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Review

Measuring concentration in the Colombian telecommunications market

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Abstract: Telecommunications markets have a giant impact on countries' economies. An example of this is the great potential offered by the internet service, which allows growth in various aspects such as productivity, education, health, and connectivity. A few companies dominate telecommunications markets, so there is a high market concentrations risk. In that sense, the state has to generate strong regulation in the sector. Models for measuring competition in telecommunications markets allow the state to monitor the concentration performance in these markets. The prediction of competition in the telecommunications market based on artificial intelligence techniques would allow the state to anticipate the necessary controls to regulate the market and avoid monopolies and oligopolies. This work's added value and the main objective is to measure the current concentration level in the Colombian telecommunications market, this allows for competitive analysis in order to propose effective strategies and methodologies to improve competition in the future of Colombian telecommunications services operators. The main result obtained in the research is the existence of concentration in the Colombian telecommunications market.

Keywords: algorithm; competition; market concentration; indicator; telecommunications market

1. Introduction

The synergy of information and communication technologies (ICTs) is having a growing impact on all aspects of society, and the services provided through ICTs are becoming increasingly important in sectors such as government, education, health, and in general, wherever there is a need to share information. Enabling technologies such as fiber optics installation are the focus of many operators regarding infrastructure. As well as the installation and deployment of fifth-generation mobile technologies (5G); as support for next-generation services such as the Internet of Things (IoT) and even talk of Industry 4.0 as a leading trend of the "fourth industrial revolution," are based on telecommunications services provided through ICT. There is an increase in automation and robotics manufacturing and fully automated production, where the management of such processes is done in real-time through networks such as the internet and adapts to changing external conditions, which can be combined in a single network, interact in real-time, and constantly learn (Bardey et al., 2022; Comisión de Regulación de Comunicaciones, 2020a; RC, 2021; Ilchenko et al., 2019; OCDE, 2023).

The mobile industry is experiencing 5G, the deployment of Industry 4.0, which has led to support and gradually guiding entrepreneurs in the mobile industry. The two concepts tend to complement and open up new possibilities to unlock the industry's potential. 5G technology also complements the advent of robots and cloud-based wireless robotics in manufacturing processes in companies as a

counterpart to the existing Wi-Fi network. 5G technology combined with artificial intelligence can foster training and skill enhancement. At the same time, it can promote high-precision simulations of human-machine interaction. Real-time data, assisted decision-making, and complex in-situ scenarios can create artificial intelligence (AI)-based analysis spaces to pinpoint and eliminate inefficiencies and make good predictions. Autonomous vehicles that are estimated to hit the roads in the next 5 to 10 years will take advantage of 5G to a large extent (OFCOM, 2022; Mehrotra and Menon, 2021).

The emergence of the telecommunications industry is due to ICTs, so technological innovation plays an even more critical role in this rapid industrial growth. Several empirical results have shown that such technological change has contributed to productivity improvements in the telecommunications industry. It is mentioned an "invisible hand" (market), a "visible hand" (government), and technology as the "third hand," which fundamentally drives the development of the telecommunications industry in coordination with the other two hands (Lin et al., 2018).

On the other hand, regulators focus on areas such as data security and data protection, while issues such as interconnection and pricing are at a lower level. However, regulatory areas such as spectrum, the data protection framework, and new billing rules are growing fast, leading regulators to maintain a constant effort to understand the telecommunications services market and to increasingly recognize the importance of telecommunications services as a supporting component of a nation's government (Mehrotra and Menon, 2021).

Nowadays, the telecommunications services market is moving in increasingly flexible and adaptable environments, and there is an increase in bandwidth due to the emergence of various services and applications on the Internet. This phenomenon increases the volume of data sales and becomes a solid source of revenue for Internet Service Providers (ISPs). There is fierce competition among ISPs to maintain and attract new customers to their businesses, and they are forced to analyze the quality of service and experience to improve interaction with their customers. However, the providers' interest is to keep these customers and increase the volume of consumption of their services (Fiedler et al., 2017).

Studies have been carried out to analyze the current status of the telecommunications market in Latin American countries and to identify the need for elements such as adequate spectrum management and alignment with established policies on telecommunications services. As a result of these studies, the analysis of competition in these markets has been identified as a central point of study to improve competitiveness and reduce the digital divide, facilitating regional development and identifying potential investments. It is determined that countries that allocate greater bandwidth and achieve more competitive market structures obtain a higher number of demonstrable social benefits. Countries such as Mexico have initiated this area, and the analysis of the spectrum, its allocation, and management is included among the essential variables as a relevant topic of study, appropriating the lessons of more mature markets (Miera Berglind, 2015).

Many countries have addressed this problem by increasing the availability of radio spectrum by reallocating portions of it. But even beyond this, spectrum

allocation among mobile operators plays a significant role in achieving the goal of a freely competitive market. It has been empirically demonstrated that the accumulation of spectrum by an operator leads to lower competition in the mobile voice market, so spectrum management strategies should aim to avoid unnecessary spectrum accumulation, seeking to achieve balance in the market power of telecommunications services (Miera Berglind, 2015).

Finally, at the global level, it is clear that ICTs are a meaningful factor leading to socioeconomic development and growth in a competitive environment that enables countries, companies, and individuals to reap the benefits. Undoubtedly, they have a giant impact on areas such as commerce, health, and education; they provide new job opportunities and can help people and companies to remain competitive by running their processes more efficiently.

The above highlights the importance of adequate regulation in the telecommunications market to ensure competition in the telecommunications sector companies in order to positively impact the productivity of companies in all sectors and thus lead to the country's socioeconomic development. However, there is still much to be done in countries such as Colombia. All of the above is the main motivation for the development of this article. As mentioned above, the concentration of spectrum by a telecommunications operator leads to less competition in the market. It increases the digital divide, affecting the development of the country and the region. With this in mind, this work's added value and main objective is to measure the current concentration level in the Colombian telecommunications market. This allows a competition analysis to propose effective strategies and methodologies to improve competition in the Colombian telecommunications services' operators.

The current literature has many indexes for measuring concentration in a specific market. This paper describes the most applicable concentration indexes for the telecommunications market. It will work on concentration measurements with the three most used worldwide: Stenbacka, Herfindahl-Hirschman index (HHI), and Linda.

This work is organized and presented in seven sections. Section 2 presents some important data on the telecommunications services market in Colombia. Section 3 describes the concentration measurement indices most applicable to the telecommunications market. Section 4 presents the research methodology. Section 5 describes the results obtained. Section 6 discusses the results. The final section, section 7, establishes the general conclusions of the work.

2. Telecommunications services market in Colombia

Currently, very few works relate to the study of concentration in the telecommunications market in the Latin American region, especially in Colombia, which is the main reason for selecting the Colombian telecommunications market.

The principal figures for the telecommunications services market in Colombia are shown below.

Based on the figures presented by the Ministry of Information and Communication Technologies (MinTIC) during the fourth quarter of 2023, the total

number of fixed Internet accesses in Colombia reached 8.91 million, i.e., about 10,000 fewer than those registered in the same quarter of the immediately previous year, when a figure of 8.92 million was reached, as shown in **Figure 1** (MinTIC, 2024).

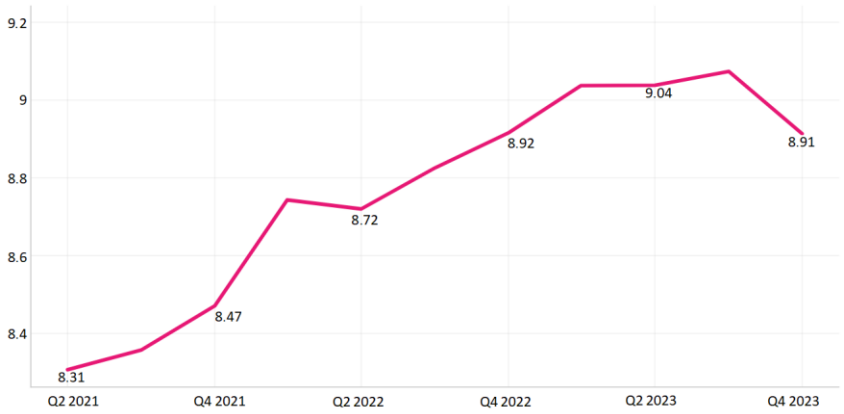

Figure 1. Landline Internet access (in millions) in Colombia (MinTIC, 2024).

On the other hand, the distribution of Telecommunication Network and Service Providers (TNSPs), according to the operational revenues in Colombian pesos produced by the provision of fixed Internet access service, shows that 16 providers had revenues equal to or above $10 billion, 61 had revenues between $1 billion and $10 billion during the fourth quarter of 2023, as shown in **Figure 2** (MinTIC, 2024).

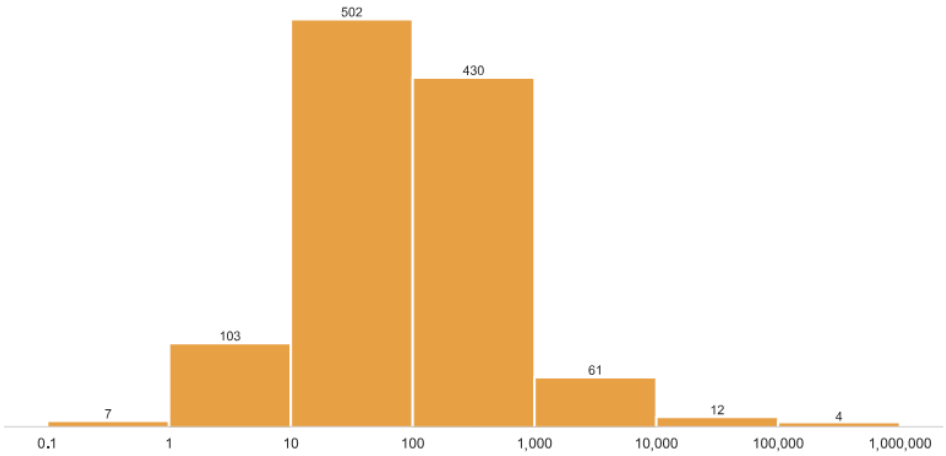

Figure 2. Number of suppliers according to operating revenues in millions COP (MinTIC, 2024).

During the fourth quarter of 2023, the provider with the highest operating revenues in COP for the provision of fixed Internet access service was UNE EPM ($405.5 billion), followed by Claro ($398.0 billion), Movistar ($263.1 billion), and ETB ($149.1 billion), as shown in **Figure 3** (MinTIC, 2024).

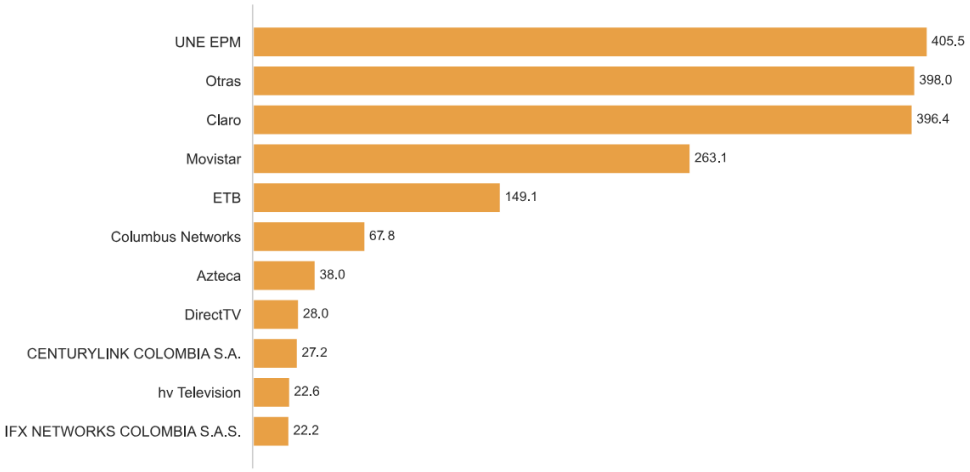

Figure 3. Principal suppliers in Colombia according to operating revenues in COP billions (MinTIC, 2024).

At the end of the fourth quarter of 2023, the largest number of fixed Internet accesses in the residential segment was located in the download speed block between 128 Mbps and 512 Mbps, while in the corporate segment, the largest number of accesses was in the range of 64 Mbps and 512 Mbps, as shown in **Figure 4** (MinTIC, 2024).

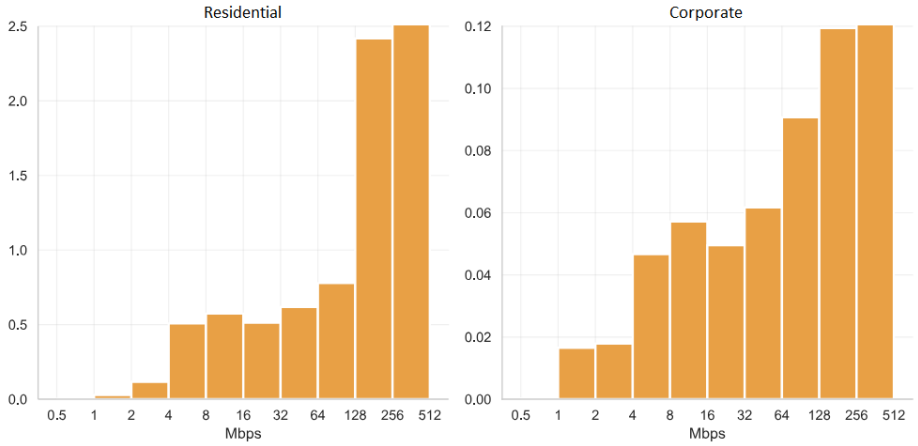

Figure 4. Internet access is based on speed and segment in millions (MinTIC, 2024).

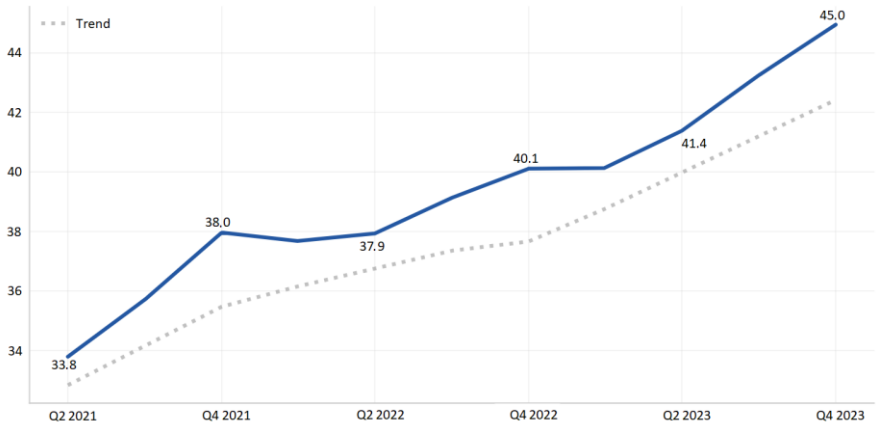

Figure 5. Mobile Internet access in millions (MinTIC, 2024).

As shown in **Figure 5** (MinTIC, 2024), total mobile Internet access in Colombia reached 45.0 million, 4.9 million more than registered in the same quarter of the previous year.

In December 2023, the provider with the highest number of mobile Internet access was Claro (23.7 million), followed by Movistar (8.8 million), TIGO (7.9 million), and WOM (3.3 million), as shown in **Figure 6** (MinTIC, 2024).

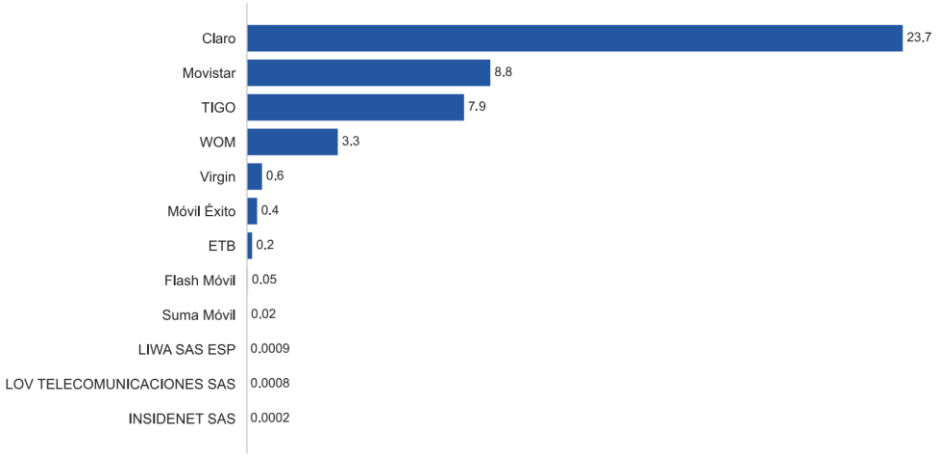

Figure 6. The number of mobile services accessed on by providers is in the millions (MinTIC, 2024).

At the end of the fourth quarter of 2023, the principal mobile Internet access technology in the subscription mode was 4G, with 40.4 million accesses, while, with a downward trend, 3G technology had 4.2 million, and 2G registers 400,000 accesses, as shown in **Figure 7** (MinTIC, 2024).

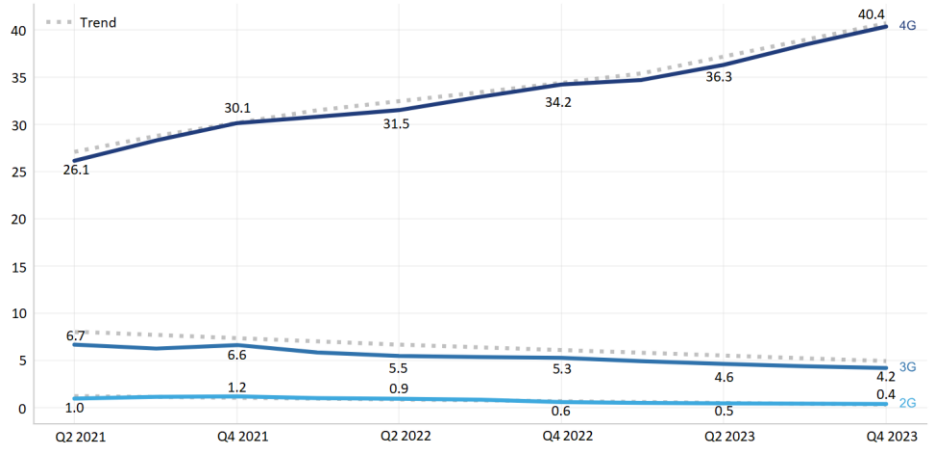

Figure 7. Mobile Internet access according to technology (MinTIC, 2024).

At the end of the fourth quarter of 2023, in Colombia, the total number of fixed telephony lines reached 7.28 million, 270 thousand fewer lines than those registered in the same quarter of the previous year, as shown in **Figure 8** (MinTIC, 2024).

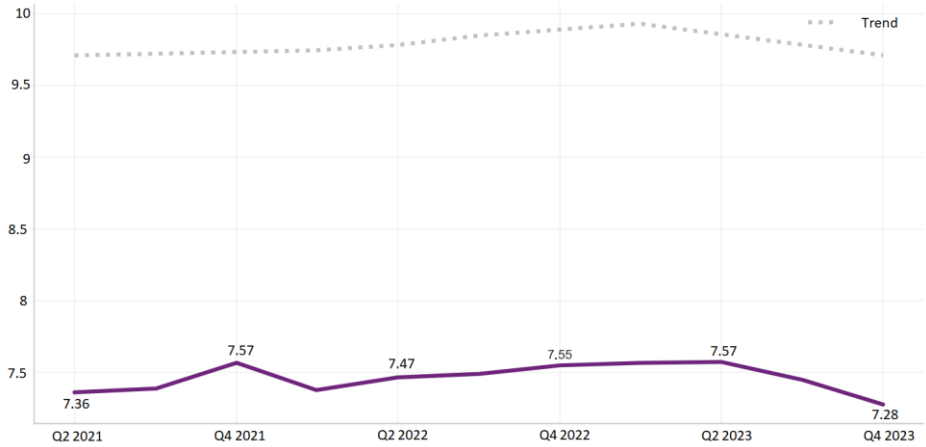

Figure 8. Number of fixed telephony lines in millions (MinTIC, 2024).

At the end of the fourth quarter of 2023, in Colombia, the total number of mobile telephony lines reached 87.4 million, 6.6 million more lines than those registered in the same quarter of the previous year, when they reached 80.8 million, as shown in **Figure 9** (MinTIC, 2024).

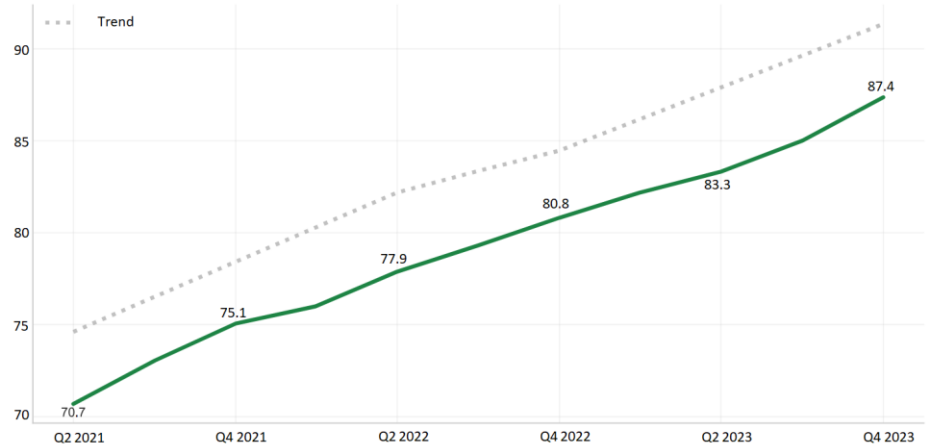

Figure 9. Number of mobile telephone lines (MinTIC, 2024).

In terms of market share, according to Comisión de Regulación de Comunicaciones (2020b) data described in **Figure 10**, three operators: Claro, Telefónica, and Tigo, account for 95.6% of mobile Internet revenues and 92.9% of mobile telephony lines, as shown in **Figure 10** (Comisión de Regulación de Comunicaciones, 2020b).

Operator	Landline		Fixed Internet		Suscription Tv		Mobile Internet		Mobile telephony	
	2019	2023	2019	2023	2019	2023	2019	2023	2019	2023
Claro	31.80%	36.50%	27.40%	28.70%	37.70%	40.00%	59.10%	62.00%	53.20%	53.80%
Telefónica	17.10%	13.70%	13.90%	13.30%	8.70%	7.80%	20.50%	19.70%	20.80%	21.30%
TIGO	25.50%	23.70%	26.90%	25.70%	18.20%	18.10%	14.30%	13.90%	17.20%	17.80%
DirecTV	0.00%	0.00%	3.10%	3.20%	29.00%	27.80%	0.00%	0.00%	0.00%	0.00%
ETB	18.80%	19.50%	8.30%	7.70%	2.40%	2.60%	0.60%	0.50%	1.50%	1.50%
Others	6.80%	6.50%	20.30%	21.50%	4.00%	3.70%	5.60%	3.90%	7.30%	5.70%

Figure 10. Operator participation in ICT services (MinTIC, 2024).

3. Indices for evaluating competition in telecommunications markets

In the current literature, several indices seek to analyze and evaluate competition in telecommunications markets, mainly based on concentration measures by telecommunications companies. These indices use revenue generated, the number of users, and traffic generated by the operator as their main variables.

The authors in Comisión de Regulación de Comunicaciones (2022) describe the principal reference indicators for the Communications Regulatory Commission, which allow it to monitor the state of competition in the relevant markets it has defined. After an analysis and evaluation process by experts, the following indices were chosen for their theoretical robustness and their application in the competition of telecommunications markets (Comisión de Regulación de Comunicaciones, 2022).

- Market penetration rate (qualitative);
- Average Revenue Per User (ARPU) indicator (qualitative);
- Market share indicator;
- Stenbacka dominance indicator;
- Concentration ratio indicator;
- Herfindahl-Hirschman index (HHI) (non-qualitative);
- Linda index;
- Dominance index.

The concentration indices must have particular characteristics that make them useful for their application, among which the following stand out: (a) they must be easy to calculate and interpret, (b) they must allow obtaining the index from a single variable, as far as possible (c) its value must be between 0 and 1, for a better understanding and comparison, (d) it must be independent of the total size of the market (Apolinario et al., 2022).

3.1. Market penetration ratio

This index measures in percentage terms the level of use of a product or service by users compared to the total estimated market for that product or service. In the case of the cellular telephony market, the market penetration index allows for estimating the growth over time of cellular telephony use for a country through the ratio between the number of people with a cellular phone and the total population for a given period (Comisión de Regulación de Comunicaciones, 2022).

Equation (1) describes the market penetration ratio.

$$\text{Market Penetration}_t = \frac{\text{Transactions}_t}{\text{Total market size}_t} \quad (1)$$

where: Transactions_t is the number of occurrences for a given event; in telecommunications markets, it can be represented by variables such as the number of subscribers and the amount of traffic generated, among others, for a given period.

Total market size_t is normally estimated through demographic variables such as the number of inhabitants in a given period.

3.2. Average revenue per user index (ARPU)

According to its name, this index is obtained by dividing the total revenue by the number of subscribers *N* of the market to be analyzed, see Equation (2). It is a widely used index in the telecommunications market and allows companies to monitor their annual growth continuously.

$$\text{ARPU}_t = \text{Total revenue}_t / \text{number of users}_t \quad (2)$$

In addition to the average revenue per user presented in Equation (2), obtaining the average revenue per unit of a product for sale is also possible. To calculate the value of the ARPU index, it is first necessary to define the period for which it is to be calculated, which could be months, quarters, or years. Then, the total revenue obtained for that period is calculated and divided by the number of users, customers, or subscribers active. For the above, the level of disaggregation to be analyzed is also considered, such as, for example, the operator, geographical area, technology, product, and service, among others (Comisión de Regulación de Comunicaciones, 2022).

3.3. Market share indicator

This indicator is a relative measure that represents the market share that a company has in percentage terms for a variable of interest, such as revenue, traffic, and number of users, among others. The market share index is a continuous monitoring measure that allows companies to detect changes in the competitive environment and, based on them, to design and plan specific strategies (Comisión de Regulación de Comunicaciones, 2022).

The market share index is obtained from the analyzed variable and for which information is available, such as revenue described in Equation (3), traffic described in Equation (4), or users described in Equation (5).

$$\text{Revenue market share } (\%) = 100 \times \frac{\text{Revenues}_i}{\text{Total market revenues}} \quad (3)$$

$$\text{Traffic market share } (\%) = 100 \times \frac{\text{Traffic}_i}{\text{Total market traffic}} \quad (4)$$

$$\text{Users market share } (\%) = 100 \times \frac{\text{Users}_i}{\text{Total market users}} \quad (5)$$

where: Revenue *i*, traffic *i*, and users *i*, are the revenue, traffic, or users of the company *i*, at a given time.

In each case, the period within which the measurements are to be made, whether monthly, quarterly, or annually, must be specified.

A high percentage of market share can infer a certain concentration level that could become a monopoly, in case a single company has a high level of participation, or oligopoly, in case a few companies have a high value of the market share. In Comisión de Regulación de Comunicaciones (2022), it is mentioned that to determine whether a company has monopoly power, the civil courts of the United States circuit generally begin with an analysis of the market share of the company, and although there is no determined threshold to determine whether a monopoly exists, they have established as a necessary condition for its possible existence that the company's share has at least a 40% market share; and, if it is equal or higher than 90%, it is assumed that there is a monopoly (Comisión de Regulación de Comunicaciones, 2022).

3.4. Stenbacka dominance index

The Stenbacka index allows one to determine whether a dominant company exists in the market. It is defined as a dominance threshold based on the shares of the two largest companies in the market. The value of the Stenbacka index estimates a threshold above which the leading firm could have market power; Equation (6) calculates this threshold (Comisión de Regulación de Comunicaciones, 2022).

$$S^D = \frac{1}{2}[1 - \gamma(S_1^2 - S_2^2)] \quad (6)$$

where: S_1 and S_2 correspond to the market share of the two largest companies, with $0 \leq S_i \leq 1$. $\gamma \geq 0$ is a given parameter obtained from the particular characteristics of each market, such as entry barriers and regulations to motivate competition. The output range of the Stenbacka index is in the interval [0, 1].

When the Stenbacka index obtains small values, there is competition low concentration. On the contrary, large values mean low competition and the presence of concentration (Comisión de Regulación de Comunicaciones, 2022). According to Ukav (2022), the higher the value of γ, the lower the threshold value and the higher the possibility of finding dominance. Due to the difficulty of estimating the γ value, regulatory and competition agencies generally assume $\gamma = 1$ as a benchmark (Comisión de Regulación de Comunicaciones, 2022).

3.5. Concentration ratio index

This index is one of the most common due to its simplicity. Its calculation is based on the participation of the N largest companies in the market under analysis. It allows for the evaluation of market power in a competition analysis. Its main weakness is that it does not consider small companies, but only the largest ones, see Equation (7) (Apolinario et al., 2022).

$$\text{IC} = \sum_{i=1}^{N} S_i \quad (7)$$

IC is the concentration index of first N largest firms, and $0 < \text{IC} \leq 1$. S_i is the market share of company i, that is, the percentage that company i has concerning the analyzed market; since the total number of companies is not considered, but only the N largest, it is indifferent to the structure of the shares among these companies since a value of the participation index of 0.8 can be the result of various combinations of N companies, for example, if $N = 4$, one could have a share of 0.2 for each one, or a share of 0.5 and three others of 0.1 (Apolinario et al., 2022).

Comisión de Regulación de Comunicaciones (2022) in **Table 1**. This indicator's interpretation ranges when the three largest companies ($N = 3$) are considered.

Table 1. Interpretation of the concentration ratio index for $N = 3$.

Concentration	Range
Low	<0.45
Moderate	0.45 to 0.7
High	>0.7

3.6. Concentration ratio index

The Herfindahl-Hirschman index (HHI) is most widely used after the concentration ratio index. It is represented by the sum of the squares of the shares of the companies in the market, as described in Equation (8) (Melnik et al., 2008).

$$\text{HHI} = \sum_{i=1}^{N} S_i^2 \tag{8}$$

where: N is the number of companies in the market; S_i is the market share of the company i in percentage terms.

The HHI has an output range in the interval [0, 1] if the share is expressed in decimal values between zero and one and the interval [0, 10,000]. And, if the share is expressed in percentage values, the value of the HHI index is directly proportional to the market concentration (Melnik et al., 2008).

The HHI, unlike the concentration ratio index, does consider all the companies in the market. In addition, it weights the companies proportionally to their share because it squares it, so a company with a small share has a lower weighting than a company with a larger share.

In the case of a single company, its share value would be 1% or 100%, which squared would give 1 or 10,000, representing the maximum possible value of the HHI, indicating that the market is a pure monopoly. On the other hand, the lowest value is given when N companies have the same participation, in which case the HHI takes the value of $1/N$; if N is large, then $1/N$ tends to be zero (Melnik et al., 2008).

In Comisión de Regulación de Comunicaciones (2022), it is mentioned that according to the criteria established by the US Department of Justice, the interpretation of the HHI to determine the level of market concentration is described on the left side of **Table 2**. According to the European Commission, the interpretation of the HHI is given in terms of the presence of competition problems, which would be the opposite of the concentration described on the right side (**Table 2**).

Table 2. Interpretation of the HHI.

USA Department of Justice		**European Commission (for horizontal concentrations)**	
Concentration	Range	Presence of competition concerns	Range
Competitive or non-concentrated	<1500	Not probable	<1000
Moderately competitive or concentrated	1500 to 2500	Improbable	1000 to 2000
Non-competitive or highly concentrated	>2500	Probable	>2000

3.7. Lind's index

This index focuses on the distribution of the k companies with the largest market share; since it is designed to evaluate the degree of inequity in a market and the presence of oligopolies. So, unlike the previous indexes, it compares the concentration between two groups of companies, those with the largest market share (leaders) and the others, allowing one to calculate their joint relative incidence about the rest of the companies (see Equation (9)) (Apolinario et al., 2022).

$$L = \frac{1}{N(N-1)} \sum_{i=1}^{N-1} \frac{\bar{X}_i}{\bar{X}_{N-i}} \quad (9)$$

where:

$\bar{X}_i$ is the average market share of the first *i* companies.

$\bar{X}_{N-i}$ is the average market share of the remaining companies.

N is the total number of companies in the market.

The range of values of Linda's index is between zero and infinity, and its interpretation can be seen in **Table 3** (Melnik et al., 2008).

Table 3. Interpretation of the Linda index.

Concentration	Range
Low	<0.2
Moderate	0.2 to 0.5
High	0.5 to 1
Very high	>1

3.8. Dominance index

This index is calculated from the HHI, measuring market concentration based on the company share in the HHI, as described in Equation (10) (Ruíz Porras and Hernández Reyes, 2023).

$$\text{ID} = \sum_{i=1}^{N} h_i^2 \quad (10)$$

where *N* is the total number of companies, $h_i = (S_i)^2/(\text{HHI})$, and S_i is each company's share in the market according to the analysis variable. The range of the dominance index result is similar to the HHI, i.e., it is in the interval of [0, 1]. The dominance index approaches the value of 1; the smaller, the less dominant the company is, which can be interpreted as a monopolistic market for ID = 1. On the contrary, the closer it is to zero, the more it could be interpreted as a market without concentration for ID = 0 (Ruíz Porras & Hernández Reyes, 2023).

Table 4. Concentration range associated with the entry barrier.

Concentration	Range
Low	<0.25
Medium	0.25 to 0.5
Moderate	0.5 to 0.75
High	>0.75

The Communications Regulation Commission in Comisión de Regulación de Comunicaciones (2022) establishes, in **Table 4**, the interpretation of the dominance index ranges.

4. Material and methods

It is important to emphasize once again that the main objective of this work is to measure the current concentration level in the Colombian telecommunications market, which allows for a competitive analysis. For this purpose, the HHI, Stenbacka, and Linda market concentration indexes will be used and constructed from real data from the telecommunications companies operating in the Colombian market.

This section presents the test scenarios of the research project; the real data of accesses, revenues and traffic of each operator in the Colombian market, provided by the Colombian Communications Regulatory Commission; the concentration measurement indexes described in the previous section, and from which the three most important ones were selected: HHI, Stenbacka and Linda; from the data, these indexes were constructed and their results were plotted for a better observation; and finally, an analysis was developed based on these results.

4.1. Test scenarios

The objective of having a definition of test scenarios for the project is to achieve the design of an artificial intelligence model that allows characterizing and predicting competition in the telecommunications market for mobile service in terms of Internet traffic, number of Internet accesses, and Internet revenues in Colombia.

The test scenarios for the project are described below.

1) Collect data on the variables Internet traffic, number of accesses and revenues for the mobile market in Colombia.
2) Perform a cleaning of the available data with the defined variables.
3) Perform a standardization and/or homogenization of the variables with which the model is to be generated.
4) Calculate the most relevant indexes found in the literature, such as Stenbacka, Linda and HHI.

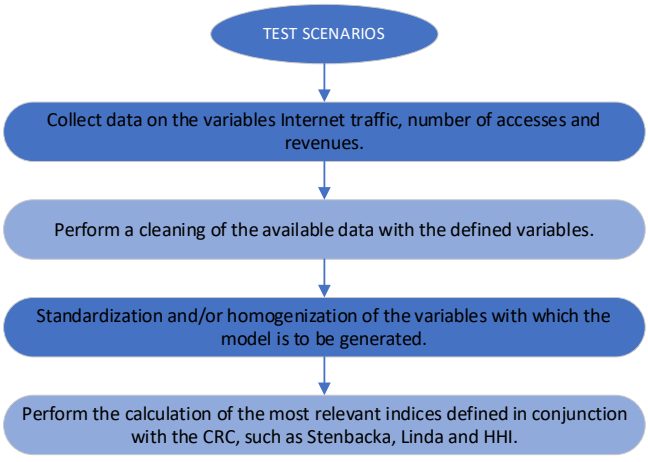

Figure 11. Test scenarios.

This methodology, described sequentially, can be summarized through a flow chart, such as the one shown in **Figure 11**.

4.2. Database with collected information

For this activity, we used the information presented by the Communications Regulatory Commission in the following links:

https://www.postdata.gov.co/dataset/abonados-ingresos-y-tr%C3%A1fico-de-internet-m%C3%B3vil-por-demanda

https://www.postdata.gov.co/dataset/suscriptores-ingresos-y-tr%C3%A1fico-de-internet-m%C3%B3vil-por-cargo-fijo

A Python program was then developed to organize and filter the variables of interest (accesses, revenues, and traffic) for each month and by the operator from 2012 to 2022, cleaning and adapting the information. Then the demand and fixed charge values were added, obtaining results by mobile operator.

4.3. Definition of input and output data

The model's input and output data are described below.

In accordance with the analysis of the variables affecting the competition market, and in order to measure and analyze such competition in the mobile services market, the following input variables are defined:

Traffic: Amount of traffic produced by operators in a given month.

Revenue: Amount of revenue reported by operators in a given month.

Users: Amount of users reported by operators in a given month.

Model output data include:

Stenbacka index: Historical or future values of the index.

HHI index: Historical or future values of the index.

Linda index: Historical or future values of the index.

5. Results

The following are the results of the HHI, Stenbacka, and Linda indices, obtained in terms of the number of accesses, revenues and traffic, for the data from 2012 to 2022.

5.1. Herfindahl-Hirschman Index

The Herfindahl-Hirschman Index is a common measure of an industry's market concentration and is used to determine its competitiveness. It is calculated by squaring the market share of each competing firm in the industry and then summing up the resulting numbers. A low degree of concentration means that the industry is closer to a perfect competition scenario, where many firms of roughly equal size share the market. Increases in HHI generally indicate a decrease in competition and an increase in market power, while decreases indicate the opposite.

Figures 12–14 present the graphs for the HHI of access, revenue and traffic, respectively.

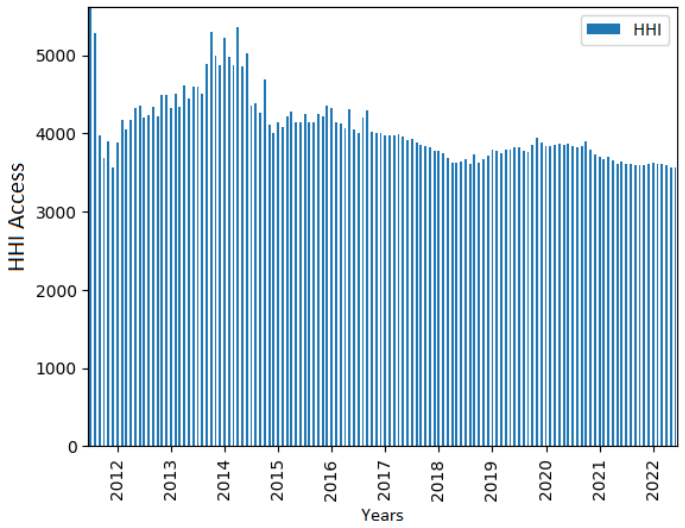

Figure 12. HHI for the number of mobile internet accesses.

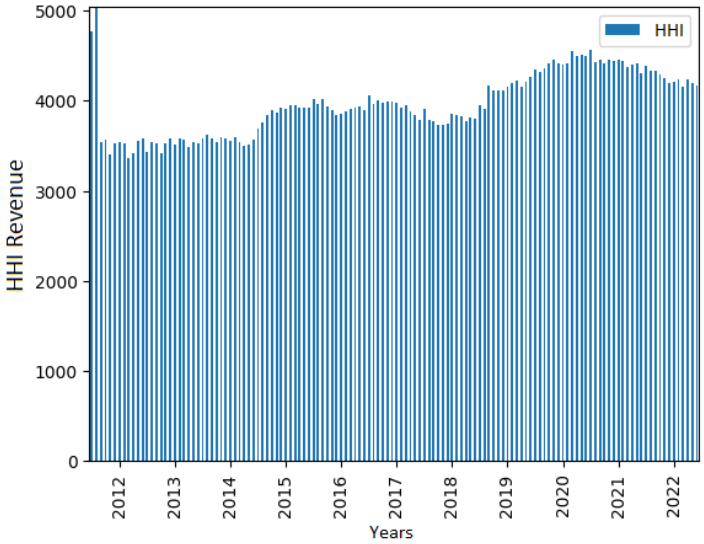

Figure 13. HHI for mobile internet revenues.

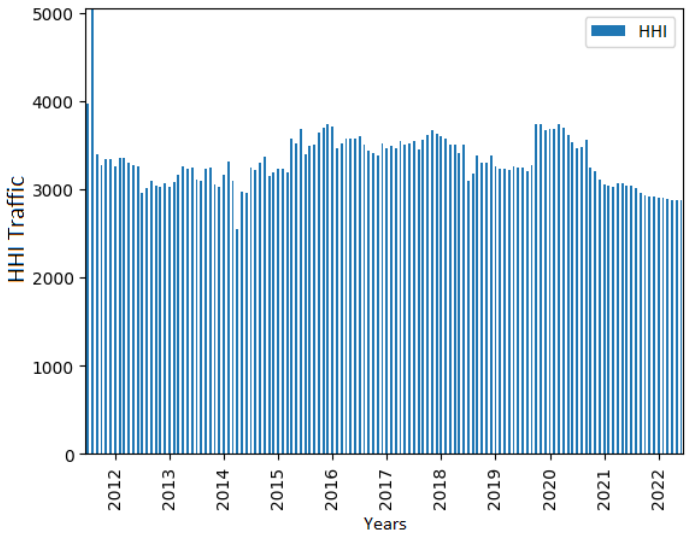

Figure 14. HHI for mobile Internet traffic.

5.2. Stenbacka Index

The Stenbacka index was constructed based on the first two operators for each variable: accesses, revenues, and traffic, which correspond to Claro and Colombia Telecommunications in the three cases. **Figures 15–17** present the graphs for the Stenbacka index for accesses, revenues and traffic, respectively.

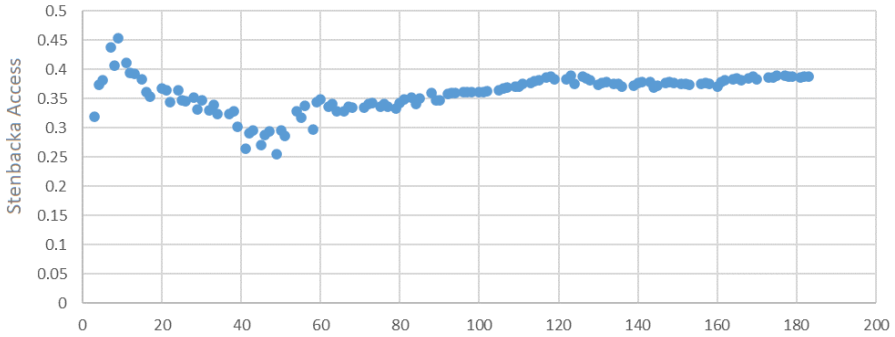

Figure 15. Stenbacka index for number of mobile internet accesses.

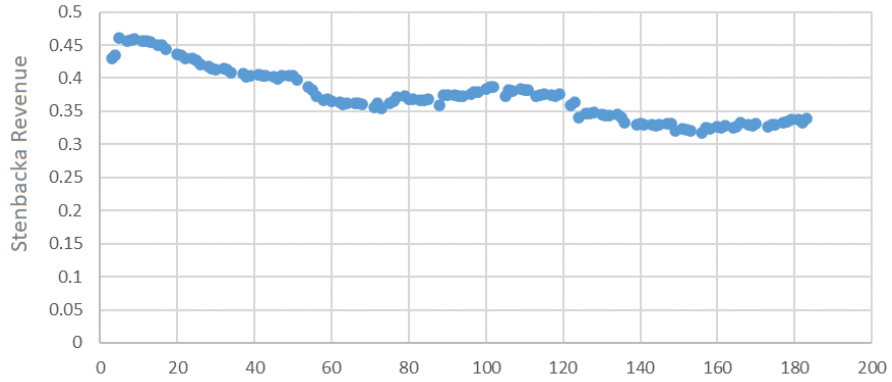

Figure 16. Stenbacka index for mobile internet revenues.

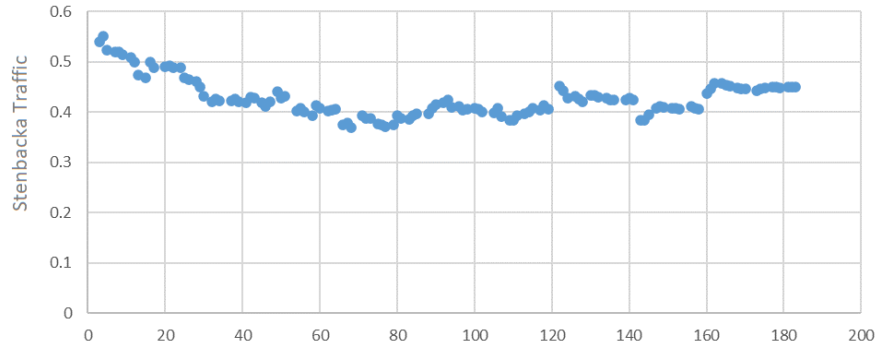

Figure 17. Stenbacka index for mobile internet traffic.

5.3. Linda index

This indicator is usually used to measure the possible existence of oligopoly and inequality between different market shares. In addition, similar to the concentration ratio, it is calculated for a number n of leading companies in the market, so that their joint relative incidence can be calculated about the rest of the participants at that end

of the market (supply or demand). This indicator can be mathematically defined as shown in Equation (6) (Comisión de Regulacion de Comunicaciones, 2023).

Initially, the data corresponding to the variables of analysis, such as: traffic, revenue and subscribers, were obtained for each of the telecommunications companies that operated and operate in Colombia from 2012 to September 2022 (inclusive); this information was obtained from the post-data database of the Communications Regulation Commission (Comisión de Regulación de Comunicaciones, 2023). Subsequently, the data was organized in Excel to create a database with the information of interest organized chronologically. Here finally nine databases were obtained: (1) fixed charge mobile internet demand traffic (postpaid); (2) fixed charge mobile internet demand revenue (postpaid); (3) fixed charge mobile internet demand subscribers (postpaid); (4) on-demand mobile internet demand traffic (prepaid); (5) on-demand mobile internet demand revenue (prepaid); (6) on-demand mobile internet demand subscribers (prepaid); (7) global mobile internet demand traffic (postpaid + prepaid); (8) global mobile internet demand revenue (postpaid + prepaid); (9) global mobile internet demand subscribers (postpaid + prepaid).

As Linda index forecasts are planned for a later phase, it was decided to calculate this index monthly to obtain a larger amount of data. According to the procedure required to calculate the Linda index, it was necessary that for each period (month), the telecommunications companies were ordered from highest to lowest according to the value of the variable to be analyzed (traffic, revenues or subscribers).

Finally, the Linda index was calculated for each database mentioned above. Here it was found that the Linda index was indeterminate for the periods where some of the companies had a value of zero in the variable of interest. If it was very close to zero, it increased exponentially. Due to the above, it was decided to eliminate the data equal to zero since the interpretation of these data means that the company did not operate in that period. Additionally, it was decided to eliminate all data less than 50,000 in the traffic and revenue databases, both in postpaid and prepaid. Overall, the total amount of data eliminated was 36, which gives approximately a value of less than 0.4% of the total database.

For the months in which more than three companies were operating, more than one Linda index was obtained; since this index compares groups of companies, the first Linda obtained is if at least three companies are competing in the market and would correspond to Linda 2 (L2), if there are four companies, L2 and L3 would be obtained. So on, that is, the last Linda corresponds to N-2, where N is the number of companies competing in the market. Since there are periods where up to 14 companies operate simultaneously, Linda indexes of up to L12 are obtained; plotting each of them would represent an extension of this document, so it was decided to plot only the Linda 2 (L2) of each period and rather present the table with the information of all Lindas of the period.

Figures 18–20 present the graphs for Linda's index of access, revenue and traffic, respectively.

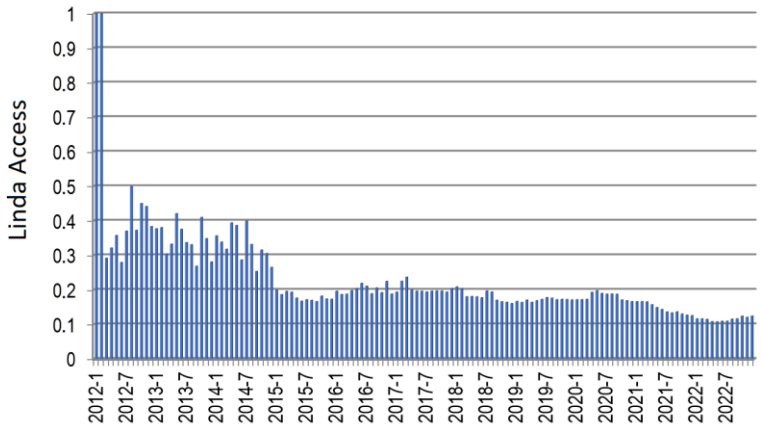

Figure 18. Linda index for number of mobile internet accesses.

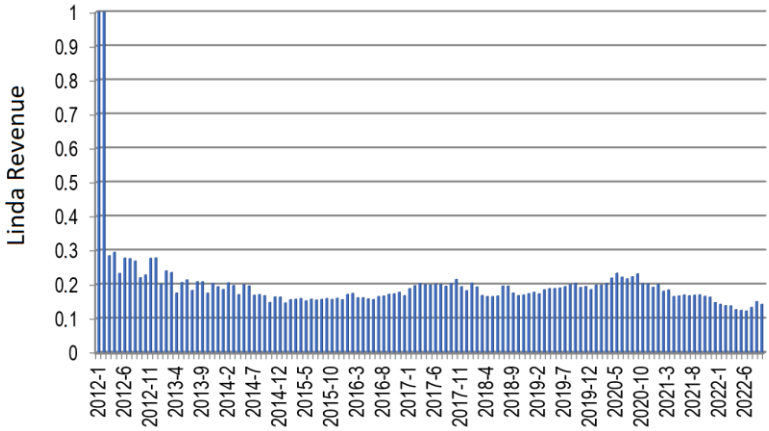

Figure 19. Linda index for mobile internet revenues.

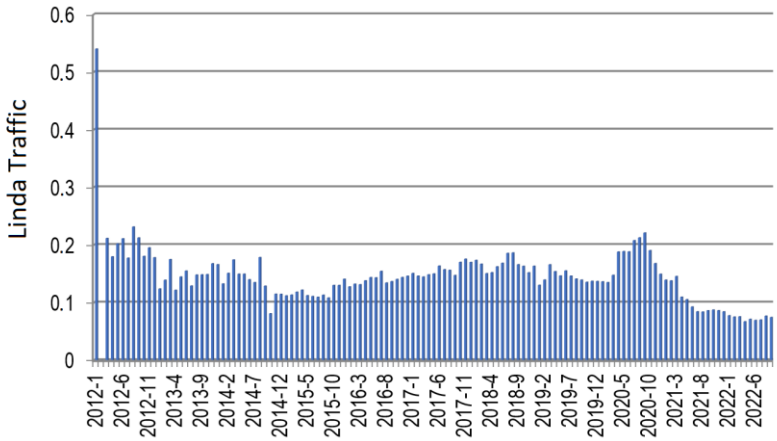

Figure 20. Linda index for mobile Internet traffic.

6. Discussion

The main findings of the analysis of the results obtained in the previous section are mentioned below.

With respect to the HHI index, the values obtained in the three variables, access, revenues, and traffic, for mobile internet show a high concentration, which indicates low competition in the Colombian telecommunications market.

The highest average HHI value is for the number of accesses, with 4069.6 and a standard deviation of 434.2.

The lowest average HHI value is for traffic with 3324.6 and a standard deviation 295.48.

The HHI of access, revenue and traffic correlation values show a low relationship between these variables.

When comparing the analysis of variance between the data of HHI access—HHI revenue, HHI Revenue—HHI traffic, and HHI access—HHI traffic of the companies, the null hypothesis indicates that there are significant differences between the average values of the evaluated groups is rejected.

Regarding the Stenbacka index, the ANOVA is calculated for the means, taking as a reference the information available for the three variables by number of accesses, revenues, and traffic.

A summary of the results of the Stenbacka calculation is shown in **Table 5**.

Table 5. ANOVA summary for Stenbacka Indices.

Groups	Account	Sum	Average	Variance
Accesses	129	46.29479062	0.358874346	0.001022802
Traffic	129	55.15193865	0.427534408	0.001380868
Revenue	129	48.15736749	0.373312926	0.001503484

From the above, an average of 35% Accesses, 37% Revenue and 42% Traffic is observed, with a maximum variance of 0.0015. The ANOVA calculation results in what is shown in **Table 6**.

Table 6. ANOVA result for Stenbacka indices.

Origin of variations	Sum of squares	Degrees of freedom	Mean squares	*F*	Probability	Critical value for *F*
Between groups	0.33809377	2	0.169046886	129.7979811	8.66641×10^{-44}	3.019225163
Within the groups	0.50011566	384	0.001302385	-	-	-
Total	0.83820944	386	-	-	-	-

With the *F* and calculated *F* results, it is deduced that there are differences between the means of the Stenbacka of the three variables, rejecting the hypothesis that the mean is close. The *p* value is very low, therefore, the null hypothesis is rejected.

A trend analysis of the Stenbacka indexes of the three variables analyzed was also performed and the following was found.

For the Stenbacka index of accesses, the *R*-squared results are close to 19% with the linear trend. The logarithmic trend is 3.3%, and the polynomial trend of degree 5 is close to 70%.

For the Stenbacka traffic index, the *R*-squared results are close to 9.7% with the linear trend. The logarithmic trend is 39%, and the polynomial trend of degree 5 is close to 84%.

For the Stenbacka revenue index: with the linear trend, the *R*-squared results are close to 83%. The logarithmic trend is 83% and the polynomial trend of degree 5 is

close to 94%.

The above results show that the most stable Stenbacka index is revenue. With traditional methods, the predictions will be below 90%, except for the Income Stenbacka, which will be close to 94%.

The highest values of the Linda 2 index are given for the revenue of mobile internet demand, which is 21.11 and has a standard deviation of 1.85, and for the number of accesses of mobile internet demand, which is 20.72 and has a standard deviation of 2.49.

The lowest Linda value is for traffic with a value of 0.067 and a standard deviation of 0.0499.

For mobile internet demand, the Linda index values, on average, have larger differences: traffic 0.14 indicates low concentration, revenues 0.36 indicates moderate concentration, and the number of accesses 0.53 indicates high concentration.

It is important to emphasize that the Linda 2 index compares the groups of the two companies with the highest value of the variable of interest (traffic, revenues or accesses) about the groups of the other companies. In some cases, a higher concentration is likely evident for the group of the 3 or 4 most dominant companies in the market.

Linda traffic, revenue, and access index for mobile internet demand shows a high concentration, indicating low competition in this market.

7. Conclusions

The measurement and monitoring of competition in the telecommunications market allow the state to implement strategies aimed at improving market regulation to avoid the formation of oligopolies and monopolies.

The main purpose of this work is to measure and analyze the concentration in the Colombian telecommunications market. This was achieved from the information corresponding to three variables: access, revenue, and traffic. Each variable corresponds to each of the active operators in Colombia during that period, with information from 2012 to 2022 corresponding to each. Three concentration measurement indexes best evaluated in the current literature were used for the above.

Although each of the three indexes selected does not have exactly the same approach and characteristics, they do reach the same finding: the presence of concentration in the Colombian telecommunications market. This significantly affects competition and, therefore, the benefits it brings to improving society's welfare and productivity.

Another interesting contribution of this work is using real information on each telecommunications operator in the Colombian market.

One of the main limitations of adequate regulation to improve the concentration and competition of the Colombian telecommunications market is the assertive prediction of such indexes in the future, so that anticipated, preventive, and not reactive planning can be carried out.

In accordance with the above, future work will study, validate, and evaluate prediction techniques of concentration measurement indexes in the Colombian

telecommunications market. This will allow the proposal of effective strategies and methodologies to improve competition in the Colombian telecommunications services' operators in advance.

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