analysis and graphical computing, facilitating the organization, processing, and analysis of export and import databases. Finally, the results were presented in reports and graphs reflecting the conclusions of the project, facilitating their understanding by key actors, such as public and private institutions.

This methodology guarantees a solid foundation for the subsequent application of the DEA, providing inputs that enable the evaluation of departmental performance in terms of logistics and trade.

## Results

### International logistics infrastructure

As part of the study on national logistics infrastructure, information was gathered from various official sources. The entities included: Aeronáutica Civil (2022), Agencia Nacional de Contratación Pública [National Public Producrement Agency] (2021), Agencia Nacional de Infraestructura - ANI [National Infrastructure Agency] (2024), Alianza por Venezuela (2022), Actualícese (2024), Asociación Nacional de Comercio Exterior [The National Administrative Department Foreign Trade] - Analdex (2024), Departamento Administrativo Nacional de Estadística [The National Administrative Department of Statisstics] - DANE (2025), Dirección de Impuestos y Aduanas Nacionales [The National Tax and Customs Directorate] - DIAN

(2024), Ministerio de Comercio, Industria y Turismo [Ministry of Commerce, Industry, and Tourism] (2022), PROCOLOMBIA (2024), and the Superintendencia de Transporte [Superintendence of Transportation] (2024).

Decree 1165 of 2019, issued by the Ministry of Finance and Public Credit, regulates the Customs Regime in Colombia and establishes the legal relationships between the customs administration (DIAN) and the various actors in foreign trade, such as importers, exporters, carriers, and users of primary customs zones. Its main objective is to facilitate foreign trade through clear rules and efficient processes, promoting principles such as efficiency in customs management, favorable interpretation of regulations, fair treatment of operators, and security throughout the logistics chain (Ministerio de Justicia y del Derecho de Colombia [Ministry of Justice and Law of Colombia], 2019).

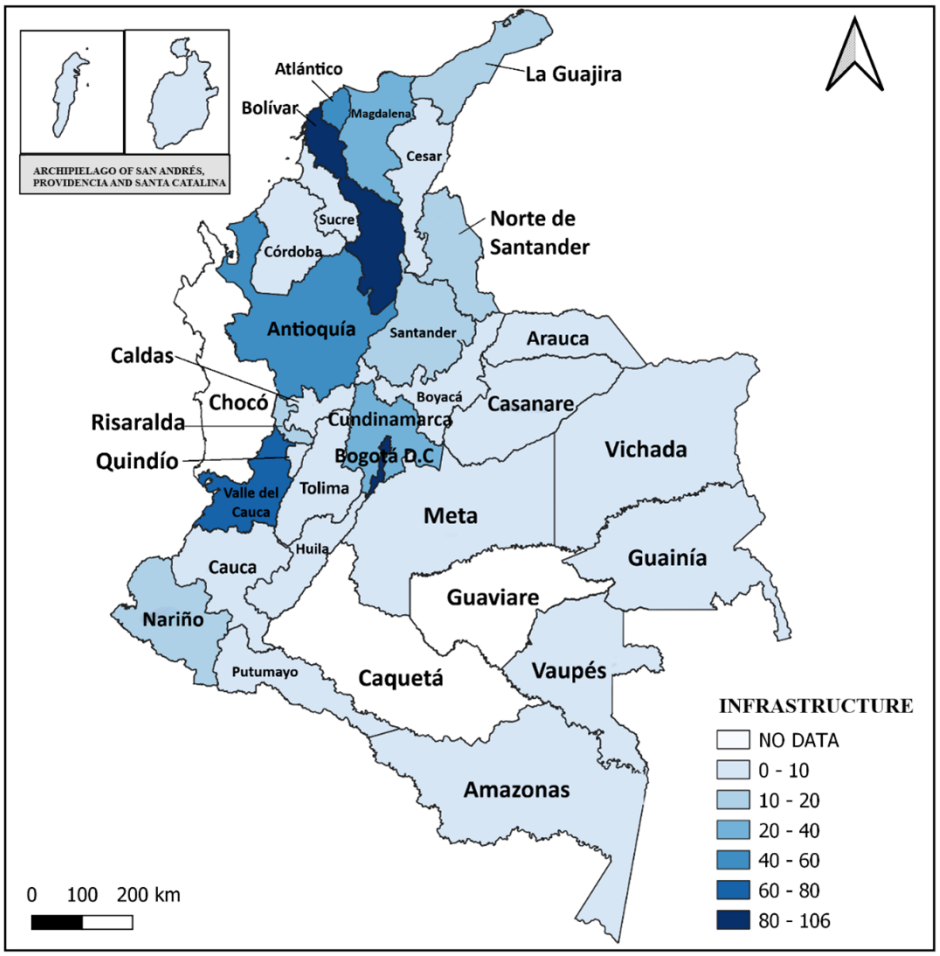
Resolution 46 of 2019 was issued by the General Director of DIAN. This resolution regulates Decree 1165 of 2019, specifying the procedures, formats, and technical criteria for the application, evaluation, and granting of authorizations, as well as the physical and technological conditions of logistics facilities (DIAN, 2019).

Based on these provisions, an information database was consolidated that included only the infrastructures that were in force and operational during the period analyzed, such as free trade zones, ports, international airports, border crossings, customs warehouses, and operational railway sections. These regulations were a key source for identifying which infrastructures were formally authorized, ensuring that the analysis was based on logistics assets that function for foreign trade operations in Colombia.

To characterize the distribution of logistics infrastructure in Colombia, the information collected was organized by department. This systematization made it possible to consolidate a table showing the total number of logical assets, such as ports, international airports, free trade zones, customs warehouses, border crossings, and railways present in each territory. From this, it was possible to construct a heat map that facilitated the geographical visualization of the concentration and coverage of these assets (Figure 2).

**Figure 2**

*Heat map of international logistics infrastructure*




*Note:* The map shows the departmental distribution of logistics infrastructure in Colombia, categorized by quantity ranges. The intensity of the color represents the number of logistics facilities identified per department.

*Source*: Prepared by the authors based on data collected and analyzed.

The analysis showed that the departments with the highest concentration of logistics infrastructure were Bogotá, Bolívar, Valle del Cauca, Atlántico, and Antioquia. As can be seen in the heat map, these departments share key characteristics that explain their position as logistics hubs in the country. Their advantage is related to the presence of large urban and industrial centers, access to port infrastructure and international airports, and high road connectivity. These conditions allow them to integrate more efficiently into global supply chains, consolidating themselves as strategic hubs for Colombian foreign trade.

For their part, departments such as Caquetá, Chocó, and Vaupés do not necessarily

represent the opposite contrast, but rather respond to very different structural realities. These are territories with low population density, geographical limitations, and less large-scale industrial or commercial presence, factors that directly affect logistics development.

**Compilation of trade balance information**

The research used the ETL (Extract, Transform, Load) process to consolidate a structured database of exports and imports for the period 2020-2024. ETL is a procedure that involves extracting data from various sources, transforming it to improve its quality and consistency using specific rules, and finally loading this data into a data warehouse or database for analysis.

According to Kimball and Caserta (2024), ETL is a fundamental stage in the development of data warehouses, as it involves extracting data from heterogeneous systems, transforming it to ensure quality and consistency using specific rules, and loading it into structures ready for strategic analysis.

Given the volume and complexity of the databases used, the ETL process was developed in the R programming language. The size of the files made it difficult to process them in traditional tools such as Excel, due to limitations in the efficient handling of large data sets. RStudio offered the flexibility and capacity needed to consolidate the information, thus ensuring data integrity and consistency throughout all phases of the ETL process.

Once all the databases corresponding to exports and imports for the period 2020-2024 had been consolidated, the department and FOB value were identified as key variables for analysis. The latter represents the value of goods in dollars, excluding international transport and insurance costs to the final destination, and is a standard metric in international trade for assessing the real value of transactions. A table was constructed with the consolidated information by department. This table included the department code, the department name, exports (aggregated FOB value), and imports (aggregated FOB value) for each the years studied.

Subsequently, an additional column called “trade balance” (Equation 1) was added, which calculated the difference between the total value of exports and imports by department.

$$\text{Trade balance} = \text{Total exports} - \text{Total imports} \quad (1)$$

This procedure made it possible to clearly see which departments had a trade surplus (when exports exceeded imports) and which had a deficit. Finally, a grand total was included at the end of the table to reflect the aggregate performance of the country in terms of its trade balance during the period analyzed.

**Analyzing the trade balance**

The trade balance measures the difference between the total value of exports and imports of a country or region in each period. A positive trade balance (surplus) indicates higher exports than imports, while a negative balance (deficit) reflects the opposite. In Colombia, this indicator is key to assessing regional competitiveness in foreign trade (DANE, 2024b).

The trade balance is one of the key indicators for understanding the economic relationship of a country with the global markets. In the case of Colombia, its performance during the 2020-2024 period reflects a constant trend toward deficit, meaning that the country has imported more than it has exported. This implies a net outflow of foreign exchange and evidence of structural weaknesses in the productivity and export capacity of the country.

During 2020, the trade balance was -US$10.13 billion FOB, in a context marked by the COVID-19 pandemic, which affected global economic activity and reduced both exports and imports. In the case of Colombia, exports fell mainly in the fuel and mining products sectors (DANE, 2021). However, in 2021, the deficit worsened significantly reaching -15.259 billion, representing a decrease of 5.129 billion dollars compared to the previous year. This situation occurred in a scenario of economic reopening, where imports grew rapidly in response to the recovery in consumption and investment, while exports had not yet fully recovered (Banco de la República, 2022).

In 2022, although the deficit remained, there was a slight improvement compared to the previous year, with a balance of -14.536 billion, i.e., a reduction in the deficit of 723 million dollars. This variation may be related to the rise in international prices for oil and coal, which are key products in export basket of Colombia (Portafolio, 2022). By 2023, the most notable

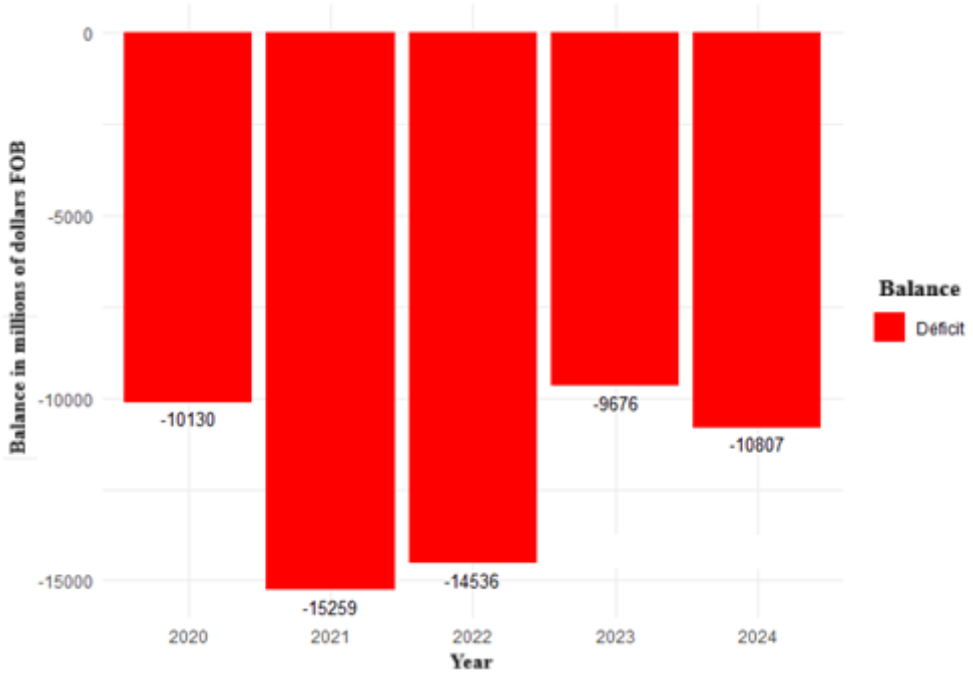
improvement of the period was observed, with a deficit of -9.676 billion, which meant a reduction of 4.860 billion compared to the previous year. This positive trend could be linked to the strengthening of certain non-traditional export sectors and lower domestic demand for imported goods (DNP, 2024).

However, in 2024, the balance deteriorated again, with a deficit of -10.807 billion, representing an increase of 1.131 billion compared to 2023. This reversal could be associated with weaker export dynamics in some sectors, volatility in international prices, and factors such as the exchange rate and domestic consumption patterns (OECD, 2024).

Overall, Figure 3 shows that Colombia maintains a structurally negative trade balance. Although there are years with some recovery, such as 2023, the general trend reveals an economy that is heavily dependent on imported goods, while its exports remain concentrated in a few products and sectors. This behavior has implications for both economic policy and regional development planning, as it directly affects foreign exchange generation, macroeconomic stability, and the competitiveness of the country in the international market.

**Figure 3**

*Trade balance by year*




*Note*: National trade balance in millions of dollars FOB per year.

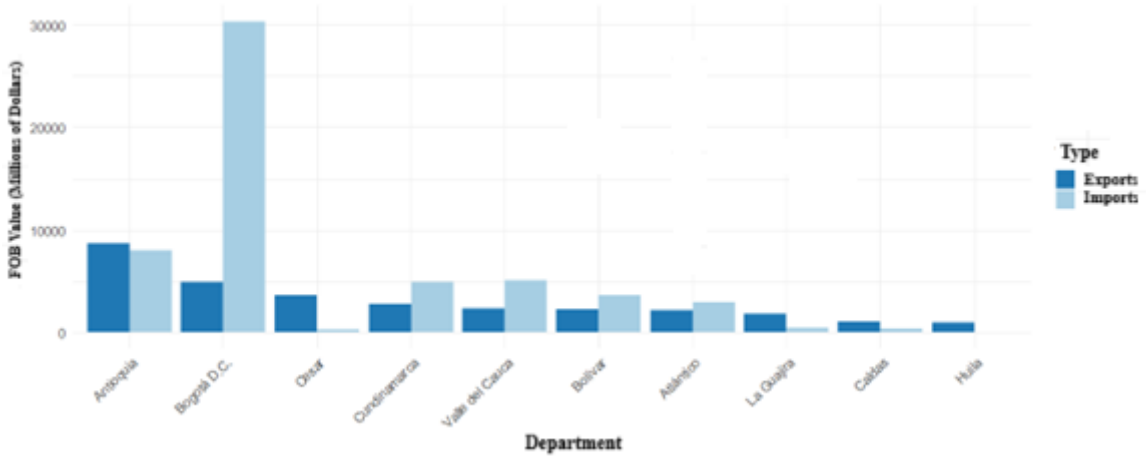
*Source:* Prepared by authors based on DANE data, processed with RStudio.

## Trade balance for 2024

The year 2024 brought some positive signs, especially due to the recovery of Antioquia, which for the first time in the period achieved a surplus of $683 million (Figure 4), the result of a better balance between exports and imports. Cesar stood out again with a surplus of $3.352 billion, consolidating its leadership in the trade efficiency. La Guajira, Caldas, and Huila also posted significant positive balances, confirming the strong performance of these agricultural and mining regions. In contrast, Bogotá maintained its structural deficit trend, closing the year with a deficit of $25.43 billion, which continues to highlight its role as an importer in the national economy. Cundinamarca and Valle del Cauca continued to have considerable deficits, despite being departments with strong industrial activity. This concludes that 2024 closed with an uneven distribution of trade balances, highlighting the improvement in traditionally deficit departments such as Antioquia, which experienced a significant surplus.

**Figure 4**

*Trade balance by department 2024*




*Note*: The graph shows the trade balance of Colombian departments in 2024, expressed in millions of dollars. The data is sorted from highest to lowest according to the value of exports. *Source:* Prepared by the authors based on DANE data, processed with RStudio.

## DEA Model Modelo DEA

In developing the DEA model, the relative efficiency of 33 territorial units in Colombia, (32 departments and Bogotá as a separate unit) was evaluated using data-from 2024. Variables were selected based on their relevance to regional competitiveness and trade balance management.

It is crucial to note that this study excludes the variable corresponding to oil and its derivatives. This decision is due to the fact that DANE discriminates against information from this sector, treating it as if it were an independent department. Therefore, the analysis focused exclusively on the geographical departments included in the sample, without considering the dynamics and figures associated with oil production and exports.

**Inputs variables**

The input variables selected for the DEA model reflect the resources available in each department that directly influence its capacity to manage the trade balance. These variables make it possible to assess how physical, logistical, and human factors contribute to efficiency in the mobilization and export of goods.

**Territorial area (km²):** The territorial area of each department was taken from Instituto Geográfico Agustín Codazzi (2024), the entity responsible for the official cartography of the country. This variable represents the number of square kilometers that each department has, and was used as an input in the DEA model. It is important to note that, unlike other variables, territorial area does not vary from year to year, so a single constant value was used for each territory throughout the analysis period (2020-2024). This variable considers the physical dimensions that influence the availability of infrastructure, logistical resources, and market access.

**Logistics infrastructure:** Evaluates the availability and quality of roads, ports, airports, and cargo centers. This variable is crucial, as it facilitates the movement of goods and reduces time and costs in foreign trade. Departments with robust infrastructure are more efficient in the logistics chain, while those lacking adequate resources face limitations that are reflected in lower efficiency results.

**Economically Active Population (EAP):** This corresponds to the total number of people of working age who participate in the labor market, either by working or actively seeking employment. This information was extracted from DANE statistics (2024a), which provide official employment data for the country. This variable was considered another key input in the analysis, as a larger EAP can translate into greater production capacity and regional economic dynamism.

**Output variables**

The output variables selected for the DEA model reflect the results achieved by each department in terms of foreign trade and competitiveness. These variables make it possible to evaluate how available resources (inputs) translate into effective comercial performance and value generation capacity in international trade.

- **Number of exporting companies (2024):** Number of companies registered as exporters during 2024 in each department.
- **Departmental competitiveness index:** This is a composite indicator that reflects the ability of a department to foster business environments, innovation, and productivity by evaluating the efficient use of its resources. It is a tool developed by the Private Competitiveness Council and the Universidad del Rosario to assess and compare the level of competitiveness of regions in Colombia. Methodologically, it is based on an adaptation of the World Economic Forum's Global Competitiveness Index and is composed exclusively of indicators from official national sources. Its structure encompasses 13 pillars grouped into four main factors (enabling conditions, human capital, market efficiency, and innovative ecosystem), providing a comprehensive view of regional performance and supporting the design of evidence-based public policies (Consejo Privado de Competitividad, 2024).
- **FOB value of exports (USD - 2024):** Total value of exports by department in FOB terms, reflecting actual income from international trade.

This set of variables made it possible to construct an output-oriented DEA model, evaluating how efficiently each department converts its available resources (inputs) into tangible economic results (outputs), especially in the context of international trade.

To evaluate the relative efficiency in the management of the trade balance of Colombian departments, the DEA model was applied under two main approaches: technical efficiency, corresponding to the basic DEA model, and super-efficiency, which allows discriminating between efficient units and ranking them beyond the standard efficiency threshold (value = 1).

**Most efficient departments**

Ten departments achieved technical efficiency of 1, which means that, under the DEA approach, they used their resources optimally in relation to their export output (Table 1). These departments were: Antioquia, Bogotá, Caldas, Caquetá, Cesar, Chocó, Cundinamarca, Huila,

Quindío, and Risaralda.

**Table 1**

Technical Efficiency (DEA) and Super Efficiency by Department

| Departament | Technical Efficiency (DEA) | Super Efficiency |
|---|---|---|
| Bogotá D.C. | 1.00 | 14.38 |
| Chocó | 1.00 | 4.96 |
| Quindío | 1.00 | 4.75 |
| Cesar | 1.00 | 2.73 |
| Antioquia | 1.00 | 1.97 |
| Huila | 1.00 | 1.45 |
| Cundinamarca | 1.00 | 1.40 |
| Caquetá | 1.00 | 1.31 |
| Caldas | 1.00 | 1.05 |
| Risaralda | 1.00 | 1.05 |
| Boyacá | 0.99 | 0.99 |
| Tolima | 0.96 | 0.96 |
| Guaviare | 0.81 | 0.96 |
| Santander | 0.91 | 0.91 |
| Atlántico | 0.90 | 0.90 |
| Valle del Cauca | 0.89 | 0.89 |
| Magdalena | 0.81 | 0.81 |
| Norte de Santander | 0.80 | 0.80 |
| Casanare | 0.77 | 0.78 |
| Meta | 0.77 | 0.77 |
| Bolívar | 0.75 | 0.75 |
| San Andrés | 0.74 | 0.74 |
| Cauca | 0.74 | 0.74 |
| Sucre | 0.69 | 0.69 |
| Córdoba | 0.68 | 0.68 |
| La Guajira | 0.66 | 0.66 |
| Nariño | 0.62 | 0.62 |
| Guainía | 0.60 | 0.60 |
| Putumayo | 0.59 | 0.59 |
| Arauca | 0.58 | 0.58 |
| Amazonas | 0.55 | 0.55 |
| Vaupés | 0.47 | 0.47 |
| Vichada | 0.33 | 0.33 |

*Source:* Prepared by authors.

However, when analyzing super-efficiency, significant differences in superior performance were observed between these departments. Bogotá stood out with a super-efficiency value of 14.38, positioning it as the most outstanding territorial entity. This figure shows that, in addition to being efficient, Bogotá far surpasses its peers in the proportional use

of its resources, which is explained by its high business density, the largest logistics infrastructure in the country (106 assets), a high competitiveness index (8.14), and an export volume exceeding USD 4.9 billion.

Another finding is that of Chocó, which, despite having no infrastructure (0 assets) and a low number of exporting companies (16), achieved a technical efficiency of 1 and a super-efficiency of 4.96, placing it above many other departments with better objective conditions. This result, although paradoxical at first glance, is due to the fact that the DEA model evaluates relative efficiency based on the use of available resources. In other words, Chocó achieved a relatively high level of exports (USD 35.7 million) compared to its limited capacities, which shows optimal use within its structural context. This is explained by the high concentration of the export basket of the department in high value goods, such as raw gold, gold manufactures, and sawn wood, which represent more than 80% of its exports. While this specialization shows a significant dependence on natural resources, it also highlights the ability of Chocó to generate exports with limited infrastructure and productive base. In this sense, the DEA model identifies relative competitive efficiency in the department, which is not based on the diversification of its economy, but on the intensive use of strategic comparative advantages, allowing it to Excel over other regions with greater resources.

Departaments such as (2.73), Quindío (4.75) y Caquetá (1.31) also stood out in terms of super-efficiency, demonstrating that they can excel even without being leaders in export volume, provided that their performance is efficiently aligned with their available resources.

**Least efficient departments**

At the opposite end of the spectrum, the departments with the lowest levels of technical efficiency were Vaupés (0.47) and Vichada (0.33); the latter had the lowest value in the country, reflecting profound structural inefficiency, with no registered export companies, very little infrastructure (two assets), and no reported exports during 2024. In these cases, low efficiency is not only due to underutilization of resources, but also to the absence of basic conditions for competing in international trade.

Other departments with low efficiency include Amazonas, Putumayo, Guainía, Nariño, and Arauca, all with values below 0.62. These territories share common characteristics such as poor infrastructure, a low level of exporting companies, and a limited economically active

population, which restricts their performance in the trade balance.

## Discussion

The analysis of relative efficiency in the trade balance, using the DEA model, revealed a profound structural disparity in Colombia, aligning with the findings of the 2025 Departmental Competitiveness Index (IDC). This index reconfirms Bogotá as the absolute leader, while peripheral region continues to lag behind economically. The study places Bogotá at the top of the efficiency scale (14.37) and departments such as Vichada (0.33) at the bottom, supporting the scientific evidence of the centralization of productive and logistical factors. This shows that trade efficiency reflects the economies of scale and innovative ecosystem of large capitals.

On the other hand, remarkable relative efficiency of Choco (4.95) is an atypical finding that does not contradict the model but rather validates its ability to identify niche efficiency, interpreted as the optimal use of its scarce inputs to capitalize on a specific comparative advantage (the FOB value of gold). This situation is consistent with the economy reality of Chocó, which despite the gaps, registers specific growth based on the exploitation of resources. However, a significant limitation, which is a recurring challenge for regional empirical research in Colombia, was the quality and inconsistency of the different official database sources. The difficulty of compiling and constructing a homogeneous and reliable database, due to changes in the definition and collection of variables over time, was the greatest analytical challenge before applying the DEA model.

## Conclusions

The study reveals a complex picture of regional competitiveness and the challenges of international trade in Colombia. The Departmental Competitiveness Index confirmed the existence of deep structural gaps between regions, with infrastructure development, human capital, and the business environment being key factors. This situation is exacerbated by the low availability and uneven distribution of logistics infrastructure, a factor that limits the potential for international trade and restricts the participation of most departments in the global

market. The DEA model reinforced these findings by showing a marked concentration of efficiency in the center and west of the country.

The cases analyzed, such as Chocó (notable relative efficiency, optimizing limited resources) and Bogotá (national benchmark for effectiveness), illustrate this disparity in performance. The main relevance of this research lies in its ability to accurately identify and quantify these differences, demonstrating that foreign trade potential is not limited to centralized regions. This analysis is fundamental, given that the expansion of international trade is an engine that drives employment, the economy, and sustained growth at the local and national levels.

The greatest challenge, and at the same time the main contribution of the study, was the construction of a reliable database from inconsistent public information (DANE and DIAN). This finding highlights a critical need to standardize and improve official information systems. This process is essential to enable any rigorous analysis and to ensure that future public policies are based on solid data that is comparable over time.

In terms of contributing to public policy and future lines of research, the findings of the study serve as an informative basis for guiding regional development strategies. This includes directing investment in infrastructure and connectivity toward les efficient departments and designing foreign trade promotion strategies that recognize and boost the potential of exporting companies throughout the territory. Academically, it is suggested that detailed case studies be conducted to understand and replicate the success factors that enable regions such as Chocó to achieve high levels of relative efficiency despite their resource constraints.

## Ethical Considerations

This research was endorsed by the Ethics and Bioethics Committee of the Alexander von Humboldt University Corporation. The study was conducted using a qualitative and documentary approach, based on the analysis of secondary information from public databases. Consequently, no personal data that could imply ethical risks was used, so no additional considerations were required in this regard.

## Conflict of interest

All authors made significant contributions to the document and declare that there is no conflict of interest related to this article.

## Declaración de contribución de los autores

Sara Ximena Pinto Duarte: Methodology, Software, Validation, formal Analysis, investigation, Data curation, Writing, Redaction and Visualization.

Nolberto Gutiérrez Posada: Conceptualization, Methodology, software, supervision and project management.

Julio Ernesto Camargo Bejarano: Conceptualization, methodology, software, supervision and Project Management.

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