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Master Thesis

Land Value Impacts of Metro Line 1
in the Districts of San Borja and
Surquillo, Lima -Perú (2023)

by

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February 2024

Department of Railway Management & Policy

The Graduate School of Railway

Seoul National University of Science and Technology

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A Master Thesis submitted to the Department of Railway
Management & Policy at the Graduate School of Railway
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of Master of Engineering.

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Summary

Title: Land Value Impacts of Metro Line 1 in the Districts of San Borja and Surquillo, Lima -Peru (2023)

In the global context, there is a growing trend to incorporate mechanisms for land value capture into public policies to address challenges associated with the financing of public transportation infrastructure. For a proper assessment, it is crucial to gather information on the impacts of public actions that generate value in private assets, and such information is scarce in the Peruvian context. The main objective of the research was to estimate the impact of Metro Line 1 on housing sales price around three stations in the San Borja - Surquillo district in Lima, Peru. A quantitative methodology was proposed, with an explanatory approach, non-experimental design, and cross-sectional design (2023), for a refined sample of 339 residential properties surrounding the La Cultura, San Borja Sur, and Angamos stations of Line 1 of the Lima Metro using available information from real estate websites. The evaluation focused on estimating a hedonic pricing model that explains variations in housing sales price based on their structural attributes, neighborhood characteristics, safety attributes, and distance to the nearest station of Metro Line 1. The results show the marginal impact of a unit increase in the distance between the property and the nearest Metro station on the percentage change in the sale price, with an increase of 0.043% for residential properties up to 100m, 0.33% up to 400m, 0.21% up to 800m, and decreasing influence up to a maximum radius between 1200 to 1300 meters.

Keywords: hedonic pricing model, value capture, land value, transportation infrastructure, marginal impact, metro, San Borja.

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1. Introduction

The global expansion of mass transit systems, such as the metro, has contributed to the sustainable development of cities by improving mobility, road safety, and overall quality of life. It has also led to transformations in land use and stimulated property values in their vicinity. In the Peruvian context, despite these benefits, budget constraints have slowed down the implementation of the Basic Metro Network of Lima and Callao, which consists of six lines, with only Line 1 currently operational and Line 2 under construction.

To address these challenges, international experience highlights the valuable financial tool of land value capture, which deserves thorough exploration in the Peruvian reality, especially in the initial phase of impact assessment, given the scarcity of research contributing to the evaluation of future public policies.

Consequently, based on the available information, the guiding question for this research is: What is the impact of the proximity to Metro Line 1 on the housing sales price of identified properties in the districts of San Borja and Surquillo, in Lima, Peru? The hypothesis posits that the proximity to Metro Line 1 influences on the housing sales price.

The main objective of this research is to estimate the impact of the proximity to Metro Line 1 on the housing sales price of identified properties around three metro stations: La Cultura, San Borja Norte, and Angamos, using the hedonic pricing methodology. Through this approach, the aim is to estimate a hedonic pricing model that best represents the relationship between the studied variables, assess the marginal impact, and determine the area of influence of this proximity.

To achieve this purpose, the present research involved a literature review, compilation of observational data, analysis, and estimation of the hedonic pricing model, interpretation of results and conclusions. The inherent challenges in this field were identified, aspiring to provide methodological value for future research and contribute relevant information to the Peruvian government for the evaluation of new public policies supporting infrastructure financing.

1.1 Background

Metro Line 1 was a highly anticipated transportation system for citizens, with construction commencing in 1986. After a 25-year hiatus, the first section, spanning 22.1 km from Villa El Salvador Station to Grau Station, became operational. In 2014, a second section of 11.9 km was added, extending from Grau Station to Bayovar.

This Metro line 1 emerged from the necessity to provide Lima with a mass transit system connecting the northeast, center, and south of the city. Most of the city relied on conventional public transportation, which contributed significantly to traffic congestion, increased pollution, and accidents. The quality of public transportation ranks second (39.9%) among the key issues affecting the population's quality of life, surpassed only by concerns about public safety at 76.5% (Lima Como Vamos, 2022). [1].

It is widely recognized that mass transit systems, such as the metro, have contributed to the sustainable development of cities by improving mobility, road safety, quality of life, and influencing transformations in land use, as well as stimulating property values in their vicinity.

In the Peruvian context, there is a scarcity of research regarding the evaluation of the impacts of Metro Line 1 on property values. The typical evaluation focus is on measuring its effectiveness and benefits from the public perspective, leaving a significant knowledge gap in the assessment of land value capture public policies.

Globally, the hedonic pricing model is widely used to evaluate the determinants of housing prices by decomposing the total price into values associated with individual characteristics. This model helps understand how certain features or attributes impact housing prices in the market.

The operation of Metro Line 1 in Lima has created opportunities in the real estate, retail, and financial sectors. During the execution of Section 2 (2011-2014) of Metro Line 1, according to INEI, around 1,000 new establishments [2], emerged near this section in the year of the start of operations, benefiting from the increased connectivity generated by the project, promoting the development of mixed-use areas near the stations to integrate public transportation with housing and services.

1.2 Problem statement

Worldwide, the construction and operation of metro systems involve high long-term investment costs. Often, one of the major challenges faced by governments is the lack of sufficient financial resources, particularly in developing countries in Latin America. This is due to the dependence on the economic situation and social needs of each country, making it difficult to allocate adequate funds for public transportation, including metro systems.

According to the latest Global Competitiveness Index 4.0 (GCI 4.0) by the World Economic Forum in 2019 (WEF,2019) [3], Peru ranked 65th out of 141 countries. In comparison with other Latin American nations, it exhibited a less competitive economy than Colombia (57th), Mexico (48th), and Chile leading at 33rd place. This highlights significant challenges in the quality of road infrastructure, as well as the efficiency of railway and port services in the country.

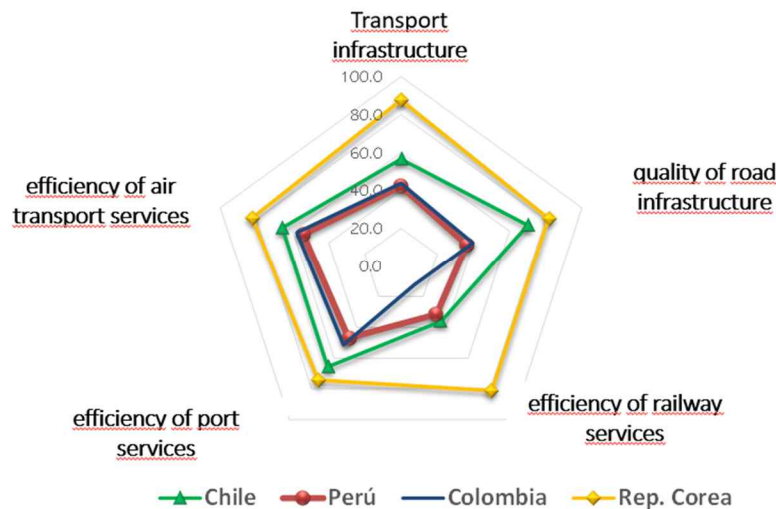


Fig. 1.1 Transport Infrastructure Quality according to the World Economic Forum 2019 assessment [3]
Own elaboration

In 2022, general government revenues accounted for 22.1% of GDP, well below the average for Latin American and Caribbean countries (30.2% of GDP) and advanced economies (37.4% of GDP). This low revenue level also determines that spending is relatively low compared to these countries. In Peru, spending reached 22% of GDP, which is lower than the figures recorded in Latin American and Caribbean countries (30.2% of GDP) and advanced economies (40.2% of GDP). (MEF, 2023) [4].

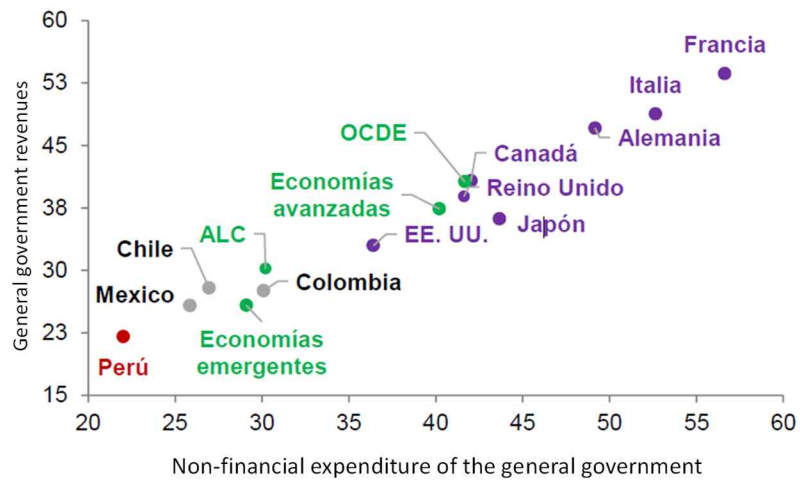


Fig. 1.2 Revenues and Expenditures of the General Government 2022¹ (% of GDP) [4]

In the current year 2023, according to Law No. 31638, the Public Sector Budget Law for the fiscal year 2023 and based on projections in the Multiannual Macroeconomic Framework 2024-2027, for the railway sector, expenses have been budgeted solely for the continuation of the construction of Line 2 and for the operation and maintenance payments of Metro Line 1 in Lima. (MEF, 2023) [5], which puts pressure on public finances.

It is evident that efforts to allocate budget to large-scale transportation projects are still insufficient. It is important to explore new alternatives that have had a significant impact on cities in Latin America and developed countries related to land value capture.

In the Peruvian context, there is a shortage of research on this topic that provides relevant information from the initial phase of impact estimation, contributing to the evaluation of future public policies. Therefore, based on the available information, this research focuses on the following research questions:

General:

What is the impact of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo, Lima, Peru?

Specifics:

- What is the equation of the hedonic pricing model that best represents the relationship between the housing sales price and the proximity to Metro Line 1 stations in the districts of San Borja and Surquillo?
- What is the estimated marginal impact of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo?
- What is the range of influence, estimated by the hedonic pricing model, of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo?

1.3 Research objectives

The main objective of this research is to:

Estimate the impact of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo, Lima, Peru (2023).

To achieve the main objective, the following specific objectives are outlined:

- Estimate the equation of the hedonic pricing model that best represents the relationship between the housing sales price and the proximity to Metro Line 1 stations in the districts of San Borja and Surquillo.
- Estimate the marginal impact of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo.
- Determine the range of influence, estimated by the hedonic pricing model, of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo.

1.4 Hypothesis

“The proximity of Metro Line 1 influences the housing sales price identified in the districts of San Borja and Surquillo, in Lima, Peru.”

1.5 Scope of study

“This research aims to estimate the impact of the proximity of Metro Line 1 on the housing sales price identified in the districts of San Borja and Surquillo, in Lima, Peru (2023), applying the Hedonic Prices model. The methodology is based on the hedonic approach, which is widely supported by research, in the

analysis of the relationship between the price of a real estate property and its various attributes, both intrinsic and environmental. In other words, an econometric model is applied to explain how a variation in a unit of each attribute or characteristic influences the price of the real estate property.

The study is limited to the evaluation of the impact on the housing sales price around three stations in the central-south area, in the districts of San Borja and Surquillo, in Lima, Peru. This is considering the following criteria:

- i) Identification of higher passenger demand at Metro Line 1 stations with residential characteristics, mainly represented by La Cultura and Angamos stations (San Borja district) and Bayovar station (San Juan de Lurigancho district) (see Chapter 4.2), excluding those heavily influenced by commercial areas like Gamarra.
- ii) Availability of housing sales price information from real estate websites, excluding properties for commercial or industrial use due to data accessibility. In this stage, Bayovar and San Juan de Lurigancho stations were excluded due to limited information on real estate websites, and Surquillo was included collaterally since it is on the district boundary where the Angamos station is located.
- iii) Sections of Line 1 with a similar structure (elevated viaduct), excluding the southern end of the line where the infrastructure is at ground level. This would imply analyzing other types of parameters and urban impacts.

The following figure illustrates the alignment of Line 1, highlighting the location of the districts of San Borja and Surquillo, where the scope of the research has been delimited.

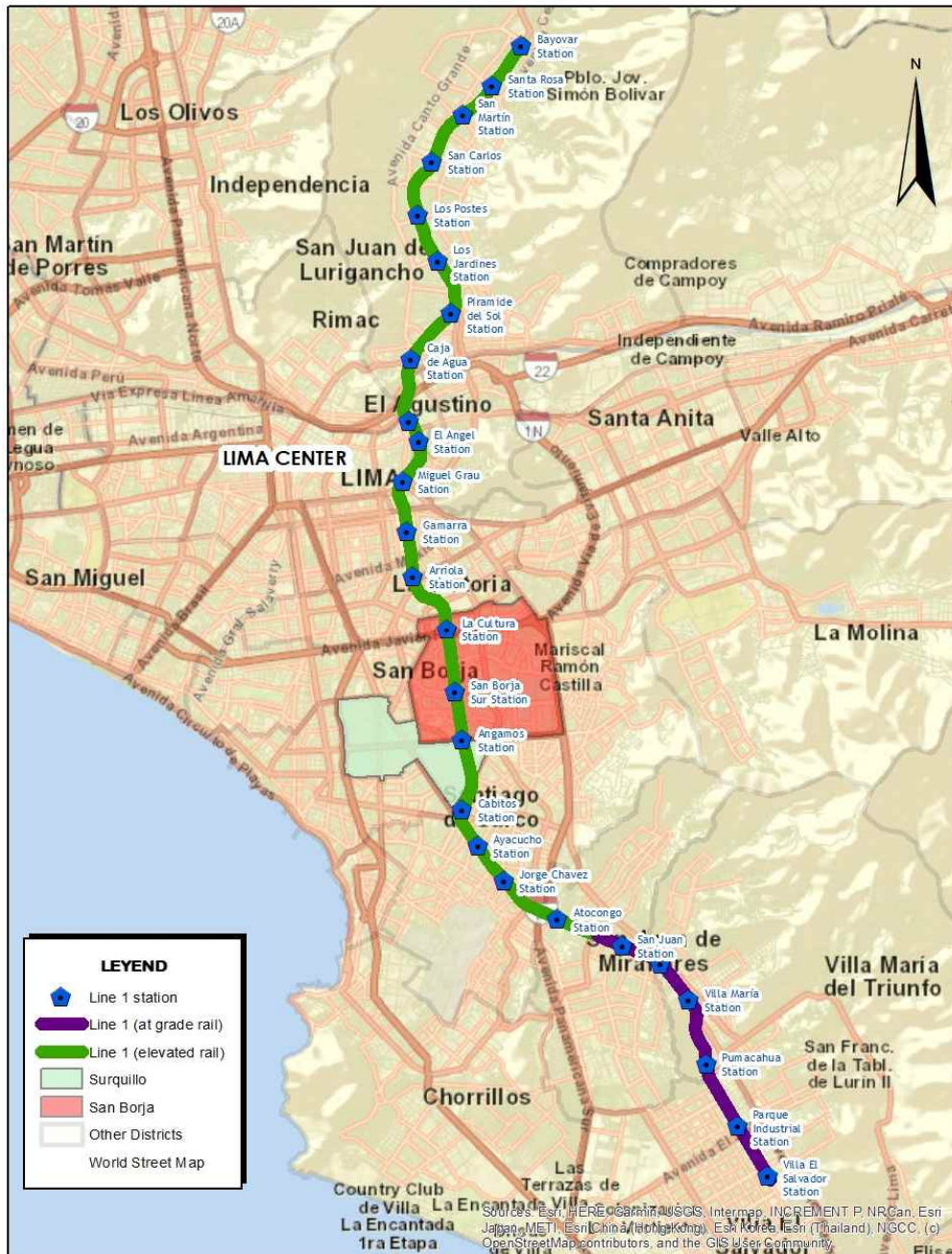


Fig. 1.3 Location of scope of study

Additionally, other common evaluations related to the impact on travel time savings, fuel savings, the environment, road safety, among others, generated by mass transportation infrastructure like a metro line, are not addressed since they are not the objectives of this research.

1.6 Research Limitations

The present research has encountered various challenges in obtaining information, including:

- Restricted access or lack of response to requests for information at the level of databases from: i) local governments, which manage cadastral data for urban properties indicating restricted access, ii) the police entity, to obtain crime data, and iii) the real estate portal Urbania in Peru.
- Restricted access to information on “purchase transaction prices“ for each property, with associated georeferencing information and attributes of each property. Instead, information available on “housing sales prices“ published on real estate portals was used, including the property’s location and attributes. These prices are subject to negotiation but are considered a close approximation to the final sale price, as they are based on the owner’s intention to sell, with knowledge of the property’s value or an inherent appraisal. Therefore, the offer price would not significantly deviate from the market value.
- The existing information, though available, was limited to individual queries for each property and attribute to be analyzed on web pages without the ability to access or download databases. This complicated and extended the data collection time to a dedicated period of 2 months, as it was necessary to manually extract the information, resulting in a database of 37,827 records. Paradoxically, this limitation led to a meticulous review of each record, correcting errors in georeferencing and attributes, enhancing the quality of the available information. Thus, the initial limitations transformed into an opportunity to refine and enrich the collected data, providing a more reliable and detailed basis for analysis.
- Nonexistent information in secondary sources related to environmental quality. There is a lack of environmental measurements for each property or sector, with only measurements from public entities in one or two monitoring stations per district, which do not meet the necessary data variability parameters to be added as an independent variable in the model. Measurement of environmental quality is not part of the research objectives. However, this type of limitation is accounted for in regression models that include the variable u , called the error term or disturbance in the relationship, representing unobserved factors affecting the dependent variable.

Due to the nature of data availability, the sample used in the research was not selected through a random sampling process. This implies that the results of the impact of the proximity of Metro Line 1 may not be generalizable to

the population of San Borja and Surquillo housing but represent the impact on the housing identified for this investigation. The absence of randomization could introduce biases in the representativeness of the analyzed cases.

Therefore, it should be considered that the results obtained reflect the relationships and effects for the analyzed properties, in line with the research objectives. Even with its limitations, the study can offer a significant contribution by identifying relevant patterns, relationships, and trends in the districts of San Borja and Surquillo.

1.7 Justification and importance

It is widely recognized that public transportation infrastructures contribute to the sustainable development of cities, improving mobility, road safety, quality of life, as well as transformations in land use and a stimulus to property values in their vicinity. In the Peruvian context, despite these benefits, the lack of budget has slowed down the implementation of the Basic Network of the Lima and Callao Metro, composed of 6 lines, with only Line 1 in operation and Line 2 under construction.

To address these challenges, international experience highlights the valuable financial tool of land value capture, which deserves thorough exploration for the Peruvian reality, starting from its initial impact assessment phase, given the scarcity of research contributing to the evaluation of future public policies.

This research aims to contribute through a pioneering empirical study in the city of Lima, estimating a hedonic pricing model that evaluates the impact of Metro Line 1 on the value of residential properties identified in its surroundings. Despite the limitations encountered, the study seeks to provide insights into patterns, relationships, and relevant trends in the districts of San Borja and Surquillo.

Another relevant aspect is that the study also offers methodological value for future research and allows for comparisons over time. Additionally, it has identified areas of opportunity for improvement in accessing, collecting, and managing information necessary at this level of study.

Ultimately, this research aspires to contribute to the Peruvian government's efforts to promote the evaluation of future Land Value Capture policies that can support the financing of public infrastructure projects, primarily in the construction of upcoming projects within the Basic Network of the Lima and Callao Metro.

2. Methodological framework

2.1 Investigation Research

Given that the objective is to estimate the impact of the proximity of Metro Line 1 on the housing sales price of identified properties in the districts of San Borja and Surquillo, a **NON-experimental design** was employed because no variable is manipulated for analysis. It is of cross-sectional nature (2023), collecting data at a single point in time due to information limitations, with the purpose of describing variables and analyzing their incidence and interrelationship at a given moment.

2.2 Research Level

The nature of the research is explanatory, as its objective is to identify cause-and-effect relationships between variables, seeking to explain why a phenomenon occurs. In this case, through the hedonic pricing model, the causal relationship of the variable of interest, proximity to Metro Line 1, is evaluated in relation to the effect on the variation of housing sales prices, while keeping other relevant variables constant.

2.3 Research approach

This research was designed under a **quantitative approach**, as it best suits the characteristics and needs of the research objectives. It is used for data collection and analysis to answer research questions and test the previously established hypothesis, relying on numerical measurement, the use of statistics, and econometrics..

2.4 Unit of Analysis

The scope of the study in the research is considered in the Province of Lima. The unit of analysis is the “urban residential property” or “dwelling,” which in this case corresponds to apartments located in areas surrounding the stations of Metro Line 1 in the districts of San Borja and Surquillo.

2.5 Population and Sample

For the research, information was collected from 349 dwellings located in the districts of San Borja and Surquillo.

Due to limitations in accessing the necessary information for this type of study, it was not possible to conduct a random sampling of dwellings. Instead, we worked with the available information from real estate portals.

2.6 Data Collection Techniques and Instruments

The data collection technique used in this research is the content analysis of secondary data sources available on official government and private company websites (real estate portals). The instrument used is the record chart.

2.7 Data Processing Techniques and Tools

The techniques used in data processing include descriptive statistics, which involve “a set of procedures aimed at presenting masses of data through tables, graphs, and/or summary measures,” and econometrics, which combines economic theory with statistical methods to estimate and test causal relationships between economic variables.

The data processing tools used include Microsoft Office Excel, ArcMAP 10.1 software, the Statistical Package for the Social Sciences (SPSS) 10.0 statistical software, and the STATA software for the regression of the econometric model.

2.8 Variable Identification

2.8.1 Dependent Variable

Housing Sales Price, as it is the variable in which the variations of the independent variables will be analyzed and measured.

2.8.2 Independent Variables

Structural characteristics, neighborhood characteristics, security attributes, accessibility to Metro Line 1 of Lima, as these are considered variables that can influence or determine variations in the dependent variable. It is worth noting that in various studies, environmental attributes (air quality and noise) are also considered. However, such secondary source information does not exist per dwelling or sector in the city of Lima, and as explained earlier, it will be

represented in the model as an unobserved factor u , called the error term or disturbance in the relationship.

The identified variables, comprising the dependent variable and the independent variables per dwelling, are detailed below:

Table 2.1 Dependent and Independent Variables in the Research

Denomination	Indicator	Variable type
Housing Sales Price	Dollar	Quantitative /Discrete
Structural Characteristics	Indicador	Tipo de variable
Occupied Area	Square meters	Quantitative /continuous
Covered Area	Square meters	Quantitative /continuous
Bedrooms Number	N° of Bedrooms	Quantitative /Discrete
Bathrooms Number	N° of Bathrooms	Quantitative /continuous
Garages Number	N° of garages	Quantitative /Discrete
Floors Number	N° of floor	Quantitative /Discrete
Rooftop Access	Yes =1 No=0	Qualitative/ nominal Dummy
Exterior view	Yes =1 No=0	Qualitative/ nominal Dummy
Years of age	Years	Quantitative /Discrete
Elevator	Yes =1 No=0	Qualitative/ nominal Dummy
Storage Number	N° of storages	Quantitative /Discrete
Dwelling type	Flat Duplex Triplex	----- Dummy Dummy
Neighborhood Characteristics	Indicator	type
Type of Consolidation of the housing land	Consolidated urban land	Qualitative/ nominal

Type of housing regulatory zoning	<ul style="list-style-type: none"> • High-Density Residential • Low-Density Residential • Workshop Residence 	Qualitative/nominal
Socioeconomic stratum level (per capita income) by households in the block where the dwelling is located	Upper-middle High	Qualitative/ordinal
Population density in the block where the housing is located	Inhabitants/hectare	Quantitative/continuous
Euclidean distance from the dwelling to the nearest school	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest College	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Mall	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Supermarket	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Hospital	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Drugstore	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Park Public	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest deport center	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest restaurant	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Bank	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest ATM	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest Public institution	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest main road	meters	Quantitative/continuous
Euclidean distance from the dwelling to the nearest bus stop	meters	Quantitative/continuous
Security Attributes:	Indicator	Variable type
Annual number of various robberies in the subsector where the dwelling is located.	N° of various robberies	Quantitative/Discretef

Annual number of vehicle robberies in the subsector where the dwelling is located	N° of vehicle robberies	Quantitative /Discrete
Annual number of various thefts in the subsector where the dwelling is located	N° of various thefts	Quantitative /Discrete
Annual number of aggravated robberies in inhabited houses in the subsector where the dwelling is located	N° of aggravated robberies in inhabited houses	Quantitative /Discrete
Annual number of vehicle thefts in the subsector where the dwelling is located	N° of vehicle thefts	Quantitative /Discrete
Annual number of homicides in the subsector where the dwelling is located	N° de homicidios	Quantitative /Discrete
Annual number of micro-drug trafficking crimes in the subsector where the dwelling is located	N° de delitos de micromercialización de drogas	Quantitative /Discrete
Annual number of scams in the subsector where the dwelling is located	N° de estafas	Quantitative /Discrete
Proximity to Metro Line 1	Indicator	Variable type
Euclidean distance from the dwelling to the nearest Metro Line 1 station	Meters	Quantitative /continuous

2.9 Information sources

The sources of secondary data collection information are detailed below.:

Table 2.2 Sources of research information

Data about:	Information source	Date
Dweeling	Real estate portals: https://urbania.pe https://www.adondevivir.com https://www.properati.com.pe https://www.infocasas.com.pe https://insideperu.com.pe/ https://babilonia.io	Oct. 2023
Soil consolidation (2023) Regulatory zoning (2023) Socioeconomic stratum (INEI 2020) Population density (2020) Main road network (2023)	Metropolitan Planning Institute (Metropolitan Information System Data Catalog Viewer - PLANMET2040 - GIS Map) https://portal.imp.gob.pe/ [6]	Various

School Hospital	National Georeferenced Data Platform Geo Peru - GIS Map https://visor.geoperu.gob.pe/	2023
College	Google Maps https://www.google.com/maps	2023
Mall		
Supermarket		
Drugstore		
Park		
Sport center		
Restaurants		
Bank		
ATM		
Public Institution		
Bus stop (buses)		
Pólíce department	National Georeferenced Data Platform Geo Peru – (GIS Map) https://visor.geoperu.gob.pe/	2023
Sectorization of San Borja Police Stations	District Municipality of San Borja District citizen security action plan 2023 CODISEC–San Borja [7]	2023
Sectorization of Surquillo Police Stations	District Municipality of Surquillo District citizen security action plan 2023 CODISEC–Surquillo [8]	2023
Annual crimes (by modality)	National Institute of Statistics and Informatics– Integrated Crime Statistics and Citizen Security System (Data–Crim) https://datacrim.inei.gob.pe/ [9]	2022

3. Literature review

3.1 Academic research background

From the review of research background in Peru regarding the impacts of any type of public transportation system such as Metro, BRT (Metropolitano), or Complementary Corridors on property value using the hedonic pricing methodology, no research has been found.

On the other hand, from the review of foreign research backgrounds, it is observed that scholars have conducted various studies related to the degree of influence on the value of properties near different types of transportation systems, including BRT, Metro, LRT, MRT, and for different phases, from the announcement of construction to the opening of the line, as well as before and after the start of construction. The results vary due to the nature of the location, the characteristics of the transportation projects, among other factors. However, a predominant trend of influence, mostly positive rather than negative, between the installation of railway transportation and the value of surrounding properties is highlighted, with some relevant references:

- **Sun H,Wang Y,Li Q (2016)** [10], The research explores how the construction of Metro Line 3 affects residential property values in Tianjin. Using the hedonic pricing model, three approaches are analyzed: linear, logarithmic, and semilogarithmic. It is observed that the semilogarithmic equation in the regression analysis of residential value approaches 1 more closely and has the best statistical effect. The conclusion is that the construction of metro lines has a greater impact on the outskirts of the city than in the city center.
- **MacDonald, H., & Bowes, D. R. (2012)** [11], The study evaluates the impact of proximity to light rail stations on residential property values in Buffalo, New York. The model suggests that, for dwelling located in the study area, each foot closer to a light rail station increases the average property value by \$2.31 (using straight-line geographical distance) and \$0.99 (using network distance). In other words, a dwelling located within a quarter-mile radius of a light rail station can command a premium of \$1300-3000, or 2 to 5 percent of the average dwelling value in the city. The model results further suggest that three independent variables (the number of bathrooms, plot size, and location on the east or west side of Buffalo) are more influential than railway proximity in predicting property values. Individual

regression models for each of the 14 light rail system stations suggest that the effects are not uniformly felt across the entire system. Proximity effects are positive in high-income station areas and negative in low-income station areas. An analysis of actual walking distance to stations (along the street network) versus perceived proximity to stations (measured by straight-line distance) reveals that the results are statistically more significant in the network distance model than in the straight-line distance model. However, the effects are greater in the straight-line distance model, suggesting that apparent proximity to train stations is an additional locational advantage compared to physical walking distance to the station.

- **(Mendieta y perdomo 2007)** [12] Using cadastral property values for 1,547 properties within a 1 km radius of TransMilenio, the study found that residential property prices increased between 0.12% and 0.35%, depending on the distance to the BRT TransMilenio, for every 5 minutes closer walking time to a TransMilenio BRT station. The study incorporates spatial econometrics in the evaluation of the hedonic pricing model.
- **Muñoz-raskin (2006)** [13] He used data on the values of 130,692 new multifamily properties provided by the Housing and Control Department of Bogotá between 2001 and 2004. He found that properties within the immediate proximity of feeder lines (0–5 minutes walk) were valued more than those requiring a 5 to 10-minute walk. His findings also show that high-value properties were more valued if they were close to a feeder line, but in the case of trunk lines, the effect was the opposite.
- **(Rodríguez y Targa, 2004).** [14] The study was based on the asking rents for apartments in 2003 for 494 multifamily residential properties in a 1.5 km influence area surrounding two TransMilenio corridors. They detected a premium of 6.8 to 9.3 percent for every 5 minutes of walking time closer to a TransMilenio BRT station. They also found that properties along the bus route, but not necessarily close to a TransMilenio station, had a lower premium, presumably due to the negative effects of bus traffic noise and pollution.
- **Jung Lee (2002)** [15] It focused on South Korea in Gangnam-gu, Nowon-gu, and Bundang-gu, researching the impact of urban rail on housing prices. In Gangnam-gu, property prices decrease as one moves away from the subway station, while in Nowon-gu and Bundang-gu, a contrary price change is observed. It was explained that residents in Bundang-gu had a

different perception of the metro station area, as well as a different choice for a mode of transportation.

- **Guangzhou Li Wenlin, Yan Xiaopei (2002)** [15], Regarding Metro Line 2 in Guangzhou, the prices of properties in Haixin district increase by ¥300 to ¥500.

3.2 Bases Teóricas

3.2.1 Hedonic Price Model

A hedonic pricing model is an econometric model that is used in the evaluation of goods or services by breaking down the total price into the values associated with their individual characteristics. In other words, it is used to understand how certain features or attributes affect the prices of goods or services in the market.

The term “hedonism“ refers to the enjoyment or satisfaction derived from specific attributes or characteristics. In the context of hedonic pricing models, it is considered that consumers experience utility or pleasure due to certain features of a good or service, and the purpose of the model is to quantify this relationship.

Hedonic pricing models are widely used to estimate property prices, seeking an explanation for their value, with foundations based on the model developed by Sherwin Rosen (1974) for heterogeneous or differentiated products, which can be applied to the housing sector [16].

This model presents a representation of heterogeneous goods (housing) that considers the set of characteristics or components it possesses. It suggests that exchanges of heterogeneous goods (housing) that occur in the market are actually transactions of the characteristics or attributes that make up these goods, which are demanded and offered together.

In the case of housing, it refers to the set of structural attributes specific to the dwelling, those associated with the neighborhood, its location, among others. The main idea is to break down each of these attributes, determine their respective valuations, and consequently, understand the implicit demands associated with them.

This hedonic approach enables the identification of the relative importance of each attribute in the market-assigned value of real estate, allowing for the

determination of how this value will change when each of these attributes changes. This, in turn, facilitates the prediction of future prices.

The methodology used involves building an econometric model that describes the functional relationship between the property's price and its corresponding characteristics. Statistical information is provided for the construction of this econometric model, which is then subjected to regression analysis. Subsequently, the results are processed, and the implicit valuation associated with each attribute is estimated.

It is important to emphasize that the objectives of any econometric analysis are to estimate the parameters of a model and test hypotheses about them; the values and signs of the parameters determine the validity of an economic theory and the effects of certain attributes or independent variables.

In the context of empirical analysis, non-experimental data is used, also referred to as retrospective or observational, meaning without the conduct of controlled experiments, highlighting the passive nature of the researcher in data collection. These data can be cross-sectional, time series, combinations of cross-sections, and panel data. In the case of cross-sectional data, as in the current research, a sample is taken at a specific point in time, ignoring small temporal differences in data collection.

3.2.2 Model Representation [17]

The general format of a hedonic price model can be expressed as a regression equation, where the price (or the logarithm of the price) is the dependent variable, and specific characteristics of the good or service are the independent variables. To perform a regression model of the dependent variable on the independent variables that aim to explain it, a multiple regression model is used, as it allows the analysis of various observed factors that affect the dependent variable.

The model creates a price function.:

$$P = f(x_1, x_2, x_3, x_4 \dots \dots x_n, u)$$

Or expressed in regression form.:

$$P = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \dots \dots + \beta_n x_n + u$$

where:

P = Property price (dependent variable)

β_0 It is the constant or Intercept, that is, the value of the dependent variable when all the independent variables are equal to zero.

$\beta_1, \beta_2, \beta_3, \beta_4 \dots \dots \beta_n$ They are the regression coefficients of the independent variables or parameters to be estimated and describe the direction and strength of the relationship between the price of the property and each of the independent variables. That is, they are the coefficients that represent the contribution of each characteristic or attribute to the price.

$x_1, x_2, x_3, x_4 \dots \dots x_n$ attribute vectors or independent variables that represent specific characteristics or attributes.

u is the error or disturbance term in the relationship that represents influences on the dependent variable other than the independent variables, which are additional factors that cannot be identified or measured directly but that must somehow be taken into account, considered as unobserved factors. . (“unobserved“ in English).

The choice of independent variables is determined both by economic theory and by considerations about the data, knowledge of diverse literature of authors and previous research carried out with hedonic price models.

In this aspect, there is various information to consider, for example regarding the attributes to be considered of the dwelling, the variables usually chosen being: total m2, number of rooms, independent kitchen, number of bathrooms, terrace, storage room, garage, in accordance with King (1976), Kain and Quigley (1970), Palmquist (1984), among others. Likewise: Tranchez (2000) considers quality attributes of the dwellings (type of energy used, refrigeration, concierge, elevator, green areas, swimming pool, sports facilities), location attributes (accessibility, socioeconomic level of the neighborhood, level of housing assets). proximity to various educational, health services, etc.) and negative externalities (crime, pollution, etc.), as possible explanatory variables of housing prices and in order to contrast their influence. [16]

3.2.3 Functional form

The functional form (f) does not necessarily correspond to a linear expression, it is determined by the relationship between the price and its explanatory variables, with an empirical choice seeking a precise adjustment of the information of identified attributes with minimum levels of error or deviation. Epple (1985), Goodman (1978). [16]. Some of the commonly used

functional forms in order of complexity are linear, semi-logarithmic, linear-log, double-log function.

Lineal function

Linear functions have the characteristic that a unit change in x (independent variable) produces the same change in y (dependent variable), regardless of the initial value of x , which is unrealistic for many economic relationships. To address a variety of economic phenomena, it is necessary to explore nonlinear functions, which are characterized by their dependence on the initial value of x for the change in y for a given change in x .

Natural logarithm

The most significant nonlinear function in econometric analysis is the natural logarithm, represented as a log function.

$$y = \log(x) \text{ o } y = \ln(x)$$

The function $y = \log(x)$ is defined only for $x > 0$, and

When $y = \log(x)$, the relationship between (y) and (x) shows diminishing marginal returns. The elasticity of (y) with respect to (x) varies along the demand curve, representing the percentage change in (y) when (x) increases by 1%. Elasticity is not constant along the demand curve.

Meanwhile, a constant elasticity model is represented by the equation:

$$\log(y) = \beta_0 + \beta_1 \log(x),$$

β_1 is the elasticity of y with respect to x (assuming that $x, y > 0$).

Therefore, a 1% increase in x causes a variation of $\beta_1\%$ de y .

Quadratic functions

Functions that contain squares of one or more explanatory variables; They capture the decreasing or increasing effects on the dependent variable.

A simple way to capture diminishing returns is to add a quadratic term to a linear relationship.

$$y = \beta_0 + \beta_1 x + \beta_2 x^2$$

where $\beta_0, \beta_1, \beta_2$ are parameters. When $\beta_1 > 0$ and $\beta_2 < 0$, the relationship between y and x has the decreasing parabolic form, that is, there is an increasing marginal return. The maximum point of the function es $x^* = \beta_1 / (-2\beta_2)$.

The variable x has a positive effect on the variable y until a cyclical point x^* is reached, for example the first unit change in x generates β_1 and each additional year of growing until it reaches x^* , after which each additional unit of x generates a decrease in y .

When $\beta_1 < 0$ y $\beta_2 > 0$, the relationship between y and x has the increasing parabolic form, that is, there is an increasing marginal return. The minimum point of the function is $x^* = -\beta_1/2\beta_2$.

3.2.4 Box-Cox Transformation (1964) [18]

The model developed by Box-Cox (1964) provides a theoretical tool to determine the functional form that best fits, without the need to determine it beforehand, given that economics.

Box-Cox transformations (1964) offer greater flexibility of the hedonic price function and include the other functional forms as particular cases.

Let the price equation:

$$P^{(\theta)} = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 X^{(\lambda)}$$

Donde existen dos atributos en la ecuación (M y X) en los cuales los parámetros θ y λ represent the order of magnitude of the transformations of the dependent variable and the explanatory variables, respectively. These transformations are defined as:

$$P^{(\theta)} = \begin{cases} \frac{(P^\theta - 1)}{\theta} ; \text{para } \theta \neq 0 \\ \ln P ; \text{para } \theta = 0 \end{cases}$$

$$M^{(\lambda)} = \begin{cases} \frac{(M^\lambda - 1)}{\lambda} ; \text{para } \lambda \neq 0 \\ \ln M ; \text{para } \lambda = 0 \end{cases}$$

Box y Cox (1964) From the beginning they maintained that the transformation of variables according to this approach produces estimation residuals closer to a normal distribution and less heteroscedastic. The Box-Cox transformation has received particular attention in works estimating the hedonic price function due to its ability to encompass other simpler functional forms as particular cases:

Table 3.1 Particular cases of the Box-Cox function

Functional Form	Parameters
Linear	$\theta = 1 ; \lambda = 1$
Semi log	$\theta = 0 ; \lambda = 1$
Linear log	$\theta = 1 ; \lambda = 0$
Double log	$\theta = 0 ; \lambda = 0$

Base on [12] and complemented by own elaboration.

However, despite the flexibility of the Box-Cox model, its functional form remains restrictive, as it provides only a local approximation of the true price function. Additionally, the method does not allow the inclusion of variables that take negative or zero values, as they cannot be transformed.

The following table presents various options for functional forms for the hedonic price equation and the corresponding expressions of the implicit price in relation to its explanatory or independent variables. It is relevant to note that the partial derivative of the price with respect to the attribute of interest (dP/dM) is shown. While in the linear function, the implicit price is a constant, from the semi-log functional form, the resulting expression becomes more complex and may depend on both the values of the dependent variable and the considered explanatory variable..

Table 3.2 Functional forms considering a constant linear effect of “M” on “P”

Functional Form	Expression	Implicit Price (dP/dM)
Linear	$P = \beta_0 + \beta_1 M + B_2 X$	β_1
Semi log	$\ln P = \beta_0 + \beta_1 M + B_2 X$	$\beta_1 P$
Linear log	$P = \beta_0 + \beta_1 \ln M + B_2 \ln X$	β_1 / M
Double log	$\ln P = \beta_0 + \beta_1 \ln M + B_2 \ln X$	$\beta_1 \left(\frac{P}{M} \right)$
Box-Cox (Theta)	$P^{(\theta)} = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 X^{(\lambda)}$	$\beta_1 M^{\lambda-1} P^{1-\theta}$
Box-Cox (Lambda)	$P^{(\lambda)} = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 X^{(\lambda)}$	$\beta_1 M^{\lambda-1} P^{1-\lambda}$
Box-Cox (Left-Hand)	$P^{(\theta)} = \beta_0 + \beta_1 M + \beta_2 X$	$\beta_1 P^{1-\theta}$

Functional Form	Expression	Implicit Price (dP/dM)
Box-Cox (Right-Hand)	$P = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 X^{(\lambda)}$	$\beta_1 M^{\lambda-1}$

Based on [12] and complemented by own elaboration.

Until now, the proposed functional forms assume that the partial effect of the explanatory variables is linear or constant, which implies that the marginal effect of the explanatory variable is constant regardless of the attribute level (M or X). However, it is possible to make this approach even more flexible by introducing quadratic functional forms to evaluate the possibility of increasing or decreasing effects. In this scenario, the estimated relationship between P and M also depends on the level of M.

Table 3.3 Functional forms considering a quadratic effect of “M” on “P”

Functional Form	Expression	Implicit Price (dP/dM)
Linear	$P = \beta_0 + \beta_1 M + B_2 M^2 + \beta_3 X$	$\beta_1 + 2B_2 M$
Semi log	$\ln P = \beta_0 + \beta_1 M + B_2 M^2 + \beta_3 X$	$(\beta_1 + 2B_2 M)P$
Linear log	$P = \beta_0 + \beta_1 \ln M + B_2 \ln M^2 + \beta_3 \ln X$	$(\beta_1 + 2B_2 \ln M) \left(\frac{1}{M}\right)$
Double log	$\ln P = \beta_0 + \beta_1 \ln M + B_2 \ln M^2 + \beta_3 \ln X$	$(\beta_1 + 2B_2 \ln M) \left(\frac{P}{M}\right)$
Box-Cox (Theta)	$P^{(\theta)} = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 (M^{(\lambda)})^2 + \beta_3 X^{(\lambda)}$	$(\beta_1 M^{\lambda-1} + 2\beta_2 M^{\lambda-1} M^{(\lambda)}) P^{1-\theta}$
Box-Cox (Lambda)	$P^{(\lambda)} = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 (M^{(\lambda)})^2 + \beta_3 X^{(\lambda)}$	$(\beta_1 M^{\lambda-1} + 2\beta_2 M^{\lambda-1} M^{(\lambda)}) P^{1-\lambda}$
Box-Cox (Left-Hand)	$P^{(\theta)} = \beta_0 + \beta_1 M + \beta_2 X$	$(\beta_1 + 2B_2 M) P^{1-\theta}$
Box-Cox (Right-Hand)	$P = \beta_0 + \beta_1 M^{(\lambda)} + \beta_2 X^{(\lambda)}$	$\beta_1 M^{\lambda-1} + 2\beta_2 M^{\lambda-1} M^{(\lambda)}$

Based on [12] and complemented by own elaboration..

3.3 Glossary of terms

For the purposes of this research, the following definitions have been defined, and in the case of the econometric and statistical aspects, taking Wooldrifte (2010) [17]:

Apartment: It is a residential property that is part of a building with at least two levels and has a connection to the public road through a corridor, hallway, staircase, or elevator. It also includes dwellings located on the first floor of the building, which have direct access to the street.

Ceteris Paribus: It is a Latin expression that translates to “All other relevant factors remain constant.” It is used to indicate that the effect of a change in one variable is being examined while assuming that all other relevant variables remain unchanged. If the goal is to infer that one variable has a causal effect on another variable, finding a relationship between two or more variables may be suggestive, but not conclusive unless causality can be established. The concept of ceteris paribus plays a significant role in causal analysis. If other factors do not remain constant, then the effect of a change in price on quantity demanded cannot be determined.

Covered Area: It is the sum of the covered surfaces or areas in a dwelling..

Cross-Sectional Database: A database of a population at a specific point in time.

Empirical analysis: A study that employs data in a formal econometric analysis to test a theory, estimate a relationship, or determine the effectiveness of a policy.

Euclidean Distance: Straight-line distance between two points. For the present investigation, as there are geographical coordinates available for various attributes of the research, the following formula was used to calculate the geodesic distance between two points, considering the Earth’s surface (kilometers).

$$d = R \cdot \arccos(\sin(\text{lat}1) \cdot \sin(\text{lat}2) + \cos(\text{lat}1) \cdot \cos(\text{lat}2) \cdot \cos(\text{lon}1 - \text{lon}2))$$

where::

- R is the radius of the Earth (approximately 6371 km).
- arccos is the arccosine function.
- sin and cos are trigonometric functions.

Elasticity: Percentage change in one variable, given a ceteris paribus increase of 1% in another variable.

Goodness of fit measure: A statistic that summarizes how well a set of explanatory variables explains a dependent or response variable.

Hedonic Price: Refers to the decomposition of the price of a good or service based on its individual characteristics or attributes. In other words, hedonic pricing considers how different features affect the price of a good.

Housing or Dwelling: In this research, it is delimited to a residential apartment. See Apartment.

Implicit Price: It is the estimate of the value of a specific characteristic or attribute, obtained by observing how the total price changes when that characteristic changes while keeping the others constant.

Land Value Capture: Mechanisms for generating public resources resulting from the total or partial recovery of the increase in land value generated by actions other than the owner's (undeserved income-private benefit). This is the result of public investment and changes in land use regulations with the purpose of reinvesting these funds in financing public infrastructure for the benefit of the community, based on the principle that every public action should generate public benefit

Marginal impact: refers to the additional change in a dependent variable resulting from a one-unit change in a specific independent variable, holding all other variables constant. In other words, it is the effect that a small variation in one variable has on another, keeping the other variables constant.

Multiple Linear Regression (MLR) Model: Linear model in its parameters, where the dependent variable is a function of the independent variables plus an error term.

Residential Urban Property, in this research is delimited to an apartment. See Apartment.

Standard Deviation: Common measure of the dispersion of the distribution of a random variable.

Ordinary Least Squares (OLS): Method for estimating the parameters of a multiple linear regression model. Ordinary Least Squares estimates are obtained by minimizing the sum of squared residuals.

Occupied area: he surface or covered and uncovered area of a dwelling.

4. About Lima city and Metro Line 1

4.1 Lima City

Population, transportation and accidents

The Province of Lima, capital of Peru, and the Constitutional Province of Callao, where the large port and international airport of Peru are located, make up the largest, most extensive and most populated Metropolitan Area of Lima in Peru, with an estimated 11.3 million inhabitants for the year 2023 (INEI,2023) [19], with an area of 2,819 km² and an average population density of 4,023 inhabitants/km², being one of the five largest megacities in Latin America and the 41st largest in the world [20].

According to the IDB 2018 sustainability report, ten cities, including Lima, generate 1/3 of the GDP of Latin America [21], and Metropolitan Lima leads the GDP at the national level, contributing 48.1% [22] of the total; In addition, it is the main consumption, distribution and production node in the country, considered the Main National Logistics Node by the Ministry of Transportation and Communications.

The department of Lima has a motorization rate (2021) of 83 vehicles/1000 inhabitants and has 2,155,777 light and heavy vehicles that represent 65.3% of the national vehicle fleet (includes non-smaller units: motorcycles and mototaxis) (Asociación Automotriz del Perú- AAP, 2022) [23].

The number of trips per day in the city has varied from 16.5 to 26.7 million, in the period from 2004 to 2018. The rate of trips per inhabitant per day in Lima is approximately 2.6, which is a medium magnitude, which indicates that There is still a great need for travel to cover (PLANMET,2040) [21].

Regarding the modes of transportation used for the main mobilization of the trips of the inhabitants of Lima and Callao who study or work away from home, on average 69.4% use some mode of mass transportation (combi or custer, bus, metropolitan, bus, Lima metro and complementary corridors), 20.6% opt for individual transportation (car, mototaxi, taxi, motorcycle), while 10% use active modes (Non-motorized) (bicycle, walk). (Lima como vamos, 2022) [1].

Regarding satisfaction with the modes of public transport in Metropolitan Lima, 6 out of every 10 people feel dissatisfied, only in the case of Line 1 of the Lima Metro there is a greater number of satisfied people with 67.2%,

being the The most valued aspect in this is speed with 63.8%. (Lima as we go, 2022) [1].

A network composed of 6 Metro lines is planned for the city, whose planned routes were approved by DS 059-2010-MTC and updated by DS 009-2013-MTC, with Line 1 in operation since 2010 (first section) and expanded in 2014 (second section), Line 2 is in the construction stage, lines 3 and 4 at the level of pre-feasibility studies and lines 5 and 6 in projection.



Fig. 4.1 Basic Network of the Lima and Callao Metro
Source: ATU

Regarding road safety in 2022, 52% of traffic accidents in the country were concentrated in Lima and Callao, the main causes being driver recklessness and excessive speed. Likewise, at the national level, 3,328 fatalities were recorded, with Lima having a mortality rate of 5 deaths per 100,000 inhabitants and Callao 3 deaths per 100,000 inhabitants. (Asociación Automotriz del Perú-AAP, 2022) [23].

Urban growth

The urban growth of Lima began in 1535 (year of founding of the country's capital) with only 37.49 hectares of land located mainly in the center of Lima and by the port of Callao and gradually expanded to the areas adjacent to the ravines, from north to south and from east to west. [22].

In the evolution and development of Lima's urban growth, five stages have been identified that have influenced the pattern of its urban expansion over time: the intramuros colonial stage (since its founding in 1535), the expansions in the main arteries urban and the beginning of urban consolidation (1939); a new model of urbanization, expansion of the city and neighborhoods (1940 –

1969); the consolidation of peripheral metropolitan areas (1970 – 1995); and the current metropolis and growth by continuous aggregation (1996 – today). (Metropolitan Municipality of Lima, Metropolitan Planning Institute, 2022) [21].

As urban areas increase, so does population and population density. Currently, around 33.6% of the Peruvian population resides in the metropolitan area of Lima (INEI 2023) [19], with an average annual growth rate in the urban area of 1.2% in the city of Lima and 1.3% in the Province Constitutional Court of Callao (according to the INEI 2017 Census).

The weakness or absence of the State in the planning and management of the city is a constant characteristic throughout its history, which causes the city to continue expanding in a disorderly and fragmented manner, revealing a metropolis with very low population density outside of its traditional center, due to various social, economic and political factors, where the informal economy is present (Metropolitan Municipality of Lima, Metropolitan Planning Institute). [21].

In the transition from a monocentric city to a polycentric one, metropolitan centralities and their physical distribution in the city have not changed; They continue to concentrate in the central area, confirming that key metropolitan centers continue to have their influence near Lima Center. The new urban concentrations located in peripheral areas, where low-income residential areas with few services and infrastructure predominate, have experienced a consolidation process that includes the emergence and development of a variety of businesses and services, based on an informal and formal economy. , far from a territorial planning and management model. (Metropolitan Municipality of Lima, Metropolitan Planning Institute, 2022) [21].

According to surveys carried out among the population of Lima and Callao, the characteristics that they value most in a dwelling are proximity to the workplace or studies (51.6%), to shops (44.1%), to parks and green areas (42.8%) and public transportation (37.7%). (Lima as we go, 2022) [1].

Housing [21]

The PLANMET 2040 indicates that the quality of housing decreases concentrically from Lima Center towards the peripheral districts, as the further away from the center the quality decreases. In 2020, a housing deficit of 777,442 housings is projected, led by San Juan de Lurigancho with 115,363, San Borja with 5,980 and Surquillo with 5,480, among others, while in Cercado de Lima there is a decrease in the housing deficit.

Towards 2040, the development vision focuses on satisfying the demand for land due to the projected increase in the population that is estimated to reach 12,113,158 inhabitants, for which strategies will be developed considering the demand for land according to social strata and location, being that the Residential demand is concentrated in the North (32.2%), East (31.9%), and South (22.8%), with predominance in Middle Low, Middle and Low strata. In contrast, the Center of Lima has 6.7% of the demand, oriented towards Middle High, Medium and High strata.

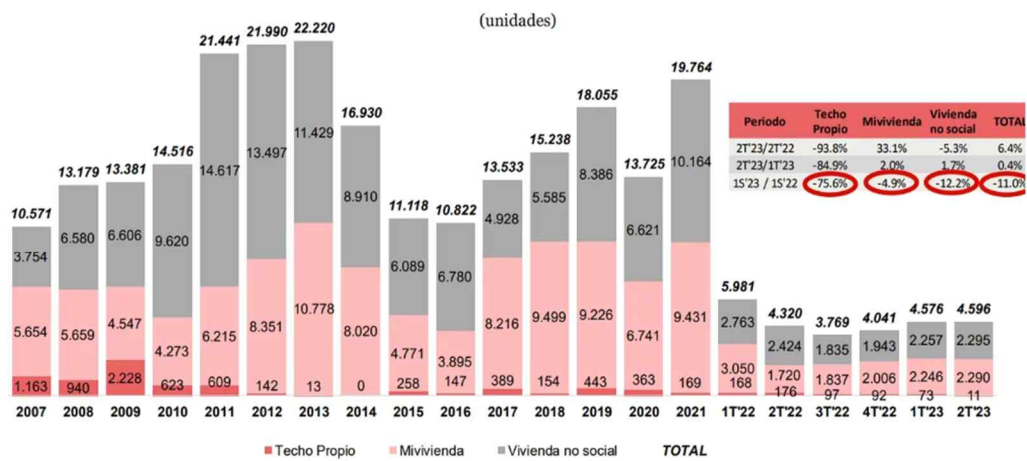
To achieve this, three main lines of action are proposed:

- **Urban densification**, consider taking advantage of public or private land, in central or peripheral areas following the compact city model. It is proposed to increase the building height **in a range of approximately 300 meters on each side of transportation axes and metropolitan centralities**. In addition, it includes densifying areas near the slopes of hills with available services, air collection and soil created to prevent informal expansion on the city limits.
- **Regeneration or transformation** of occupied land, seeks to change the use of urban areas to generate residential public land and parks. 10 industrial sectors are identified in central locations with a potential of 2,300 hectares to be converted to mixed residential use. The reconfiguration of land occupied by activities that limit their potential in consolidated areas is considered, prioritizing recreational and residential uses, especially social housing.
- **Urban expansion** on unoccupied land, proposes using vacant or semi-vacant land in urban interstices or peripheral areas with potential for urbanization, proposing more than 15,000 hectares of land in 27 sectors for logistical activities and mixed development, which require comprehensive planning to transform them into urban land, offering significant potential for varied uses, especially social housing and services..

Real estate market and land value

According to the Association of Real Estate Companies ASEI, a union that brings together the main real estate companies, approximately 1,200 dwellings are sold on the market monthly, the majority of which are located in the districts of Miraflores, Jesús María and similar ones. [21]

According to the Peruvian Chamber of Construction, in the first half of 2023, the sale of new dwellings in Metropolitan Lima decreased by 11% compared to the same period in 2022. The segment of government social assistance programs called “Mivivienda” registered the smallest drop in sales (-4.9%), while “Techo Propio” experienced a reduction of 75.6% and non-social housing decreased by 12.2%. Lima Norte (3.1%) and Callao (52.3%) showed increases in sales, while Lima Top remained relatively constant. However, Modern Lima and Eastern Lima experienced significant drops of 21.4% and 20.5%, respectively. This has led to a situation of relative oversupply in the new housing market in Lima Top and Lima Moderna. (Infobae,2023) [24]



Fuente: Plataforma del Mercado de Edificaciones Urbanas en Lima Metropolitana – PME CAPECO Agosto 2023

Fig. 4.2 Housing sold by market segment (units) 2007–2023

Likewise, with respect to the districts where the analysis of this research is carried out, there is the following reference data for m2 value of land:

Table 4.1 Reference value of m2 of housing in the study districts

District	PLANMET (Sep 2022) [6]	Portal Urbana (October 2023) [25]	BCRP (3er Trim 2023) [26]
San Borja	S/. 6637 (\$ 1702)	S/.7,347 (\$1933)	US \$1946
Surquillo	S/.6616 (\$ 1696)	S/.6552 (\$1724)	US \$1722

Own elaboration

Likewise, below are the general characteristics of these districts in which the dwellings that will be evaluated to measure the impact of Line 1 are located.

4.1.1 San Borja y Surquillo District

San Borja es un distrito ubicado en la parte central de la ciudad, que abarca 9.96 km² , se caracteriza por su carácter consolidado y principalmente residencial. Con una población estimada de 133,000 habitantes para el año 2022, se destaca como parte de Lima Moderna, según Estudios de Mercado y Opinión Pública S.A.C. (CPI), con una distribución poblacional en los segmentos AB (76.8%), C (17.4%), D (4.5%), y E (1.3%).

In the San Borja district there are emblematic buildings such as the Banco de la Nación Tower, the Lima Convention Center, the National Library of Peru, the Great National Theater, various public institutions such as the Ministry of Education and the Ministry of Culture; and sports such as the Eduardo Dibós Dammert Coliseum. Entertainment spaces, such as shopping centers such as Real Plaza Primavera and La Rambla Shopping Center, have contributed to the consolidation of the District as an important space in the urban dynamics of the Lima metropolis.

Its predominant zoning is low-density residential (yellow), while in specific sectors such as the Torres de San Borja and Torres de Limatambo housing complexes, medium-density residential zoning (orange) is evident. Commercial activity has been focused on three main axes of the district: Av. Aviación where Metro Line 1 circulates, whose stations have made this route even more dynamic, Av. San Luis and Guardia Civil, the latter bringing together health establishments. In the following figure you can see the regulatory zoning of San Borja.

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dynamic, Av. San Luis and Guardia Civil, the latter bringing together health establishments. In the following figure you can see the regulatory zoning of San Borja.



Fig. 4.3 Regulatory zoning of the San Borja district [6]

The district is administratively divided into 12 sectors and has 2 police stations: San Borja (7 sectors with 30 subsectors) and Chacarilla (1 sector with 4 subsectors). Each of these police stations operate according to these 34 subsectorizations in total, an aspect that has been considered in the analyzes carried out in this investigation, and which is detailed in the following figure:

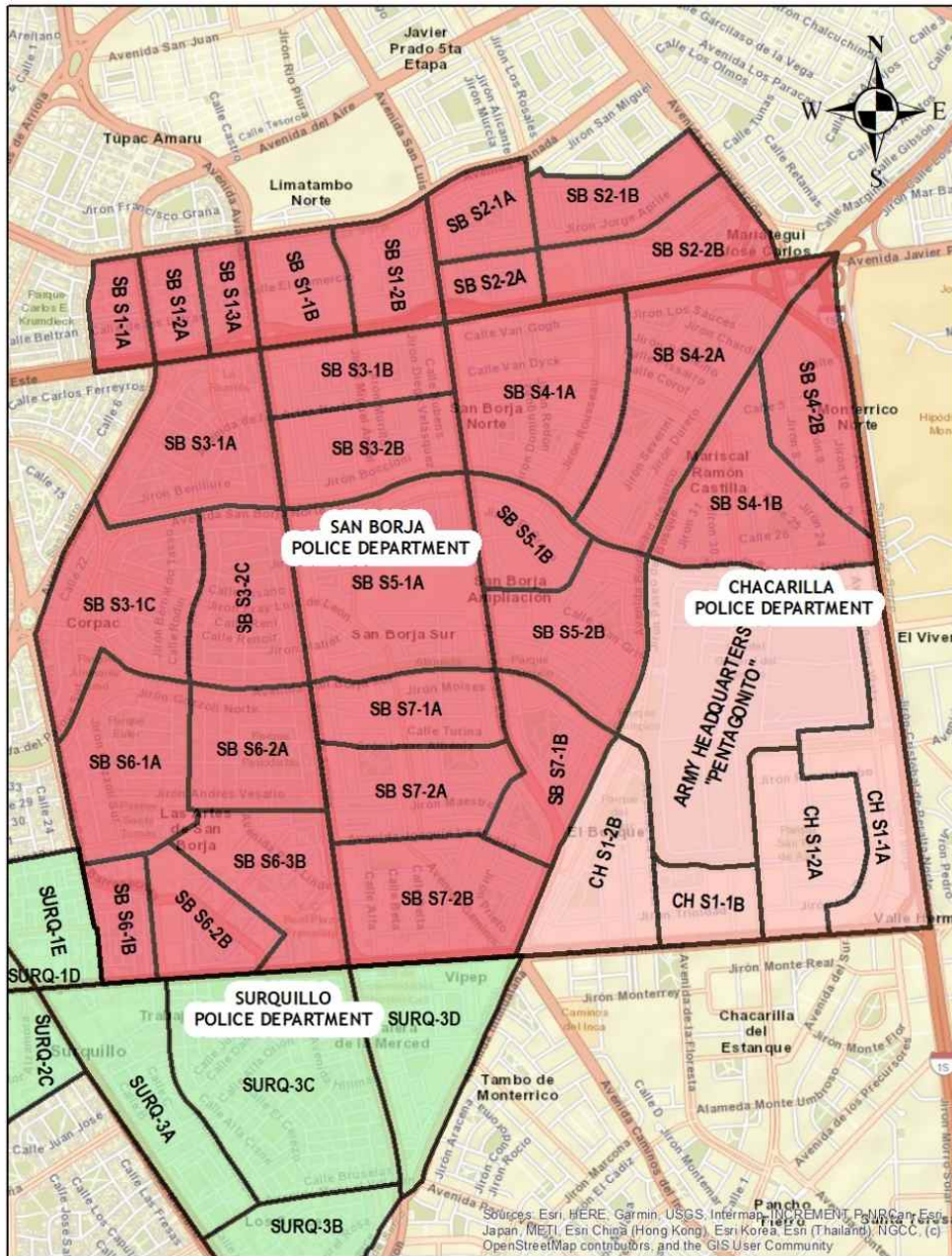


Fig. 4.4 Operational sectorization of the San Borja District

Own elaboration

In the previous figure you can see the sectorization of the Surquillo district, which has a police station: the Surquillo Police Station. For the purposes of this investigation, collaterally, 2 subsectors (3C and 3D) have been considered because the Angamos station of Line 1 of the Lima Metro is located on the district boundary between San Borja and Surquillo.

It is important to highlight that the district of Surquillo has an estimated population in 2022 of 102,223 inhabitants, made up mainly of socioeconomic levels C (44.4%) and D (26.7%) and only 4.1% corresponds to the level socioeconomic E..

The aforementioned police stations are responsible for registering reports of crimes, with the district of San Borja having the highest incidence of crimes against property, which in 2021 reached 1,517 crimes [7] and by 2022, only in the sectors where the police stations are located. identified dwellings (around 31 subsectors) 1,436 crimes were recorded [9] such as: robberies, thefts, homicides, drug sales and scams, according to the information on the crime map of the DATA-Crim portal of the INEI, whose spatial distribution of the crimes is shown in the following figure.

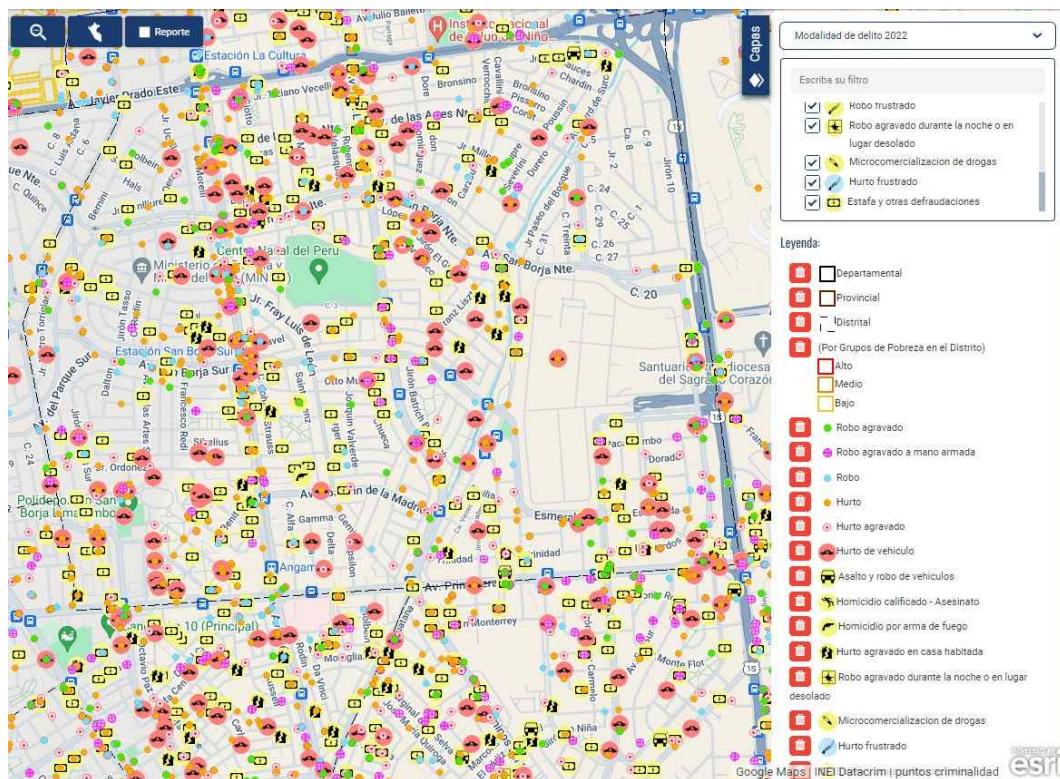


Fig. 4.5 Map of Crimes registered in police departments (2022) [9]

También se puede visualizar en la figura anterior, los delitos registrados en la Comisaría de Surquillo, con mayor incidencia delitos contra el patrimonio que en el año 2022 alcanzaron 975 [8] y solo en los sectores donde se ubican las viviendas identificadas (2 subsectores) se registraron 265 delitos [9] como: robos, hurtos, homicidios, comercialización de drogas y estafas.

Es relevante destacar la presencia de la línea 1 del Metro de Lima en la parte central sur de su ruta, con tres estaciones clave: Estación La Cultura, Estación San Borja Sur y Estación Angamos. Esta última se encuentra en el límite de los distritos de San Borja y Surquillo. Las viviendas identificadas en las proximidades de estas estaciones serán objeto de estudio en el marco de la presente investigación.

4.2 Metro Line 1

Line 1 of the Lima Metro is the first and only metro in the city of Lima currently operational, which runs from the north-east to the south of the city in 54 minutes, covering 11 districts, in which are the districts of largest population to the east such as San Juan de Lurigancho and to the south Villa Maria del Triunfo and Villa El Salvador, benefiting approximately 3.73 million inhabitants, which is equivalent to 33% of the total population of the province of Lima, consolidating itself as one of the axes for mobility in the capital city (Ositran, 2022) [27].

It has a constructed area of 34 km and 26 stations. The first section connects Villa El Salvador (Estacion Villa el Salvador) with the Cercado de Lima (Estacion Miguel Grau) which extends along 22.1 km covering 16 stations with commercial operation in 2012. Later, in 2014, a second was expanded. 11.9 km stretch that covers 10 stations (Ositran, 2022) [27] from Cercado de Lima (Miguel Grau Station) to San Juan de Lurigancho (Bayovar Station). Operationally, it has a commercial distance of 33,128 km and a frequency of 3 minutes during peak hours (ATU, 2022) [28].

The following figure shows the alignment of Line 1 of the Lima Metro.



Fig. 4.6 Metro Line 1 alignment

This line has a concession that began on April 11, 2011 for the Operation–Public-Private Partnership Co-financed for 30 years with the Sociedad Concesionaria Tren Urbano de Lima S.A. (formerly GYM Ferrovías S.A) [27].

Regarding its infrastructure, Line 1 has 75% of its extension as a double-track elevated viaduct, which extends into 20 stations. The remaining 25% comprises the first six stations in the south that are located at surface level. Likewise, it has a fleet of 44 trains (05 Ansaldo trains and 39 Alstom), 1 workshop yard in Villa El Salvador and 1 shunting yard in San Juan de Lurigancho. (ATU,2022) [28]



Fig. 4.7 Metro Line 1 views

In 2022, passenger traffic on Line 1 amounted to 129.6 million during 2022, experiencing a recovery of 60% compared to 2021, in line with the restoration of maximum capacity on trains (100% from April 2022) and the growing demand

due to the gradual return to presence at work and studies in the City of Metropolitan Lima and Callao. The service has a social rate of S/ 1.50 (adult) equivalent to \$0.40 and S/ 0.75 (middle and university) equivalent to \$0.20 and is provided from Monday to Saturday from 5:00 a.m. to 5:00 p.m. m. until 10:00 p.m. m. and on Sundays from 05:30 a.m. m. until 10:00 p.m. m (Ositran,2022) [27].

Respecto a la demanda por estación, en el año 2022, la estación que recibió la mayor afluencia de pasajeros fue la estación de Gamarra (La Victoria) influenciado por la alta concurrencia a la zona comercial de Gamarra con 12,5 millones de pasajeros (9,6 %), dejando en segundo lugar a la estación Bayóvar (San Juan de Lurigancho) con 10,8 millones de pasajeros (8,4 %), seguido por la estación La Cultura (San Borja) con casi 10,1 millones (7,8 %), así como la estación Angamos tuvo una afluencia de 6,7 millones de pasajeros (5,2 %).(OSITRAN, 2022) [27].

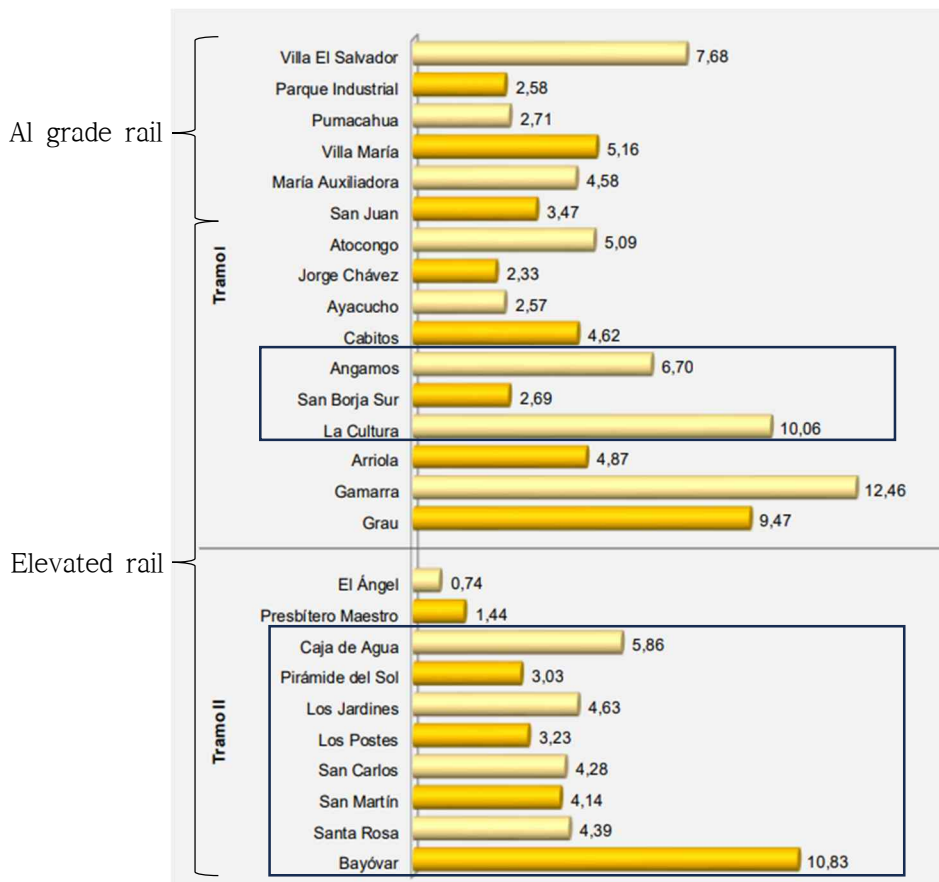


Fig. 4.8 Annual passenger traffic of Metro Line 1 by boarding station, 2022 (In millions of passengers) [27]

Likewise, the start-up of Line 1 of the Lima Metro has promoted opportunities in the real estate, retail and financial sectors, promoting the

development of mixed uses near the stations to integrate public transportation with housing and services. Thus, during the execution of Section 2 (2011–2014) of Line 1 of the Lima Metro, according to the INEI, around 1,000 new establishments [2], including restaurants, pharmacies, schools, retailers such as Maestro en el Cercado of Lima, Tottus Supermarket in San Juan de Lurigancho, shopping centers as well as real estate projects emerged near this section in the year it began operations (2014), benefiting from the greater connectivity generated by the project, as can be seen in the following figure ::

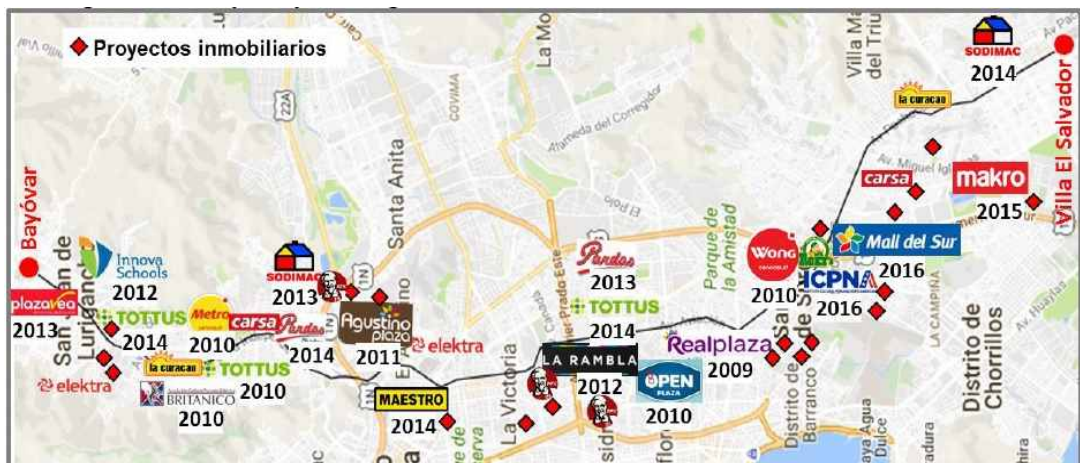


Fig. 4.9 Some of the main businesses created around Metro Line 1 [2]

It is important to highlight that this type of impact is not part of this research, recognizing the need to analyze it in a new research dedicated to this specific commercial area.

5. Research analysis

5.1 Reseach data

The database compiled for the research includes 349 dwelling around 3 stations of Line 1 of the Lima Metro, La Cultura Station, San Borja Sur Station and Angamos Station, included in the Districts of San Borja and Surquillo.

The average value of properties in San Borja is \$286,638, while in Surquillo, it is \$129,028.

Annex I contains the information from the compiled database.

Table 5.1 Data collected for research

Property value (\$)	N	Mean	Std.Dev.	Mín	Máy
San Borja	331	286,637.93	134,785.28	77,500	1,150,000
Surquillo	18	129,027.64	24,496.91	97,000	190,000
Total	349				

Own elaboration

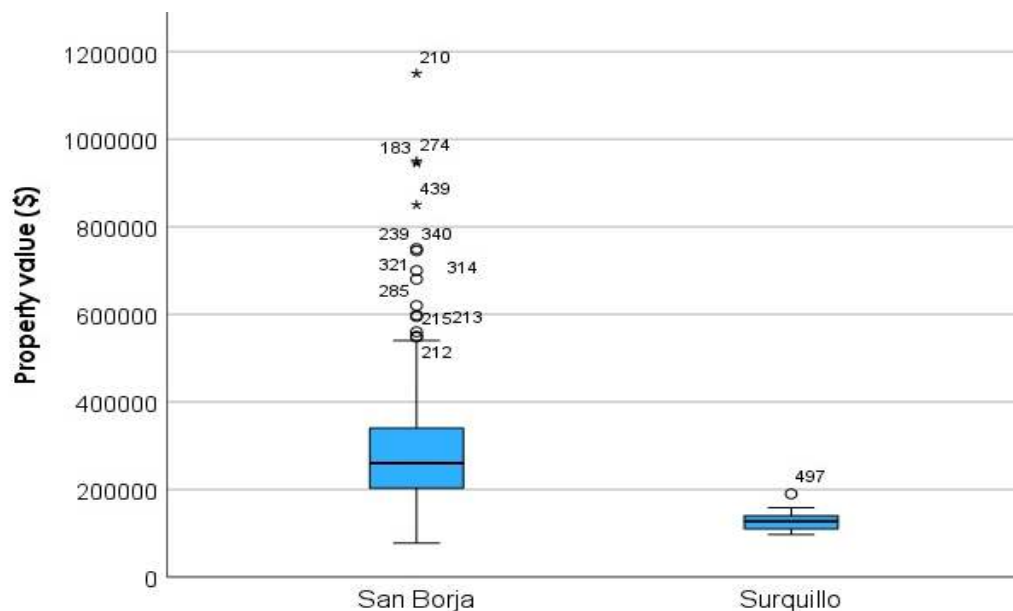


Fig. 5.1 Box plot of housing sales price by district

Own elaboration

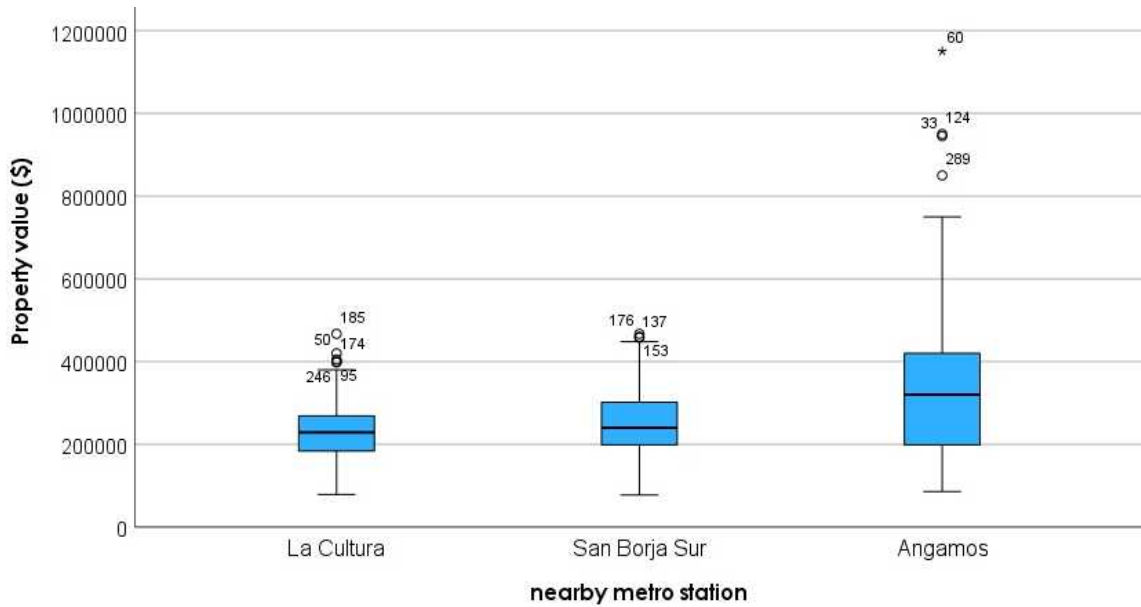


Fig. 5.2 Box plot of the sale price of housing according to proximity to the Metro Line 1 station
Own elaboration

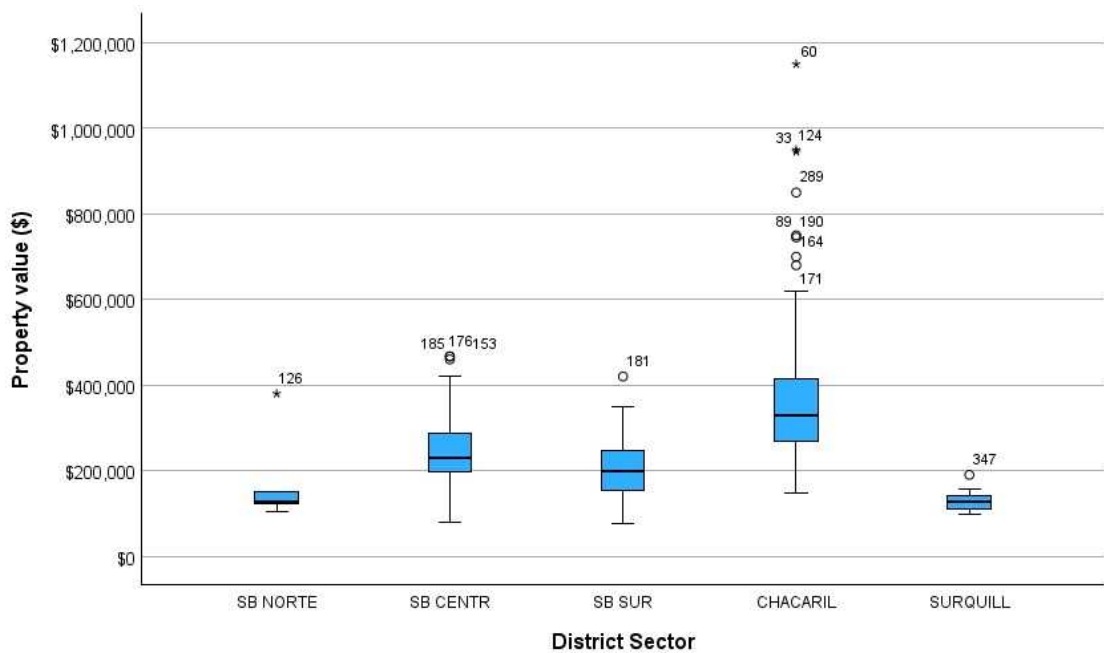


Fig. 5.3 Box plot of the housing sales price according to sectors of the San Borja-Surquillo district
Own elaboration

The preceding graph illustrates variations in housing sales prices across sectors within the San Borja District. The residences in Chacarilla (Sector Chacarilla and Sector 4B) command higher values, while the variations are less pronounced among the remaining areas of San Borja Norte (Sector 1 and 2), San Borja Centro (Sector 3, Sector 4A, and Sector 5), and San Borja Sur (Sector

7). The Surquillo district follows a different pattern but approaches the average housing sales price in the northern area of the San Borja district.

It is important to note that the treatment of outlier data will be examined in the subsequent preparatory stage of the hedonic pricing model.

The following figure displays the spatial distribution of housing data included in this study.

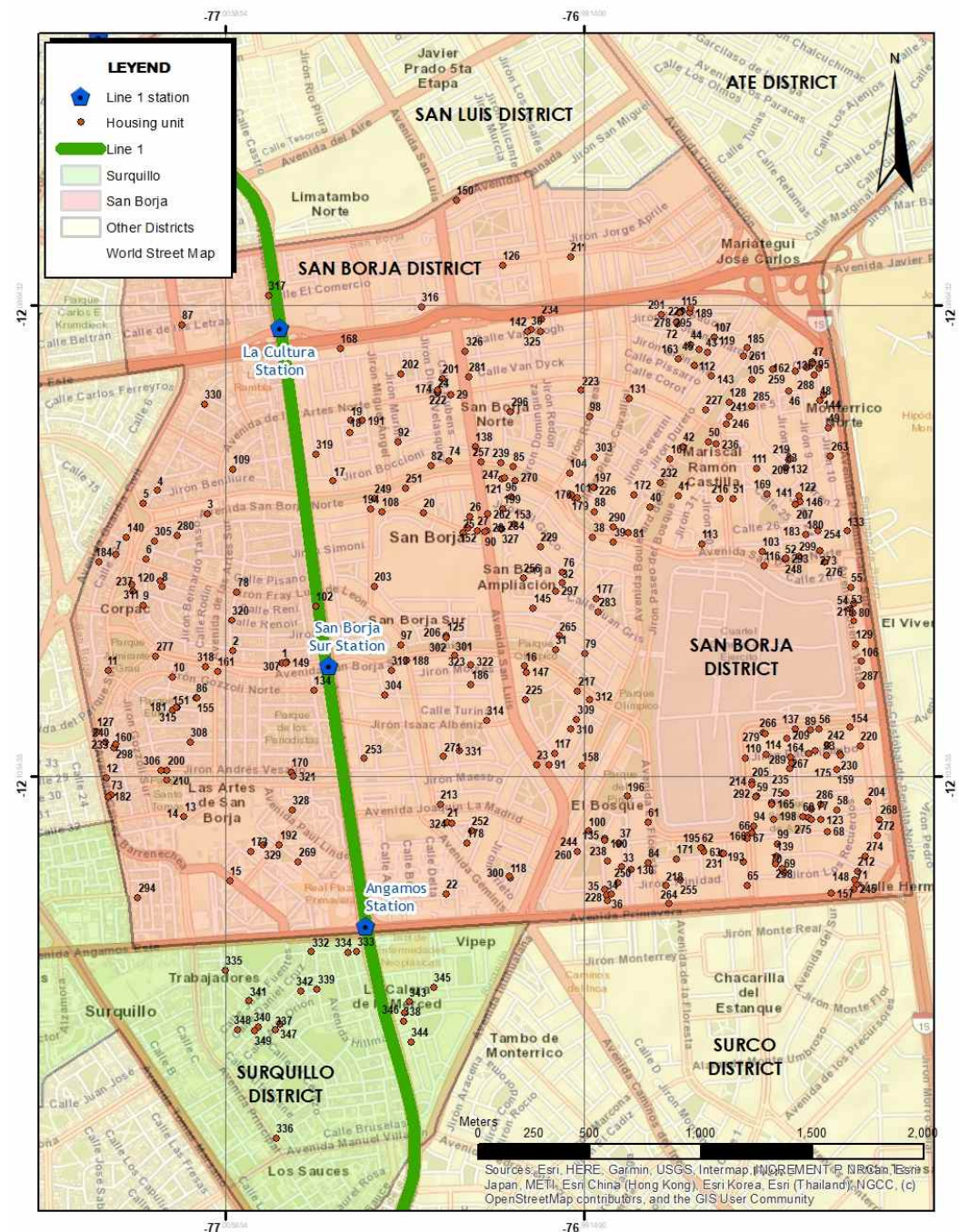


Fig. 5.4 Spatial distribution of the housing data under study (San Borja-Surquillo District)
Own elaboration

5.2 Research Methodology

The methodological aspects related to estimating the hedonic pricing equation and obtaining the marginal impact and implicit prices of the attributes that compose it are now developed.

To achieve this, the process begins by specifying and estimating a hedonic pricing function ($P(\cdot)$) defined over a vector of observable characteristics of the housing and its geographic location within the study area. Subsequently, the results obtained are used to calculate marginal prices (dP/dM) for the feature of interest (the Euclidean distance between the housing's location and the nearest station of the Lima Metro). This derivative represents the marginal willingness to pay for the feature, i.e., the value attributed to the housing's location relative to the nearest station of Line 1 of the Lima Metro.

5.2.1 Data and Model Variables

The database consists of a total of 349 dwellings located in two districts of the capital: San Borja and Surquillo.

The variable of interest in the hedonic function is the sales price (dollars \$) of the dwellings located in the study area around three stations of Metro Line 1.

The explanatory variables of the model have been classified into four groups: (i) variables related to the structural characteristics of the property, (ii) variables related to neighborhood characteristics, (iii) variables related to security attributes, and (iv) the variable of interest related to proximity to Metro Line 1.

It is worth noting that different specifications of the hedonic pricing model were tested, including additional variables such as population density or socioeconomic stratum by block. Ultimately, these variables were discarded due to multicollinearity issues with other regressors or a lack of sufficient variability in the information.

Below is the list of explanatory variables in the model:

- i. Variables related to the structural characteristics of the property:**
 - o Area occupied by the construction (m²)
 - o Number of bedrooms (variable in levels and quadratic term)
 - o Number of bathrooms

- Number of garage (variable in levels and quadratic term)
 - Number of storage in the building
 - Type of dwelling (dummy), categories include flat, duplex, and triplex. This feature is measured by including a set of dummy variables for each considered category. To avoid the dummy variable trap, the flat apartment category, which serves as the reference base for the analysis, is removed.
 - Age of the dwelling (variable in levels and quadratic term)
 - Dwelling with an exterior view (dummy), Dummy variable that takes the value of 1 if the dwelling has an exterior view and 0 otherwise.
 - Floor location of the dwelling in the building
 - Availability of an elevator (dummy), Dummy variable that takes the value of 1 if the building has an elevator and 0 otherwise.
 - Private access to the building's rooftop (dummy), Dummy variable that takes the value of 1 if the dwelling is located on the rooftop of the building or has private access to it, and 0 otherwise
- ii. Variables related to neighborhood characteristics:**
- Distance to the nearest school (meters)
 - Distance to the nearest College (meters)
 - Distance to the nearest Mall (meters)
 - Distance to the nearest supermarket (meters)
 - Distance to the nearest hospital or health center (meters)
 - Distance to the nearest drugstore (meters)
 - Distance to the nearest public park (meters)
 - Distance to the nearest restaurant (meters)
 - Distance to the nearest bank (meters)
 - Distance to the nearest public institution (meters)
 - Distance to the nearest main road (meters)
 - Distance to the nearest bus stop (meters)

iii. Security attribute variables

- o Number of reported theft cases (reported cases), including the total sum of reported cases of various thefts, aggravated thefts in houses, and theft of vehicles in the subsector where the dwelling is located.
- o Number of homicides (reported cases) in the subsector where the dwelling is located.

iv. Variable of interest related to proximity to Metro Line 1

- o Distance to the nearest station of the Lima Metro (meters)

To define the work sample, the analysis began by identifying outliers in the housing sales price distribution. These outlier observations have extreme values in the upper and lower percentiles of the distribution compared to the rest of the data, representing segments that are underrepresented in the database. To address these cases, observations above the 1st and 99th percentiles of the housing sales price distribution were excluded (trimming). As a result, the sample is reduced to a total of **339 observations**.

Table 5.2 Descriptive statistics of the model variables

Variable	N	Mean	Std. Dev.	Min	Max
Sales price	339	270,670.10	111,754.20	97,000.00	850,000.00
Lima Metro (meters)	339	1,307.49	643.13	117.10	2,445.32
Area (m ²)	339	156.69	70.02	40.00	506.00
Years of age	339	11.05	10.03	1.00	50.00
Bedrooms (number)	339	3.04	0.67	1.00	5.00
Bathrooms (number)	339	2.89	1.04	1.00	7.00
Exterior view	339	0.95	0.22	-	1.00
Floor's number	339	3.31	2.16	1.00	13.00
Flat	339	0.68	0.47	-	1.00
Duplex	339	0.30	0.46	-	1.00
Triplex	339	0.02	0.15	-	1.00
Elevator	339	0.72	0.45	-	1.00
Garage (number)	339	1.39	0.73	-	3.00
Storage (number)	339	0.35	0.51	-	2.00

Variable	N	Mean	Std. Dev.	Min	Max
Rooftop access = 1	339	0.01	0.08	-	1.00
School (meters)	339	427.53	239.43	30.96	1,313.08
College (meters)	339	1,489.11	703.07	35.34	3,137.57
Mall (meters)	339	1,156.17	449.86	115.53	2,156.84
Super market (meters)	339	771.86	377.01	114.16	1,760.12
Hospital (meters)	339	713.02	358.68	45.95	1,436.71
Drugstore (meters)	339	542.66	334.34	10.08	1,590.61
Public park (meters)	339	138.99	100.33	4.49	526.56
Restaurant (meters)	339	436.00	335.79	24.34	1,482.98
Bank (meters)	339	533.79	330.20	15.17	1,553.14
Public institution (meters)	339	868.69	499.30	23.35	2,234.60
Main road (meters)	339	259.91	248.80	0.00	1,329.87
Bus stop (meters)	339	372.53	234.01	10.65	1,329.87
Various thefts (cases)	339	3.92	2.80	-	12.40
Homicides (cases)	339	0.01	0.12	-	1.00

own elaboration

functional form

In order to proceed with the model estimation, it is necessary to choose a suitable functional form for the price equation. The functional form determines the relationship between the housing sales price and the feature of interest. This, in turn, affects how the measures of well-being are estimated and their statistical properties. In the literature, there are various approaches to hedonic modeling of the relationship between prices and attributes of the same good. Some of the commonly used functional forms in order of complexity are the linear function, semi-logarithmic, linear-logarithmic, double-logarithmic, and Box-Cox linear functions, which were detailed in Chapter 3.2 Theoretical Foundations.

5.2.2 Estimation of the hedonic price function

As a starting point, different approaches the general Box-Cox will be explored, various assumptions about the values of the transformation parameters θ and λ . As shown in Table No. 5.3, the more general models (Theta and Lambda), which assume different degrees of transformation for both sides of the equation simultaneously, lack statistical significance. On the contrary, the left-hand-side (LHS) and right-hand-side (RHS) models obtain optimal and statistically significant values, considering that the transformation is performed only on one side of the equation (dependent or explanatory).

Table 5.3 Box-Cox Model

	(1) Box-Cox LHS Model Coef.	(2) Box-Cox RHS Model Coef.	(3) Box-Cox Lambda Model Coef.	(4) Box-Cox Theta Model Coef.
Theta	0.346***	1	-0.074	-0.098
Lambda	1	1.148***	-0.074	-0.004
No Transformed Variables				
Years of age	-1.122	-3,709.922	-0.005	-0.004
Years of age # Years of age	0.022	76.206	0.000	0.000
Bedrooms (number)	7.427	11,347.654	-0.005	0.000
Bedrooms (number) #	-1.176	-1,958.868	0.001	-0.000
Bedrooms (number)				
Bathrooms (number)	1.601	2,558.914	0.002	0.002
Exterior view	0.412	5,624.053	0.003	0.001
Floor number	-0.355	-761.142	-0.001	-0.001
Duplex	-0.264	-5,482.344	-0.014	-0.011
Triplex	-2.997	-16,097.905	-0.043	-0.030
Elevator	4.734	17,247.408	0.027	0.020
Garage (number)	6.481	1,116.684	0.026	0.022
Garage (number) # Garage (number)	-0.705	6,266.626	-0.002	-0.002
Storage (number)	0.440	740.320	0.005	0.003
Rooftop access = 1	-3.274	-24,464.879	0.000	0.000
Various thefts (cases)	-0.771	-2,026.058	-0.002	-0.001
Homicide (cases)	-1.789	-10,779.043	-0.003	-0.001
Constant	147.618	82,031.460	6.206	6.012
<hr/>				
Sigma	9.683	37,445.617	0.047	0.035
<hr/>				
Transformed Variables				
Lima Metro (meters)	0.006	6.468	0.044	0.022
Area (m ²)	0.304	555.915	0.410	0.217
School (meters)	-0.000	2.896	0.011	0.005
College (meters)	0.000	0.998	0.001	0.000
Mall (meters)	0.002	1.734	0.020	0.009
Super market (meters)	-0.003	-4.820	-0.011	-0.006
Hospital (meters)	0.001	0.709	-0.002	-0.001
Drugstore (meters)	0.008	11.132	0.027	0.015
Public Park (meters)	-0.005	-8.474	-0.007	-0.004
Restaurant (meters)	0.002	1.460	0.008	0.004
Bank (meters)	-0.006	-4.908	-0.029	-0.015
Public institution (meters)	-0.009	-13.525	-0.036	-0.018
Main road (meters)	-0.001	0.434	-0.000	-0.000

	(1) Box-Cox LHS Model Coef.	(2) Box-Cox RHS Model Coef.	(3) Box-Cox Lambda Model Coef.	(4) Box-Cox Theta Model Coef.
Bus stop (meters)	0.003	0.851	0.010	0.005
Observations	339.000	339.000	339.000	339.000
Log-likelihood	-4,004.425	-4,050.909	-3,970.523	-3,969.854
AIC	8,010.850	8,103.818	7,943.045	7,943.708
BIC	8,014.676	8,107.644	7,946.871	7,951.360

*** p<0.01, ** p<0.05, * p<0.1

own elaboration.

The following table presents the results of the likelihood ratio test for the different Box–Cox functional forms. In the case of the Theta model (the most general and therefore unrestricted functional form), it is not possible to reject the null hypothesis that the model converges to a logarithmic function. A similar result is obtained in the case of the Lambda model (assuming the same lambda adjustment parameter for both terms of the equation).

Table 5.4 Likelihood Ratio Test

Functional Form	Null Hypotesis	P - value
Box-Cox (Theta)	$\theta = 0 ; \lambda = 0$	0.131
	$\theta = 1 \lambda = 1$	0.000
Box-Cox (Lambda)	$\lambda = 0$	0.332
	$\lambda = 1$	0.000
Box-Cox (Left-Hand)	$\theta = 0$	0.000
	$\theta = 1$	0.000
Box-Cox (Right-Hand)	$\lambda = 0$	0.000
	$\lambda = 1$	0.192

own elaboration.

On the other hand, when evaluating the RHS (Righ-Hand Side) model, in this case, it is not possible to reject the null hypothesis that the second member of the equation (explanatory variables) converges to a linear function. Correspondingly, the LHS (Righ-Hand Side) model cannot reject the hypothesis that the dependent variable is better fit with a logarithmic form.

Table 5.5 Identification of Box–Cox Functional Form

Functional Form	Parameters
Linear	$\theta = 1 ; \lambda = 1$
Semi log	$\theta = 0 ; \lambda = 1$
Linear log	$\theta = 1 ; \lambda = 0$
Double log	$\theta = 0 ; \lambda = 0$

own elaboration.

Therefore, the previous results in this first step give us indications that the most suitable functional form for the hedonic pricing model is one in which a logarithmic specification is maintained for the dependent variable and, simultaneously, a linear form for the explanatory variables; that is, in this first step, the **most suitable functional form according to the Box-Cox methodology is the log-linear or semi-logarithmic function**. However, for the purpose of expanding the analysis, as a second step, it is proposed to estimate the hedonic pricing function considering the four standard functional forms: linear, semi-logarithmic, linear-logarithmic, and double-logarithmic.

For all cases, the “Ordinary Least Squares“ (OLS) method was employed with robust standard errors to address the potential issue of heteroscedasticity in the estimation residuals. All estimates indicate significance levels at 99% ($p < 0.01$), 95% ($p < 0.05$), and 90% ($p < 0.1$) confidence.

The specification shown in the following table assumes that the effect of the proximity of the housing to the Lima Metro station can be represented by a linear and constant effect. Later, in a third step, the analysis also considers the possibility that this effect is nonlinear by including a quadratic term for the distance between the housing and the nearest Metro station in the model. This implies that an additional term should be included later in each equation of the form $\gamma_j(DM\ etro\ i)^2$ for the linear and linear-log equations, or correspondingly, $\gamma_j h (DM\ etro\ i)^2$ for the semi-log or double-log forms.

Table 5.6 Functional specifications evaluated

Lineal Model
$Price\ i = \alpha_0 + \gamma_1 DM\ etro\ i + B_1 Area\ i + B_2 year\ i + B_3 (year\ i)^2 + B_4 room\ i + B_5 (room\ i)^2 + B_6 bat\ h\ i + B_7 garage\ i + B_8 (garage\ i)^2 + B_9 duplex\ i + B_{10} triplex\ i + B_{11} fbor\ i + B_{12} elevator\ i + B_{13} storage\ i + B_{14} rooftop\ i + B_{15} Ext\ i + \gamma_2 Dsc\ hool\ i + \gamma_3 D\ ca\ e\ g\ e\ i + \gamma_4 Dm\ al\ i + \gamma_5 Dm\ arket\ i + \gamma_6 Dhospital\ i + \gamma_7 Ddrugstore\ i + \gamma_8 Dpark\ i + \gamma_9 Drestaur\ i + \gamma_{10} Dbank\ i + \gamma_{11} Dinst\ i + \gamma_{12} Dm\ airoad\ i + \gamma_{13} Dbus\ i + \gamma_{14} thefts\ i + \gamma_{15} hom\ i\ tle\ i + \varepsilon_i$
Semi log Model
$hPrice\ i = \alpha_0 + \gamma_1 DM\ etro\ i + B_1 Area\ i + B_2 year\ i + B_3 (year\ i)^2 + B_4 room\ i + B_5 (room\ i)^2 + B_6 bat\ h\ i + B_7 garage\ i + B_8 (garage\ i)^2 + B_9 duplex\ i + B_{10} triplex\ i + B_{11} fbor\ i + B_{12} elevator\ i + B_{13} storage\ i + B_{14} rooftop\ i + B_{15} Ext\ i + \gamma_2 Dsc\ hool\ i + \gamma_3 D\ ca\ e\ g\ e\ i + \gamma_4 Dm\ al\ i + \gamma_5 Dm\ arket\ i + \gamma_6 Dhospital\ i + \gamma_7 Ddrugstore\ i + \gamma_8 Dpark\ i + \gamma_9 Drestaur\ i + \gamma_{10} Dbank\ i + \gamma_{11} Dinst\ i + \gamma_{12} Dm\ airoad\ i + \gamma_{13} Dbus\ i + \gamma_{14} thefts\ i + \gamma_{15} hom\ i\ tle\ i + \varepsilon_i$
Linear log Model
$Price\ i = \alpha_0 + \gamma_1 h\ DM\ etro\ i + B_1 hArea\ i + B_2 year\ i + B_3 (year\ i)^2 + B_4 room\ i + B_5 (room\ i)^2 + B_6 bat\ h\ i + B_7 garage\ i + B_8 (garage\ i)^2 + B_9 duplex\ i + B_{10} triplex\ i + B_{11} fbor\ i + B_{12} elevator\ i + B_{13} storage\ i + B_{14} rooftop\ i + B_{15} Ext\ i + \gamma_2 hDsc\ hool\ i + \gamma_3 hD\ ca\ e\ g\ e\ i + \gamma_4 hDm\ al\ i + \gamma_5 hDm\ arket\ i + \gamma_6 hDhospital\ i +$

$\gamma_7 \ln Ddrugstore_i + \gamma_8 \ln Dpark_i + \gamma_9 \ln Drestaurant_i + \gamma_{10} \ln Dbank_i + \gamma_{11} \ln Ddist_i + \gamma_{12} \ln DMairroad_i + \gamma_{13} \ln Dbus_i + \gamma_{14} \ln thefts_i + \gamma_{15} \ln homile_i + \varepsilon_i$
Doble log Model
$\ln Price_i = \alpha_0 + \gamma_1 \ln DMetro_i + B_1 \ln Area_i + B_2 \ln year_i + B_3 (year_i)^2 + B_4 \ln room_i + B_5 (room_i)^2 + B_6 \ln bath_i + B_7 \ln garage_i + B_8 (\ln garage_i)^2 + B_9 \ln duplex_i + B_{10} \ln triplex_i + B_{11} \ln fbor_i + B_{12} \ln elevator_i + B_{13} \ln storage_i + B_{14} \ln rooftop_i + B_{15} \ln Extview_i + \gamma_2 \ln Dschool_i + \gamma_3 \ln Dcollege_i + \gamma_4 \ln DMall_i + \gamma_5 \ln DMarket_i + \gamma_6 \ln DHospital_i + \gamma_7 \ln Ddrugstore_i + \gamma_8 \ln Dpark_i + \gamma_9 \ln Drestaurant_i + \gamma_{10} \ln Dbank_i + \gamma_{11} \ln Ddist_i + \gamma_{12} \ln DMairroad_i + \gamma_{13} \ln Dbus_i + \gamma_{14} \ln thefts_i + \gamma_{15} \ln homile_i + \varepsilon_i$

Own elaboration.

Considering the different functional forms used, the correct interpretation of the estimated coefficients in each case is essential. In the linear model, the coefficients indicate the change in the dependent variable resulting from a one-unit change in the explanatory variables, holding everything else constant. However, the logarithmic transformation adds some complexity, so the following table is presented to facilitate interpretation.

Table 5.7 Interpreting coefficients in logarithmically models

Functional Form	Expression	Implicit Price (dP/dM)
Linear	$P = \beta_0 + \beta_1 M + B_2 X$	A 1 unit increase in M, will increase P in β_1 units
Semi log	$\ln P = \beta_0 + \beta_1 M + B_2 X$	A 1 unit increase in M, will increase P in $\beta_1 * 100$ percent
Linear log	$P = \beta_0 + \beta_1 \ln M + B_2 \ln X$	A 1% increase in M, will increase P in $\beta_1/100$ units
Double log	$\ln P = \beta_0 + \beta_1 \ln M + B_2 \ln X$	A 1% increase in M, will increase Y in β_1 percent

Based on [12] and supplemented own elaboration.

Table No. 5.8 presents the estimation results for the four standard specifications of the price equation assuming that the effect of the proximity of the dwelling to the Metro route is linear and constant.

As observed by reviewing the coefficient of determination (R^2), the fit of each model is adequate in all cases. The R^2 in all models is close to or greater than 0.9, indicating that the specified equations can explain the majority of the variability in the evaluated data. Additionally, the global significance test (F-Test) rejects, in all cases, at a 99% confidence level, the null hypothesis of no overall significance of the proposed specification.

To determine, in a second step, which of the four functional forms provides the best fit for the available data, we examined the measurement of the Akaike Information Criterion (AIC) and the Bayesian Schwarz Criterion (BIC) reported at the bottom of the table. Both criteria are used in statistics and econometrics for model comparison and selection, aiming to strike a balance between the goodness of fit and model complexity. As a general rule, **the model with the lower AIC or BIC value should be chosen** as it indicates a good model fit with the least complexity. From the reported values, we conclude **in this second step that the double logarithmic and semi-logarithmic models, in that order**, provide a better fit for the available data (higher R^2 and lower AIC and BIC).

To assess the contribution of different dwelling characteristics and their spatial location to the formation of the final sales price, a Student's T-test (T-Test) is used to evaluate the individual significance of the estimated coefficients in each of the functional forms. Under the null hypothesis that the model parameters are not significant, the test assesses whether the estimates reject the null hypothesis at a 99% (***) $p < 0.01$, 95% (**) $p < 0.05$, and 90% (*) $p < 0.1$ statistical confidence level.

Table 5.8 Hedonic Price Function (Constant effect of proximity to Metro Line 1 on housing sales Price)

	(1) Linear Model Coef./S.E.	(2) Log - Linear Model Coef./S.E.	(1) Linear - Log Model Coef./S.E.	(2) Double Log Model Coef./S.E.
Lima Metro (meters)	19.197*** (7.248)	8.31e-05*** (2.75e-05)	13,649.530* (7156.728)	0.069*** (0.022)
Area (m ²)	1,223.858*** (103.138)	0.004*** (0.000)	193,152.806*** (12770.237)	0.719*** (0.033)
Years of age	-3,660.726*** (650.692)	-0.015*** (0.002)	-3,096.270*** (770.197)	-0.014*** (0.002)
Years of age # Years of age	74.751*** (16.118)	0.000*** (0.000)	64.695*** (17.397)	0.000*** (0.000)
Bedrooms (number)	6,798.412 (15760.980)	0.136** (0.053)	-30,148.762 (21190.644)	-0.007 (0.054)
Bedrooms (number) # Bedrooms (number)	-1,287.677 (2938.641)	-0.021** (0.009)	5,187.982 (3576.237)	0.001 (0.009)
Bathrooms (number)	1,653.471 (3881.414)	0.029** (0.012)	-1,875.802 (4839.340)	0.005 (0.011)
Exterior view=1	5,565.859 (7343.951)	-0.004 (0.031)	12,106.597 (7650.271)	0.007 (0.026)
Floor number	-531.075 (1253.140)	-0.006 (0.004)	546.830 (1297.772)	-0.002 (0.004)
Duplex	-7,401.281 (7410.483)	0.005 (0.023)	-8,752.166 (7877.697)	-0.035 (0.021)
Triplex	-18,705.090 (18295.249)	-0.027 (0.082)	-37,586.067** (17530.681)	-0.104 (0.074)
Elevator=1	17,740.758***	0.064**	20,378.278***	0.068***

	(1) Linear Model Coef./S.E.	(2) Log - Linear Model Coef./S.E.	(1) Linear - Log Model Coef./S.E.	(2) Double Log Model Coef./S.E.
	(6277.473)	(0.026)	(7551.474)	(0.023)
Garage (number)	-2,305.206 (10885.926)	0.132*** (0.039)	-27,470.553 (17465.360)	0.061* (0.033)
Garage (number) # Garage (number)	7,359.729 (4790.485)	-0.027* (0.015)	17,916.924** (8119.654)	-0.002 (0.014)
Storage (number)	616.620 (5168.626)	0.007 (0.016)	4,158.736 (5648.701)	0.011 (0.015)
Rooftop access = 1=1	-24,414.711*** (9121.929)	-0.021 (0.053)	-20,799.069* (12311.276)	-0.007 (0.034)
School (meters)	9.276 (11.155)	-0.000 (0.000)	10,887.139** (4266.341)	0.018 (0.012)
College (meters)	2.013 (4.031)	-0.000 (0.000)	524.215 (4843.977)	0.000 (0.014)
Mall (meters)	4.338 (6.407)	0.000 (0.000)	-496.095 (7089.304)	0.028 (0.022)
Super market (meters)	-13.625 (10.670)	-0.000 (0.000)	-2,143.638 (6007.744)	-0.017 (0.020)
Hospital (meters)	-1.093 (8.322)	0.000 (0.000)	-6,182.890 (4118.428)	-0.005 (0.014)
Drugstore (meters)	29.540* (16.050)	0.000* (0.000)	14,133.414** (5651.993)	0.049*** (0.018)
Public Park (meters)	-20.537 (26.107)	-0.000 (0.000)	-3,947.848 (3065.649)	-0.013 (0.008)
Restaurant (meters)	6.145 (18.658)	0.000 (0.000)	6,544.480 (4665.751)	0.015 (0.014)
Bank (meters)	-15.467 (11.988)	-0.000* (0.000)	-14,356.563*** (4854.574)	-0.052*** (0.015)
Public institution (meters)	-36.792*** (7.349)	-0.000*** (0.000)	-22,082.697*** (4247.321)	-0.062*** (0.014)
Main road (meters)	3.097 (11.952)	-0.000 (0.000)	1,009.148 (1140.614)	-0.001 (0.004)
Bus stop (meters)	0.029 (13.088)	0.000 (0.000)	2,351.838 (3730.556)	0.017 (0.011)
Various thefts (cases)	-1,758.685* (1010.147)	-0.012*** (0.004)	249.023 (1285.246)	-0.004 (0.003)
Homicide (cases)	-10,751.046 (10115.710)	-0.012 (0.047)	-17,126.218 (13691.613)	-0.011 (0.039)
Constant	65,993.145** (28849.205)	11.492*** (0.105)	- (80632.678)	8.513*** (0.247)
Observations	339.000	339.000	339.000	339.000
R ²	0.887	0.885	0.851	0.912
Log-likelihood	-4,051.758	197.643	-4,098.624	242.622
AIC	8,165.516	-333.286	8,259.249	-423.245
BIC	8,284.122	-214.680	8,377.855	-304.639

(Robust standard errors for heteroscedasticity in parentheses)

*** p<0.01, ** p<0.05, * p<0.1

The results of the hedonic pricing modeling in a semilogarithmic form with a constant effect are as follows:

Among the dwelling characteristics that constitute significant determinants of the hedonic equation, it is observed that an increase in the occupied area (m²) of the dwelling has a statistically significant and positive effect on the sales price. In particular, the sales price increases by approximately 0.4% for

each additional square meter of space (semi-log model). On the other hand, the maintenance of the structure and facilities (approximated by the age of the dwelling) is another feature valued by buyers; it is estimated that the sales price decreases by just over 1% on average for each additional year of age during the first 10 years (semi-log and double-log models). From there, the depreciation effect of the dwelling over time gradually diminishes until approximately year 20.

On another note, it is interesting to note that, on average, the property's sales value increases by 5.1% (semi-log model) for the second bedroom; however, this effect lacks significance when the number of rooms is greater. A similar trend is observed for the effect of an additional parking space as part of the property; in this case, the sales value increases by 13% (semi-log model) when the apartment has a garage compared to those that do not have any. However, this increase is lower when referring to dwellings with two parking spaces compared to those with only one (7.8%). Another factor that contributes to increasing the value of the dwelling is the availability of an elevator in the building; on average, the sales price is between 6.4% (semi-log model) to 6.8% (double-log model) higher than those in buildings without an elevator.

Regarding the location of the property, it is observed that properties lose value when located in areas with less security and a higher incidence of house and/or vehicle thefts (on average, a decrease of 12.3% in value for every 10 reported thefts). On the other hand, there is no statistically significant effect associated with ease of access to amenity and service areas near the property. Regarding the proximity to the metro, it is evident that properties farther away have a higher total housing price (properties increase slightly (0.8%) for every 100 meters of distance). This could reflect a more residential nature typical of the San Borja district. Therefore, to determine the contribution of the Metro to the housing price, implicit price calculations will be performed later.

Additionally, as a third step and as a premise in empirical research to explore non-linear functions that help characterize a variety of economic phenomena, the evaluation of a quadratic effect on the independent variable distance to the metro was added. This considers that various investigations show non-constant phenomena, allowing the identification of whether the estimated effect remains constant regardless of the length of the Euclidean distance that separates the dwelling from the station or if, on the contrary,

an increasing or decreasing effect is observed as we move away or closer. The results of the estimation modeling for the four basic functional forms are shown in the following table.

Table 5.9 Hedonic Price Function (Quadratic Effect of proximity to Metro Line 1 on Sales Price)

	(1)	(2)	(1)	(2)
	Linear Model	Log - Lin Model	Lin - Log Model	Double Log Model
	Coef./S.E.	Coef./S.E.	Coef./S.E.	Coef./S.E.
Lima Metro (meters)	110.204*** (20.591)	4.56e-4*** (8.01e-05)	69,988.601 (79765.091)	0.339 (0.277)
Lima Metro (meters) # Lima Metro (meters)	-0.037*** (0.008)	-1.52e-07*** (3.08e-08)	-4,330.800 (6067.543)	-0.021 (0.021)
Area (m ²)	1,204.233*** (99.811)	0.004*** (0.000)	192,902.614*** (12727.241)	0.718*** (0.033)
Years of age	-3,629.654*** (641.476)	-0.015*** (0.002)	-3,050.307*** (784.575)	-0.014*** (0.002)
Years of age # Years of age	72.032*** (15.261)	0.000*** (0.000)	63.823*** (17.613)	0.000*** (0.000)
Bedrooms (number)	-1,430.649 (15288.922)	0.103** (0.051)	-31,043.702 (21314.398)	-0.011 (0.053)
Bedrooms (number) # Bedrooms (number)	258.840 (2912.368)	-0.015* (0.008)	5,317.469 (3600.207)	0.001 (0.009)
Bathrooms (number)	738.044 (3713.933)	0.026** (0.011)	-1,722.847 (4803.597)	0.006 (0.011)
Exterior view=1	6,107.791 (8046.661)	-0.002 (0.033)	12,066.924 (7744.758)	0.007 (0.027)
Floor number	-1,369.632 (1260.505)	-0.010** (0.004)	466.098 (1314.946)	-0.002 (0.004)
Duplex	-7,970.833 (7204.425)	0.002 (0.023)	-8,844.150 (7889.101)	-0.035* (0.021)
Triplex	-15,952.935 (15043.815)	-0.016 (0.064)	-37,000.581** (17186.903)	-0.101 (0.072)
Elevator=1	15,700.762*** (5973.573)	0.055** (0.025)	20,622.779*** (7625.361)	0.069*** (0.023)
Garage (number)	-4,717.355 (10384.642)	0.122*** (0.037)	-28,172.940 (17754.016)	0.057* (0.034)
Garage (number) # Garage (number)	8,370.013* (4614.715)	-0.022 (0.014)	18,317.237** (8291.917)	-0.000 (0.014)
Storage (number)	-978.508 (5145.546)	0.000162 (0.016)	3,904.261 (5670.797)	0.010 (0.015)
Rooftop access = 1	-28,917.581*** (8698.876)	-0.039 (0.052)	-21,002.079* (12449.180)	-0.007 (0.034)
School (meters)	13.246 (11.191)	-1.10e-05 (3.90e-05)	11,297.451*** (4265.274)	0.020 (0.012)
College (meters)	3.492 (3.999)	5.43e-06 (1.51e-05)	1,532.998 (4834.893)	0.005 (0.014)
Mall (meters)	3.605 (6.139)	3.57e-05 (2.34e-05)	-607.650 (7082.096)	0.027 (0.022)
Super market (meters)	-5.020 (11.417)	-4.00e-06 (4.57e-05)	95.429 (6194.084)	-0.006 (0.020)
Hospital (meters)	7.562 (8.123)	6.24e-05* (3.57e-05)	-4,934.089 (4236.022)	0.001 (0.014)
Drugstore (meters)	39.721** (15.829)	0.000154** (5.68e-05)	13,811.976** (5667.886)	0.047** (0.018)

	(1) Linear Model	(2) Log - Lin Model	(1) Lin - Log Model	(2) Double Log Model
	Coef./S.E.	Coef./S.E.	Coef./S.E.	Coef./S.E.
Public Park (meters)	3.045 (25.903)	2.76e-05 (9.01e-05)	-3,759.759 (3082.018)	-0.012 (0.008)
Restaurant (meters)	6.555 (18.143)	1.92e-05 (6.54e-05)	6,920.976 (4753.954)	0.017 (0.014)
Bank (meters)	-13.768 (11.870)	-7.47e-05 (4.58e-05)	-14,478.167*** (4888.927)	-0.052*** (0.015)
Public institution (meters)	-37.554*** (7.129)	- (3.08e-05)	-21,447.566*** (4136.209)	-0.059*** (0.013)
		0.000124** *		
Main road (meters)	-3.192 (11.050)	-5.80e-05 (4.16e-05)	1,027.643 (1145.801)	-0.001 (0.004)
Bus stop (meters)	-2.602 (12.273)	4.63e-05 (4.49e-05)	1,908.302 (3723.921)	0.015 (0.011)
Various thefts (cases)	-715.134 (1007.132)	-0.008** (0.004)	288.016 (1292.143)	-0.004 (0.003)
Homicide (cases)	-3,377.095 (12156.046)	0.018 (0.043)	-16,981.154 (14712.070)	-0.010 (0.041)
Constant	20,417.520 (27847.330)	11.305*** (0.110)	-865,508.726*** (298655.132)	7.497*** (1.011)
Observations	339.000	339.000	339.000	339.000
R ²	0.895	0.896	0.851	0.912
Log-likelihood	-4,038.622	214.833	-4,098.366	243.411
AIC	8,141.243	-365.666	8,260.732	-422.821
BIC	8,263.675	-243.234	8,383.164	-300.389

(Robust standard errors for heteroscedasticity in parentheses)

*** p<0.01, ** p<0.05, * p<0.1

As can be seen, the model fit statistics improve for the semilog function with an R² of 89.6% model representation (previously 88.5%), and lower AIC and BIC indicators are achieved, used for model selection considering a balance between model goodness of fit and complexity.

To determine the statistical significance of the inclusion of this quadratic term, a joint significance test (Test – F) was performed for the expression $\gamma_1 h DM etro_i + \gamma_2 (h DM etro_i)^2$. For this purpose, a significance test will be conducted for both parameters since $DM etro_i$ y $(h DM etro_i)^2$ are essentially the same variable. The goal of this test is to compare whether the parameters γ_1 and γ_2 are statistically different from zero and, therefore, significant.

Table 5.10 Joint Significance Test for the Quadratic Effect of Proximity to Metro Line 1

Null Hypothesis	Linear Model (P – value)	Log - Lin Model (P – value)	Lin - Log Model (P – value)	Double Log Model (P – value)
F - stat	14.67	16.89	1.89	4.38
Prob > F	0.000	0.000	0.153	0.013

own elaboration

The results of the F-test show that the null hypothesis of no joint significance of distance and its quadratic term is rejected for the linear and semi-logarithmic models at a 99% confidence level. Additionally, the null hypothesis is also rejected for the double-log model at a 95% confidence level. These results demonstrate that the inclusion of the quadratic term is relevant for the model.

Therefore, the results obtained in this third step of the hedonic equation show a statistically significant effect associated with the Metro at a 99% confidence level for the linear and semi-logarithmic models, with a positive sign for the estimated coefficient of the level term and a negative sign for the quadratic term.

The results of the hedonic pricing modeling in a semilogarithmic form with a quadratic effect are as follows:

It is estimated that among the significant determinants of the hedonic equation, an increase in the occupied area (m²) of the housing has a statistically significant and positive effect on the sales price. In particular, the sales price increases by approximately 0.4% for each additional square meter of space or, similarly, an increase in the final sales price of just over \$1,000 per square meter (linear and linear-log models). On the other hand, the maintenance of the structure and facilities (approximated by the age of the dwelling) is another feature valued by buyers; it is estimated that the sales price decreases by an average of just over 1% for each additional year of age during the first 10 years (semi-log and double-log models), translating to a estimated decrease of between \$3,000 to \$3,600 per year (linear and linear-log models). From there, the depreciation effect of the dwelling over time gradually diminishes until approximately the 23rd year.

Additionally, it is interesting to note that, on average, the property's selling price increases by 4.3% (semi-log model) for the second bedroom; however, this effect is not significant when the number of rooms is greater. A similar trend is observed for the effect of an additional garage as part of the property; in this case, the selling price increases by 12.2% (semi-log model) when the apartment has a garage compared to those without any, yet this increase is lower when it comes to dwellings with two garages compared to those with only one (7.7%). Another factor contributing to the increase in the property value is the availability of an elevator in the building; on average, the selling price is 5.5% higher for apartments in buildings without an elevator.

Regarding the property's location, it is observed that properties lose value when located in areas with less security and a higher incidence of house and/or vehicle thefts (an average decrease of 8% in value for every 10 reported thefts). On the other hand, no statistically significant effect is observed regarding the ease of access to amenities and services in the vicinity of the property. However, there is evidence of an effect associated with the proximity of the housing to a station of the Lima Metro; on average, our results suggest that the value of properties increases slightly (0.58%) for every 100 meters of distance. In other words, the selling price seems to increase slightly as the property moves away from the Metro's influence zone. This could reflect a more residential nature typical of the San Borja district. To determine how much the Metro contributes to the housing price, implicit price calculations will be performed later on.



Fig. 5.5 Predictive change in sales price
 own elaboration

5.2.3 Marginal Impact

In Table N° 5.11, the marginal impact of the proximity of the housing to the Metro on its final selling price is estimated. These estimates represent the influence of easy access to the Metro service on property valuation, an effect independent of other property characteristics or its location.

Therefore, in the three steps of searching for the most fitting function to the hedonic pricing model data in the research, the semi-logarithmic function has demonstrated consistency and is considered the most suitable. However, the other functions can also provide reference margins. In this regard, the evaluation will be carried out using the results of the semi-logarithmic model, where the impact is measured as the growth rate or percentage change in selling prices in response to an increase in the distance (metro) between the housing and Metro Line 1.

Graph N° 5.6 estimates the marginal impact of a unit increase in the distance separating the property and the nearest Metro station on the percentage change rate of the selling price. As observed, the growth rate of the selling price decreases very subtly but progressively as the housing moves away from the Metro station. The estimated marginal impact is an increase of 0.043% in the value of properties located up to 100 meters from the station; however, when evaluating a property with statistically similar characteristics but located 400 meters from the station, the increase in the selling price decreases slightly to 0.033%. When the same property is situated 800 meters away, the increase in the selling price reaches 0.021%. Finally, beyond 1,300 meters, there is no statistically significant impact associated with access to the Metro service.

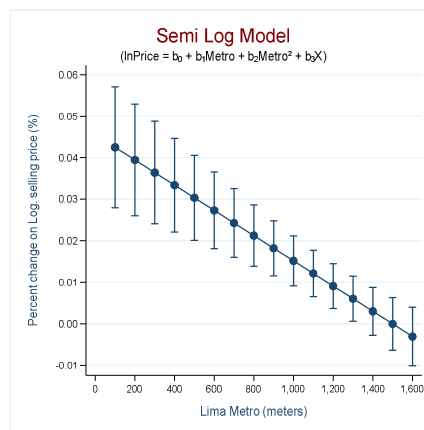


Fig. 5.6 Marginal effect of proximity to Metro Line 1 on Sales Price
(Percent change)

own elaboration

Table 5.11 Marginal effect of proximity to Metro Line 1 on Sales Price
(Percent change)

	(1)	(2)
PROXIMITY	Coef.	S.E.
100 meters	0.043***	(0.007)
200 meters	0.039***	(0.007)
300 meters	0.036***	(0.006)
400 meters	0.033***	(0.006)
500 meters	0.030***	(0.005)
600 meters	0.027***	(0.005)
700 meters	0.024***	(0.004)
800 meters	0.021***	(0.004)
900 meters	0.018***	(0.003)
1000 meters	0.015***	(0.003)
1100 meters	0.012***	(0.003)
1200 meters	0.009***	(0.003)
1300 meters	0.006**	(0.003)
1400 meters	0.003	(0.003)
1500 meters	-0.000	(0.003)
1600 meters	-0.003	(0.004)

(Robust standard errors for heteroscedasticity in parentheses)

*** p<0.01, ** p<0.05, * p<0.1
own elaboration.

5.2.4 Implicit Price

Based on the estimated coefficients for different functional forms, partial derivatives of the proximity to a station of Metro Line 1 were calculated. This derivative represents the average willingness to pay of individuals for a dwelling located near the Metro, while keeping the effect of other property characteristics constant. The expressions for Implicit Price derived in Tables 3.2 and 3.3 were used for the calculation.

Figure 5.7 illustrates the trend of the implicit price when the effect of proximity to the Metro on the sale price is constant. As observed, the marginal price remains at the same level when assuming the semi-logarithmic specification, with an average value of 22.5 dollars for every 100 meters of proximity to a Metro station.

This constant measure resulting from buyers' willingness to pay (implicit price) is derived from the inherent nature of the assumed functional forms for the price equation. In the case of the semi-logarithmic function, the partial derivative of distance with respect to price is equal to a constant (β_i). This means that the marginal impact of proximity to the metro when the dwelling

is located 100 meters away would be the same (constante β_i) as when the dwelling is located over 1,000 meters away.

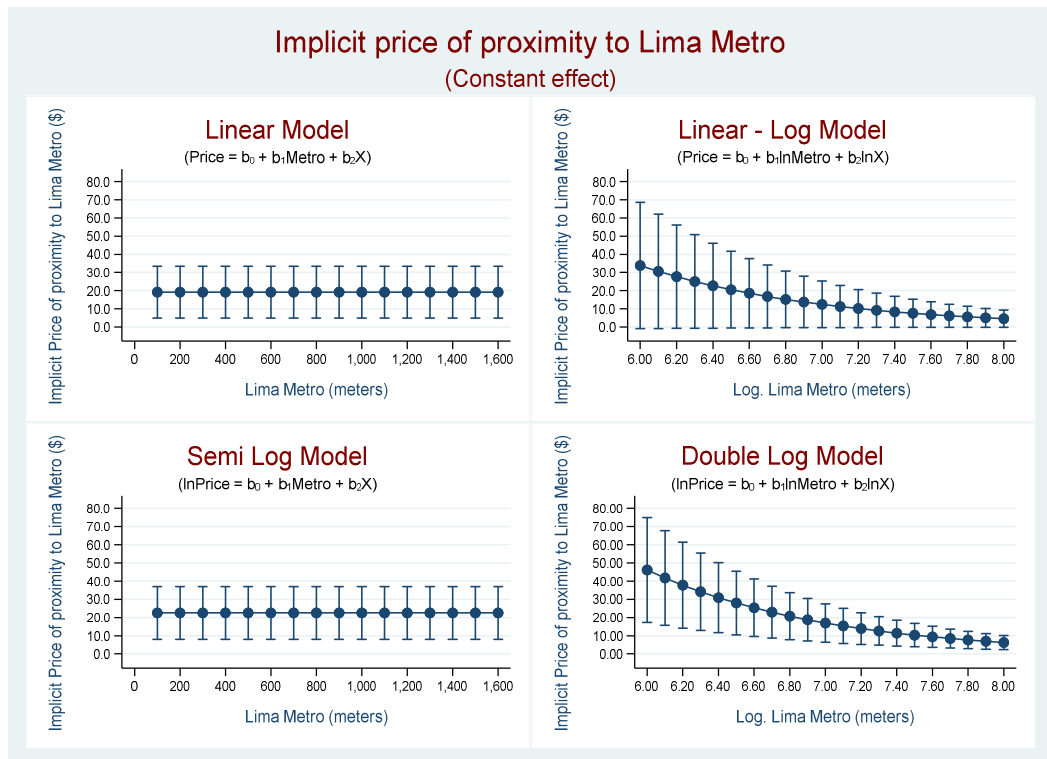


Fig. 5.7 Implicit price of proximity to Metro Line 1 (Constant effect)
own elaboration.

However, as the quadratic relationship has already been validated between price and distance (linear semi-logarithmic model), it is observed that the proximity premium decreases rapidly as we move towards dwellings located farther and farther from the Metro station.

In this regard, Table 5.12 shows that for the semi-logarithmic function (constant effect), the willingness to pay for dwellings within the range of 100 meters from the Metro route fluctuates at \$22.5 and remains constant. However, in the double-logarithmic function, as an extreme margin, it reaches up to \$186. When there is a shift in the range of 200 meters of proximity, the willingness to pay in the case of the semi-logarithmic function (constant effect) stays at \$22.5, while it reduces to \$93 for the double-logarithmic function, approximately falling below \$18 for residences that are more than 1,000 meters away from a station.

Table 5.12 Implicit Price of proximity to Metro Line 1 (US dollar)
(Constant effect of proximity to Metro Line 1)

Proximity to Lima Metro (meters)	Linear Model		Semi - Log Model		Linear - Log Model		Double Log Model	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
100 meters	19.197***	(7.248)	22.500***	(7.440)	136.495*	(71.567)	186.171***	(59.270)
200 meters	19.197***	(7.248)	22.500***	(7.440)	68.248*	(35.784)	93.085***	(29.635)
400 meters	19.197***	(7.248)	22.500***	(7.440)	34.124*	(17.892)	46.543***	(14.817)
600 meters	19.197***	(7.248)	22.500***	(7.440)	22.749*	(11.928)	31.028***	(9.878)
800 meters	19.197***	(7.248)	22.500***	(7.440)	17.062*	(8.946)	23.271***	(7.409)
1000 meters	19.197***	(7.248)	22.500***	(7.440)	13.650*	(7.157)	18.617***	(5.927)
1200 meters	19.197***	(7.248)	22.500***	(7.440)	11.375*	(5.964)	15.514***	(4.939)
1400 meters	19.197***	(7.248)	22.500***	(7.440)	9.750*	(5.112)	13.298***	(4.234)
1600 meters	19.197***	(7.248)	22.500***	(7.440)	8.531*	(4.473)	11.636***	(3.704)

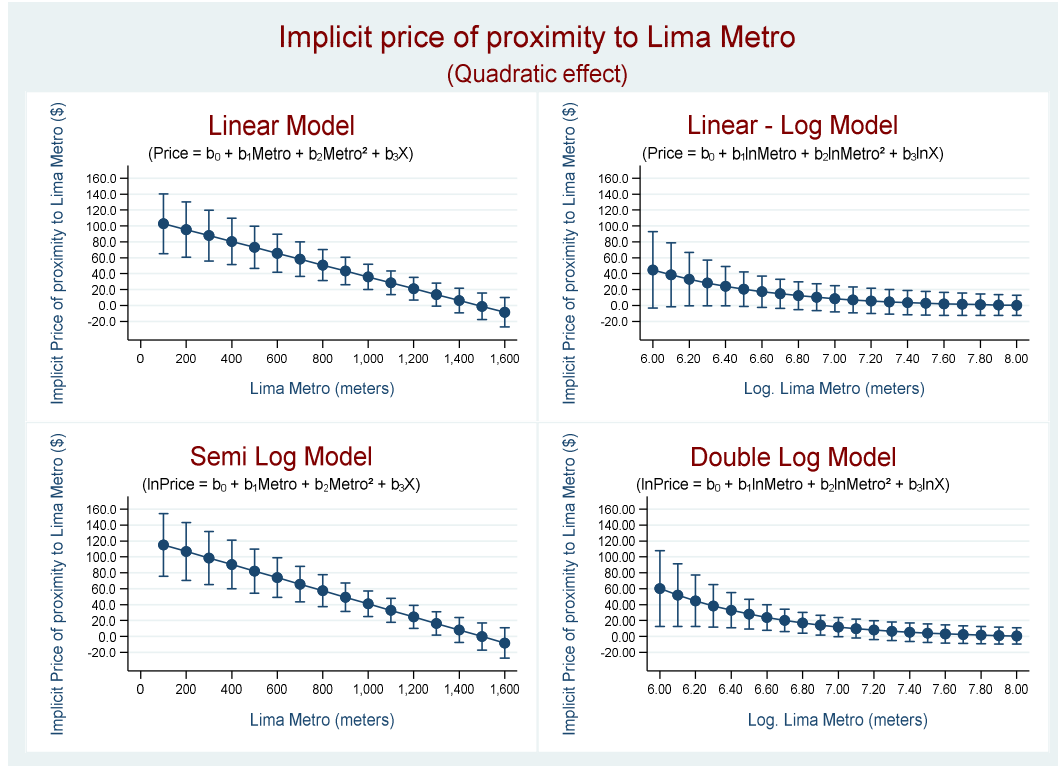
*** p<0.01, ** p<0.05, * p<0.1

own elaboration.

Regarding the quadratic function between the distance from the dwelling to the Metro and its sale price, the trend of willingness to pay or implicit price can be visualized in Fig. 5.8, showing a decreasing trend as the property moves farther away from the Metro route. This trend is similar for all functional forms considered for the price equation, and additionally, Table 5.13 shows that the estimates of the price magnitude are more similar among all selected models.

On average, the market is willing to **pay an additional \$115 (semi-logarithmic model) for dwellings located within the range of 100 meters proximity to the Metro**. This premium decreases to an approximate \$90 when it comes to dwelling that, on average, have the same characteristics but are located up to 400 meters away from the Metro line. The value of the property continues with the same decreasing trend as the dwelling moves farther away from the Metro stations until it disappears beyond 1,200 meters.

Fig. 5.8 Implicit price of proximity to Metro Line 1 (quadratic effect)



own elaboration.

Table 5.13 Implicit Price of proximity to Metro Line 1 (US dollar)
(Quadratic effect of proximity to Metro Line 1)

Proximity to Lima Metro (meters)	Linear Model		Semi - Log Model		Linear - Log Model		Double Log Model	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
100 meters	102.778***	(19.125)	115.068***	(20.127)	301.005	(246.637)	399.505*	(241.553)
200 meters	95.352***	(17.678)	106.844***	(18.586)	120.483	(84.117)	160.824*	(83.765)
400 meters	80.501***	(14.863)	90.395***	(15.584)	45.232*	(24.907)	60.948**	(24.715)
600 meters	65.649***	(12.213)	73.946***	(12.749)	24.302*	(12.622)	33.042***	(11.340)
800 meters	50.797***	(9.863)	57.498***	(10.220)	15.111	(9.436)	20.742***	(7.361)
1000 meters	35.946***	(8.078)	41.049***	(8.284)	10.156	(8.573)	14.087**	(6.316)
1200 meters	21.094***	(7.286)	24.601***	(7.420)	7.148	(8.244)	10.033*	(6.088)
1400 meters	6.242	(7.797)	8.152	(7.984)	5.173	(8.021)	7.363	(6.029)
1600 meters	-8.609	(9.400)	-8.297	(9.730)	3.803	(7.812)	5.505	(5.979)

*** p<0.01, ** p<0.05, * p<0.1

own elaboration.

6. Result and Discussion

6.1 Result Analysis

- i) In this research, four hedonic price models, namely linear, linear-log, semi-log, and double-log, have been analyzed. They were evaluated through Box-Cox transformations, the Akaike Information Criterion (AIC), and the Bayesian Schwarz Criterion (BIC). Linear and quadratic functions were introduced and validated using the F-test. Therefore, the **semi-logarithmic hedonic price model (with quadratic effect)** was elected. This model demonstrated consistency in its selection across all stages and was generated using robust regression methods, ensuring a representativeness of 89.6% (R²), indicating that the independent variables explain variations on housing sales price located near the stations of Line 1 of the Lima Metro in the districts of San Borja and Surquillo, as summarized below:“

$$\begin{aligned}
 hPrice_i = & 11.305 + 0.000456 DMetro_i - 0.00000152 (DMetro_i)^2 + \\
 & 0.00377Area_i - 0.0152year_i + 0.000282(year_i)^2 + 0.103room_i - 0.015(room_i)^2 + \\
 & 0.0255bat h_i + 0.122garage_i - 0.0224(garage_i)^2 + 0.00225duplex_i - \\
 & 0.0155triplex_i - 0.00979fbor_i + 0.0552elevator_i + 0.000162storage_i - \\
 & 0.0391rooftop_i - 0.00152Exterview_i - 0.000011Dschool_i + 0.00000543Dcollege_i + \\
 & 0.0000357Dmarket_i - 0.000004Dmarket_i + 0.0000624Dhospital_i + \\
 & 0.000154Ddrugstore_i + 0.0000276Dpark_i + 0.0000192Drestaurant_i - \\
 & 0.0000747Dbank_i - 0.000124Dinst_i - 0.0000580Dmainroad_i + 0.0000463Dbus_i - \\
 & 0.00803thefts_i + 0.0182homeile_i + \varepsilon_i
 \end{aligned}$$

- ii) Based on the results of this research, the hypothesis stating that there is an influence between the proximity to Line 1 of the Metro and the sale price of surrounding housing is accepted, considering the sample of 339 cases identified in the districts of San Borja and Surquillo.
- iii) Regarding the metro proximity and housing sales price, it is estimated that housings farther away have a higher total housing price than those closer to the metro (housing price increases slightly by 0.58% for every 100 meters of distance). This could reflect a more residential nature, especially in the Chacarilla sector of San Borja, known for its high residential character and affluent residents. To understand the contribution of the Metro to housing prices, calculations of marginal impact (%) and implicit price (\$) are performed.

- iv) The hedonic price model in semi-logarithmic form (with a quadratic effect) estimates a **marginal impact with an increase of 0.043% in the value of dwellings located up to 100 meters from the station**. However, when evaluating a property with statistically similar characteristics but located 400 meters from the station, the increase in the sale price slightly decreases to 0.033%. When the same property is located 800 meters away, the increase in the sale price reaches 0.021%. Finally, beyond 1,300 meters, there is no statistically significant impact associated with access to the Metro service.
- v) The market **would be willing to pay an additional \$115 (semi-logarithmic model with a quadratic effect) for dwellings within the range of 100 meters proximity to the Metro**. This premium reduces to an approximate \$90 when it comes to dwelling that, on average, have the same characteristics but are located up to 400 meters from the Metro line. The property value continues with the same decreasing trend as the dwelling moves further away from the Metro stations, reaching an influence of 1,200 meters.
- vi) The model estimates that the area of influence of Metro Line 1 for the dwellings identified in the study is between 1,200 to 1,300 meters, beyond which there is no statistical significance.
- vii) The model results (semi-logarithmic with a quadratic effect) also suggest that there are other more influential independent variables than the proximity to Line 1 of the metro when predicting property values. An increase in the area of the dwelling has a positive and significant effect on the sale price, increasing by around 0.4% for each additional square meter. The age of the dwelling negatively affects the price, decreasing by more than 1% for each additional year in the first 10 years (semi-log model). The second bedroom and an additional garage contribute positively to the value by 4.3% and 12.2%, respectively, while the presence of an elevator in the building also increases the price by 5.5%. The location in areas with a higher incidence of theft decreases the property value, with an average reduction of 8% for every 10 reported thefts.

6.2 Discussion of Result

The results of this research are compared with analyses conducted by some authors, acknowledging that each investigation is unique due to location, environment, and the railway system's particularities. Some coinciding trends and differences are presented:

- The estimated hedonic price model in this research is in semi-logarithmic form, which aligns with most authors, including **Sun H, Wang Y, Li Q (2016)**. However, **Mendieta and Perdomo (2007)** lean towards a more varied hedonic price model that incorporates spatial econometrics.
 - Regarding the proximity of Metro Line 1 and the housing sales price in San Borja, it is observed that dwelling identified farther away tend to have a higher total price than those close to the metro. This trend is presumed to be related to the residential nature of Chacarilla, where the metro is not the primary means of transportation. This aligns with the model's estimation, indicating that the influence decreases from 1200 to 1300 meters, coinciding with the location of this sector. A similar situation is revealed by **Jung Lee (2002)** for the Nowon-gu and Bundang-gu areas, where housing prices also increase when moving away from the metro, contrary to **Muñoz-raskin (2006)**.
 - Although there is evidence of a marginal impact of Metro Line 1 on the sales price, it is not the dominant factor. Other attributes, such as the occupied area (m²), exert a significant influence, contributing to almost 40% of the variation in housing sales prices. This finding aligns with previous research, such as **MacDonald, H., & Bowes, D. R. (2012)**.
- The estimated implicit price in this research suggests that the market would be willing to pay an additional \$115 for dwellings within the range of 100 meters proximity to Metro Line 1. This is a relatively low premium compared to other studies, such as **Rodríguez and Targa (2004)**, and slightly higher than **Guangzhou Li Wenlin, Yan Xiaopei (2002)** with a premium of ¥300 (\$42) ~ ¥500 (\$71). Additionally, further evaluations in other areas of Lima city are warranted, as **Sun H, Wang Y, Li Q (2016)** suggest that the construction of metro lines has a greater impact on the city's marginal areas than the city center or areas of higher purchasing power. Consideration should be given to expanding the evaluation range to commercial and industrial properties and areas with socio-economic differences in housing.

7. Conclusions and way forward

7.1 Conclusions

As a result of the analysis carried out in this research and in line with the research objectives, the following conclusions are drawn:

- The hypothesis stating that there is an influence between the proximity to Metro Line 1 and the sales price of surrounding dwellings is accepted. This is based on the refined sample of 339 dwellings identified in the districts of San Borja and Surquillo.
- A hedonic pricing model was successfully estimated using robust regression methods, ensuring an 89.6% representativeness in explaining variations on housing sales price near Metro Line 1 stations in the districts of San Borja and Surquillo. The model is presented as a semi-logarithmic hedonic pricing model (quadratic effect of the variable of interest, proximity to Metro Line 1), summarized as follows:

$$\begin{aligned} \ln Price_i = & 11.305 + 0.000456 DMetro_i - 0.00000152 (DMetro_i)^2 + \\ & 0.00377Area_i - 0.0152year_i + 0.000282(year_i)^2 + 0.103room_i - 0.015(room_i)^2 + \\ & 0.0255bath_i + 0.122garage_i - 0.0224(garage_i)^2 + 0.00225duplex_i - 0.0155triplex_i - \\ & 0.00979fbor_i + 0.0552elevator_i + 0.000162storage_i - 0.0391rooftop_i - \\ & 0.00152Exterior - 0.000011Dschool_i + 0.00000543Dcollege_i + 0.0000357Dmall_i - \\ & 0.000004Dmarket_i + 0.0000624Dhospital_i + 0.000154Ddrugstore_i + \\ & 0.0000276Dpark_i + 0.0000192Drestaurant_i - 0.0000747Dbank_i - 0.000124Distate_i - \\ & 0.0000580Dmainroad_i + 0.0000463Dbus_i - 0.00803thefts_i + 0.0182homeile_i + \varepsilon_i \end{aligned}$$

- The marginal impact of a unit increase in the distance between the property and the nearest Metro station on the percentage change in the sales price is an increase of 0.043% for housings located up to 100 meters from the station; 0.33% at a distance of 400 meters, 0.021% at 800 meters from the Metro, decreasing to 0.006% at 1300 meters.
- The implicit price, meaning the market would be willing to pay an additional \$115 (semi-logarithmic model) for housings within 100 meters proximity to the Metro, decreases to approximately \$90 for housings with the same characteristics but located up to 400 meters from the Metro, and further reduces to \$25 up to 1200 meters.

- The impact zone, determined by the empirical model, indicates after 1200m to 1300m, there is no influence of Metro Line 1 on housing sales price in the surroundings of the La Cultura, San Borja Sur and Angamos stations.
- The estimation (semi-logarithmic with quadratic effect) suggests that there are other variables more influential than the proximity to Metro Line 1, such as property and security attributes. An increase in the housing area has a positive and significant effect on the sales price, increasing by approximately 0.4% for each additional square meter. The age of the house negatively affects the price, decreasing by more than 1% for each additional year in the first 10 years. The second bedroom and an additional garage contribute positively to the value by 4.3% and 12.2% respectively, while the presence of an elevator in the building also increases the price by 5.5%. The location in areas with a higher incidence of thefts decreases the property value, with an average reduction of 8% for every 10 reported thefts.
- Regarding the proximity to the metro and housing sales price, it is estimated that housings farther away have a higher housing price than those closer to the metro (housing price increases slightly by 0.58% for every 100 meters of distance). This could reflect a more residential nature, particularly in the Chacarilla sector of the San Borja district, characterized by high residentiality and purchasing power.
- The conducted research represents the studied universe and may not necessarily be inferred for the entire population of dwellings in San Borja and Surquillo. Further methodological processes should be carried out, considering the challenges faced in this research.

7.2 Way forward

- It is deemed relevant to expand impact assessments of transport infrastructures on surrounding properties before, during, and after their implementation. This should encompass various areas of the city, with diverse socioeconomic strata and for various purposes such as commercial, residential, mixed-use, and industrial activities, facilitating the understanding of impacts generated by transport infrastructures.
- An opportunity for improvement has been identified based on the challenges faced in this research. It is recommended to enhance the Ministry of Housing Observatory by incorporating detailed information

on housing transactions, systematizing them by property attributes. Additionally, database-level data from real estate portals should be included to feed a comprehensive platform that integrates the necessary information to assess future public policies for land value capture, a strategy widely used by other economies to support public infrastructure development.

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9. Abstract

Land Value Impacts of Metro Line 1 in the Districts of San Borja and Surquillo, Lima -Perú (2023)

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Worldwide, there is a growing adoption of land value capture mechanisms in public policies, for which effective evaluation requires information on the impacts of public actions that generate value in private properties, a knowledge gap in the Peruvian context. The research focused on estimating the impact of the proximity to Metro Line 1 on the sale price of homes near three stations in the districts of San Borja and Surquillo. A quantitative, explanatory, and non-experimental design methodology was employed, using a cross-sectional approach (2023), with a sample of 339 dwellings obtained from real estate portals. The evaluation was based on a hedonic pricing model that considers structural, neighborhood, security, and proximity attributes to Metro Line 1 stations. The results obtained show the marginal impact of a unit increase in the distance between the property and the nearest Metro station on the percentage change in the sale price, with an increase of 0.043% for dwellings up to 100m, 0.33% up to 400m, 0.21% up to 800m, and decreasing influence up to a maximum radius between 1200 to 1,300 meters away.

10. 초록

페루 리마 산 보르자와 수르키요 지역 지하철 1호선의 토지 가치 영향(2023)

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전 세계적으로 공공 정책에 토지 가치 포착 메커니즘이 점점 더 많이 채택되고 있다는 증거가 있습니다. 이를 위해서는 페루 상황에서는 부족한 지식인 민간 자산의 가치를 창출하는 공공 활동의 영향에 대한 효과적인 평가 정보가 필요합니다. 이 연구는 San Borja 및 Surquillo 지역의 3개 역 근처 주택 판매 가격에 지하철 1호선의 근접성이 미치는 영향을 추정하는 데 중점을 두었습니다. 부동산 포털에서 얻은 339 채의 주택 샘플을 대상으로 횡단적 접근 방식(2023)을 사용하여 정량적, 설명적, 비실험적 설계 방법론을 사용했습니다. 평가는 지하철 1호선 역에 대한 구조적, 인근 지역, 안전 및 근접성 속성을 고려하는 헤도닉 가격 모델을 기반으로 했습니다. 얻은 결과는 부동산과 가장 가까운 지하철역 사이의 거리 단위 증가가 판매 가격의 백분율 변동률에 미치는 한계 영향을 보여 주며, 주택에서는 최대 100m 까지 0.043%, 최대 400m 까지 0.33% 증가했습니다. , 최대 800m 까지 0.21%, 1200~1,300m 떨어진 최대 반경까지 감소하는 방식으로 영향을 미칩니다.

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