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MASTER OF SCIENCE IN **URBAN PLANNING AND POLICY DESIGN**

ACCESSIBILITY-RELATED EFFECTS OF THE METRO NETWORK ON HOUSING PRICES IN MILAN:
ECONOMETRIC EVIDENCE AND SUGGESTIONS FOR VALUE CAPTURE FISCAL POLICIES

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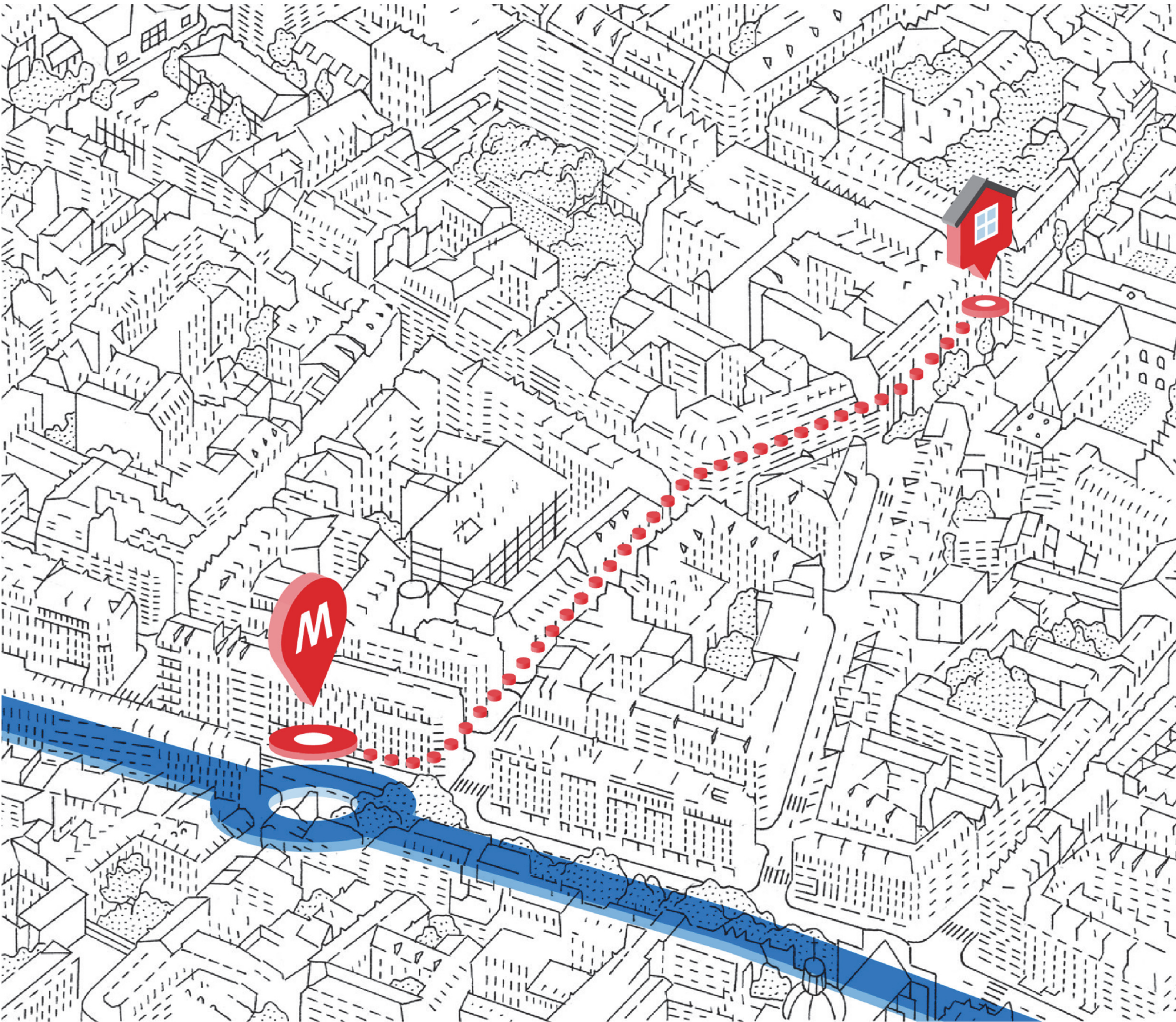

Abstract
(English version)

Urban environments are complex systems where multiple forces simultaneously interact, creating a balance that shapes the form of urban life. Some of these forces are very place-specific, but many of them can be found in most urban environments, offering the opportunity to be investigated with the broad aim of increasing the relative comprehension of urban life and improving the management of the urban environment as a whole. It is the case of the relationship between public transport infrastructure and land values, which presents recurring patterns all throughout the world and a long tradition of investigation. The specific interest in this particular element of urban life emerges with the acknowledgement that the public sector, which is often the promoter of investments in transport infrastructure, is encountering increasing difficulties in financing public transit projects due to the high initial capital costs and the limited treasury. Drawing from this consideration, this work starts with a reflection upon the relationship between urban public transport infrastructure investments, focusing on metro networks, and the potential land value uplifts generated by such physical transformations. Consequently, through a literature review of the most relevant studies on both the elements at the origin of land rent formation and on the empirical testing of land rent theories in relationship with metro station accessibility, the existence of this relationship in many cities is witnessed. Though, empirical evidence is missing for what concerns the city of Milan. To provide an answer to this knowledge gap, this work offers evidence of the relationship between land values and transportation infrastructure in the city of Milan through the development of an empirical econometric study.

This research, hence, pursues multiple goals: first, to briefly reflect upon the relationship between public transit infrastructure investment and land values; second, to understand which fiscal solutions have already been developed and applied to try and solve the emerging limitations in public transport infrastructure funding; third, and most importantly, to investigate the characteristics of the relationship between metro station accessibility and land values in the city of Milan; fourth, and lastly, to combine all these elements into a fiscal reassessment policy suggestion.

Keywords:
Accessibility; metropolitan railway; econometric analysis; hedonic price method; land value uplift; land value capture; land rent; public transport infrastructure; Euclidean distance analysis; network distance analysis.

Abstract
(Italian version)

Gli ambienti urbani sono sistemi complessi dove forze diverse interagiscono simultaneamente, generando un equilibrio che dà forma alla vita urbana. Di queste pulsioni, alcune si verificano solo in determinati luoghi, mentre molte possono essere individuate nella maggior parte degli ambienti urbani, offrendo così la possibilità di essere studiate con il generico obiettivo di aumentare la comprensione e di migliorare la gestione dell'ambiente urbano. Questo è il caso della relazione tra le infrastrutture di trasporto pubblico e i valori fondiari, che propone modelli ricorrenti in tutto il mondo e una lunga tradizione di indagine. L'interesse specifico per questo particolare elemento della vita urbana emerge con il riconoscimento che il settore pubblico, che è spesso promotore di investimenti nelle infrastrutture di trasporto, sta incontrando crescenti difficoltà nel finanziare progetti di trasporto pubblico a causa degli elevati costi iniziali di capitale e della sua limitata capacità di cassa. A partire da questa considerazione, la tesi inizia con una riflessione sul rapporto tra gli investimenti nelle infrastrutture urbane di trasporto pubblico, concentrandosi sulla metropolitana, e il potenziale aumento di valore del suolo indotto da tali trasformazioni fisiche. Di conseguenza, attraverso una revisione degli studi più rilevanti sia riguardo gli elementi all'origine della formazione della rendita fondiaria, sia riguardo le dimostrazioni empiriche delle teorie sulla rendita fondiaria in relazione all'accessibilità alla metropolitana, si testimonia l'esistenza di questo rapporto in molte città. Tuttavia, mancano prove empiriche per quanto concerne la città di Milano. Per dare una risposta a questo vuoto di conoscenza, questo lavoro si offre come dimostrazione empirica del rapporto tra l'accessibilità alla metropolitana e i valori fondiari nella città di Milano attraverso lo sviluppo di uno studio econometrico. Questa ricerca, quindi, persegue molteplici obiettivi: in primo luogo, riflettere brevemente sul rapporto tra gli investimenti nelle infrastrutture di trasporto pubblico e i valori fondiari; in secondo luogo, capire quali soluzioni fiscali siano già state sviluppate e applicate per cercare di risolvere i limiti legati al finanziamento delle infrastrutture di trasporto pubblico; terzo, e di maggior rilievo, indagare le caratteristiche del rapporto tra accessibilità alla metropolitana e valori fondiari nella città di Milano; per finire, combinare questi elementi in dei suggerimenti di riforma fiscale.

Parole chiave:
Accessibilità; metropolitana; analisi econometrica; modello di prezzi edonici; aumento del valore fondiario; cattura del plusvalore fondiario; rendita fondiaria; infrastruttura di trasporto pubblico; distanza euclidea; distanza di rete.

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Cover picture: personal elaboration, adapted from an illustration by Eva Le Roi

Preface

In an era where global population is progressively settling in cities, and cities are gradually evolving into metropolitan cities, megacities and megalopolis, urban systems of mass transportation are more and more needed to allow fast, safe and efficient commuting, and to reduce the negative externalities occurring when motorized private transportation is preferred (most importantly: traffic congestion, which leads to slower speeds, longer trip times, and increased vehicular queueing; air pollution; noise pollution). Yet, the diminishing financial power of public institutions – the usual promoters of such costly public transit investments – limits the opportunities for cities to evolve accordingly to their needs. A potential help to increase public revenues – that could then be directed to the aforementioned investments – is to structure and apply a fiscal reform which would target the increased land value benefits that originate from the increased accessibility ensured by the development of the infrastructure itself.

Prior to the proposal of a fiscal policy shift, a crucial and instrumental step is needed to verify if the preconditions apply: the econometric assessment of the relationship between accessibility to urban public transport infrastructure and land value uplifts.

Being the metropolitan city of Milan Italy's best example for the potential development of a fiscal policy reform, this research wants to empirically assess the relationship between land values and accessibility to Milan's metropolitan underground system.

Inclusively, the research is structured as following:

- The first chapter outlines the general theories on land rent formation – which constitute the base of any research in the field of applied urban economy – and the most prominent literature on the methodology used for their assessment;
- The second chapter presents a brief but important analysis of the alternative financing sources of urban transit infrastructures that go under the umbrella of Land Value Capture policies;
- The third chapter offers an analysis of the Milanese network system and real estate market, focusing on their recent history and geography;

- The fourth chapter outlines the research methodology and the dataset, with a further interest in comparing different accessibility measure techniques and selecting the less biased option;
- The fifth chapter describes the results of the empirical econometric study on Milan;
- Finally, the last chapter interprets the key findings of the research and, on their basis, proposes general suggestions for a correct development of a fiscal reform.

Research Questions

In the broad topic of accessibility-related impacts on land values, the research tries to explain the relationships occurring between investments in public transport infrastructure and real estate market in Milan. The first two questions represent the core of the research, while the third and fourth questions act as a secondary line of investigation:

1. What is the relation between residential prices per square metre and distance to the metro stations in Milan?
2. Does real estate market capitalize the value generated by the Milanese metro network?
3. At what stage of the infrastructure construction is this value capitalized?
4. Would it be possible to capture a share of this unearned private earning to improve the financial availability of the local administration and fund further public expenditure in public transport systems?

Research Objectives

Evolving from the research questions, the research objectives are:

- To critically examine existing literature in the field of accessibility-related land rent studies, both from a theoretical and from an empirical perspective;
- To outline and clarify the rationale behind land value capture policies and practices;
- To present, through the lens of international study cases, the most prominent policy solutions applied around the world aiming to tackle land value uplift recapture;

- To test the difference between alternative distance measures: the traditionally applied Euclidean distance method and the more accurate network distance method;
- Lastly, but most importantly, to provide empirical evidence on the correlation between public transport infrastructure accessibility and house prices in Milan through the development of an hedonic regression model;

Despite the effort in encapsulating as many relevant aspects related to land value uplift and land value capture, this work must not be intended as an A to Z recipe to develop and apply a land value capture policy program in the city of Milan. The aim of this research, in fact, is not to propose a fiscal reform "out of the books", rather to combine theoretical knowledge drawn from the literature and empirical evidence emerging from the analysis of the case study, and forge them into a stepping stone for further investigations and implementation, when and if the political willingness and social acceptability would allow land value capture to be positively considered.

Research Methodology

The research mainly addresses a practical issue. To tackle such issue with the necessary awareness, a dedicated theoretical study of the existing literature is first needed to fully understand theoretical and practical implications. Hence, the research follows an empirical and quantitative approach, drawing from both theoretical and empirical knowledge from the global literature of the same field, and empirical evidence from the case study of Milan. Furthermore, the ultimate goal of the research (and of the studies in the same line of research) is that of offering a justification for the proposal and potential implementation of a fiscal policy reform. From this, the secondary area of focus related to land value capture policies was investigated, to give a broad sense of the potential application of the results of the work. Specifically, the different areas of study investigated are:

- economic theory on land rent formation;
- econometric theory and evidence, and econometric practical and technical aspects for an independent set up;
- fiscal theory on land value capture policies;
- accessibility measures theory and their empirical evaluation;
- case study investigation, through a quantitative and partially qualitative approach.

Research Limitations

The first and foremost limitation of the research is the limited availability of real estate market data. The search of a dataset that could answer the needs for a micro-level econometric analysis proved to be difficult, and the obtained dataset was not ideal for the purpose of the work. Nevertheless, the utilized dataset is, to date, the best available solution.

Secondarily, the absence of a shared framework of analysis on transport network accessibility-related land value uplifts leaves most methodological choices in the hands of the author of the estimation, making it relatively hard to compare the results with other studies of the same kind, each of which developed in a methodologically different way.

Research Contributions

The research offers empirical evidence on the relationship between metro stations accessibility and residential real estate values in the city of Milan, and is intended as a first empirical step in the direction of a – now – justifiable land value capture fiscal reform, able to help the public sector in finding resources to upkeep and further expand public infrastructure systems for the Milan of tomorrow.

ABBREVIATIONS

API	Application Programming Interface
AR	Air Rights
ATM	Azienda Trasporti Milano
CBD	Central Business District
CSV	Coma Separated Value (file type extension)
DC	District of Columbia
DIF	Development Impact Fees
DLT	Development Land Tax
EXPO	Exposition
FN	Ferrovie Nord
FS	Ferrovie dello Stato
GIS	Geographic Information System
GWR	Geographically Weighted Regression
HPM	Hedonic Price Method
IMU	Imposta Municipale Unica
ISAP	Athens-Piraeus Electric Railways
JD	Joint Development
LAMTA	Los Angeles Metropolitan Transit Authority
LVC	Land Value Capture
LVT	Land Value Tax
LVU	Land Value Uplift
MTRC	Metropolitan Transit Railway Corporation
NE	Negotiated Exactions
OMI	Osservatorio del Mercato Immobiliare - Agenzia delle Entrate
OSMI	Osservatorio del Mercato Immobiliare - Borsa Immobiliare Milano
PGT	Piano di Governo del Territorio
SAC	Autocorrelation Model
SAD	Special Assessment District
SAR	Spatial Regression model
SCRTD	Southern California Regional Transit District
SDM	Durbin Model
SEM	Spatial Error Model
TIF	Tax Increment Financing
TOD	Transit Oriented Design
TUF	Transportation Utility Fees
UN	United Nations
VBA	Visual Basic for Applications

Chapter 1 | Transportation and property value creation

The structure of cities is shaped by various forces. Some, such as the location of initial settlements and of the city's more affluent residents, are the results of ancient circumstances and can only be described. Others, like the interaction between transit networks and land markets, offer a long tradition of theoretical and empirical evidence, providing, to date, sufficient material for the academic research which has been able to deliver a robust explanation for observed configurations of land value (and, consequently, development densities) in cities. This latter relationship, that of transport networks capable of influencing the patterns of urban land values in cities, is the focus of this research.

Cities are the core of the larger economies in which they are located. Their birth, evolution and existence are motivated by the possibilities enjoyed by their residents to take advantage of economies of scale in production and various sources of agglomeration economies, such as labour market pooling, input sharing and knowledge spillovers (Rosenthal & Strange, 2004). For these elements to take place, a fundamental requisite is the relatively low transportation costs provided by a highly developed transportation network, a common element of most prosperous large cities. Being able to provide reliable transport networks is one of the most important challenges facing large metropolitan areas, as their provision is a great determinant for their competitiveness, quality of life and poverty levels. When governments succeed to implement efficient transit solutions, economic growth generated by such investments – and by the consequent agglomeration economy effects – drives boosts in urban land and property values.

Furthermore, most developed and developing cities are facing common issues brought about by population growth, such as traffic congestion, air pollution and sprawling development patterns. These problems are often related to the heavy reliance on the car as a primary transportation mode (Travisi, Camagni, & Nijkamp, 2010). To reduce this dependence and thereby mitigate the undesired direct and indirect side effects of population growth, for the provision of urban transit a range of alternative transport services must be considered. The ideal solution is often found in the construction or extension of urban and suburban transit systems, which are able to provide capacity and competitive levels of service for a large number of urban travellers. Pundits argue that, because rail transit is valued as a valid alternative to private transportation, it will reduce the number of cars on the road and, as a secondary effect, encourage more compact patterns of growth by drawing real estate development closer to transport stations (Bowes & Ihlanfeldt, 2001). Furthermore, successful public transport systems result in a multiplicity of positive effects: by reducing travel time, they ease access and increase location value in both station areas and throughout their entire service corridor. As a side effect, enhanced access fosters the agglomeration economies that make cities powerful economic engines (Blanco, Moreno, Vetter, & Vetter, 2016). When this strategy is well developed by the local planning authority, favouring this virtuous cycle, cities thrive.

1.1 The relationship between transport systems and land values: accessibility

Observed patterns of land use in cities are largely explained by the interaction of land markets and transportation networks. The mediating element that represents this interaction is the concept of accessibility. Accessibility can be loosely defined as the ease of reaching desired destinations (Iacono et al., 2009). A broader and more behaviourally-relevant definition of accessibility is the potential for reaching spatially distributed opportunities from a particular location while considering the difficulty involved in travelling to them (Páez, Scott, & Morency, 2012). What exactly is meant by "desired destinations" or "opportunities" can vary depending on cultural environment and socioeconomical circumstances, but it generally involves a set of activities that households engage in on a fairly frequent basis. The most important of these activities is employment, which has been consistently identified as one of the most important (and hence, most studied) influences on the location decisions of households. Other types of activities that households might value access to include shopping destinations, entertainment venues, or educational institutions (especially higher education institutions, which are more limited in supply). Locations with higher accessibility tend to command higher prices for land, while locations with less accessibility tend to be cheaper. As noted by Iacono et al. (2009), accessibility is a dynamic concept since transportation networks are being continually modified over time, and that firms and households respond to these changes to transportation networks, and the accessibility they provide, by eventually changing their location. These location decisions and the patterns of accessibility they represent eventually become capitalized into land markets, giving rise again to a different set of location incentives.

Being generally true that the centres of major cities the places where a higher density of business, shopping and cultural activities are hosted, this is also why the closeness to the city centre is considered as a certain quality characteristic, which gets valued and priced into real estate market. The quick yet superficial conclusion is that the closer a property is to the city centre, the higher its value should be: since the distance that a city centre inhabitant must cover to reach the desired destination is lower compared to that of somebody living further away, the inner city inhabitant can exploit and make use of the amount of time that he saved by not needing to travel. This saved time has a value, strictly related to the location of residence with respect to desired destinations, which gets capitalized in the value of land upon which lays the inner city inhabitant's place of residence.

This assumption dates back to the studies of Von Thünen (Thünen, 1830) the German economist who studied the location of economic activities across space. According to his theory, accessibility to the marketplace is responsible for the difference in value between areas of farmland with similar fertility but different location. In later studies, Alonso and Muth refined this argument in a bid–rent analysis (Alonso, 1964; Muth, 1969), where they claim that the land rent that all firms are prepared to pay is the residual component of a function that includes price of production, entrepreneurial profit and quantity of product sold, and is highly reliant on transportation cost: land rent varies depending especially on the location of the land. Assuming the city to be monocentric, meaning that the vast majority of employment is located in the centre, this leads to a rent gradient that decreases as distance to the central business district (CBD) increases, for sites that have equal utility. In the analyses conducted thus far, the dominant factor explaining the difference between land (hence property) values was accessibility, as measured by the distance to the CBD and associated transport costs. However, the monocentric city model's basic development occurred in the 1960's and 1970's. Since then cities have become increasingly polycentric, and the monocentric city model, with its assumption of a single concentration of employment, has been criticized on the grounds that the cities it explains are from a different era. More complex models and estimations have been developed in the meanwhile, but many of the studies in this field still utilizes distance to the CBD as a proxy for higher employment densities, assuming the rest of the city to be uniformly decreasing in employment opportunities. Following on these theories, scholars have drawn complementary conclusions on the existence of urban areas, characterized by increasing returns to scale at the city level, which are referred to as urban agglomeration economies, comprising localization economies and urbanization economies (Mills & Hamilton, 1994).

The essential theory on real estate market prices can therefore be defined as follows: as a location becomes more attractive due to certain characteristics, demand increases and thus the bidding process pushes prices up. In most cases, being CBDs the centres of the most attractive activities (particularly in radiocentric cities like Milan), proximity to the CBD is considered an important quality that increases property prices.

Yet, to some extent investments in transport infrastructure counterbalance this demand tension around the CBD by drawing households to settle around the transit stations instead (Fejarang, 1994): because urban transit infrastructure offers a decrease in generalized transportation costs for land around a station, properties located close to the transit stations take advantage of the transport time and cost savings. This accessibility benefit in turn should create a locational advantage, cause people and firms to outbid one another for the land and result in a localized bid-rent surface that peaks at transit stations, increasing land values all around the newly constructed transit investment (Figure 1). The vast majority of studies in this field have operationalized accessibility indirectly through measures of proximity to rapid transit access points to capture this bid-rent surface as a proxy for underlying accessibility benefits (Higgins & Kanaroglou, 2016).

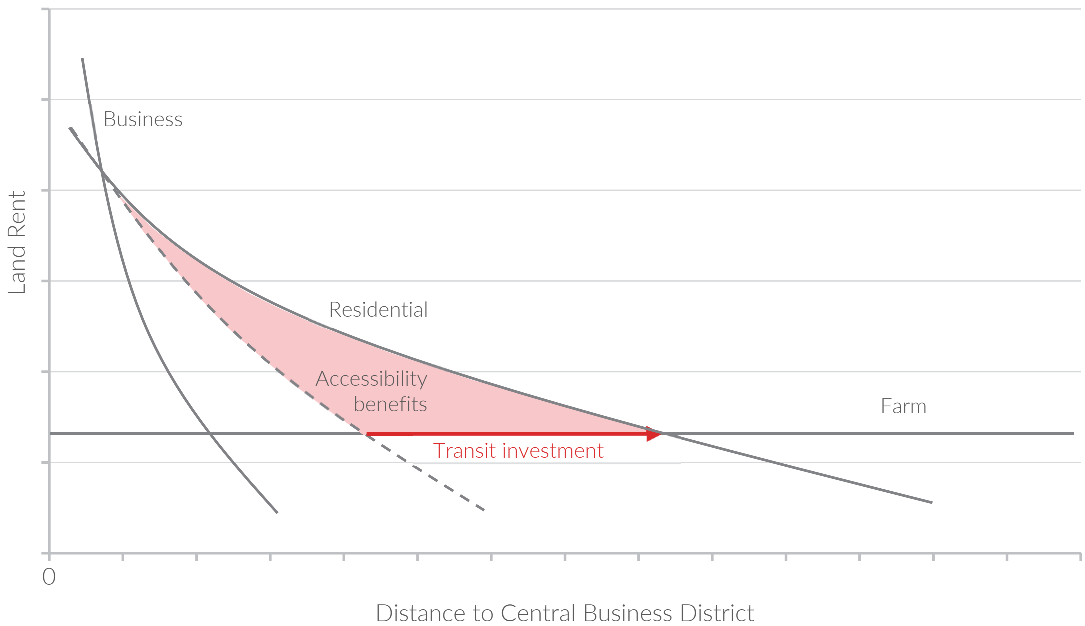

Figure 1. Residential accessibility benefits from transit investment in the monocentric city. Source: Murakami (2012)

The advantages triggered by the provision of efficient transport networks, like an intercity road or a rail transit system, are rather straight forward to imagine. A new connection might lower logistic costs of shipping goods by offering a more direct route, which in turn would reduce the labour and the energy inputs required to make a given trip. In an urban context, a new link might reduce travel costs for its users.

> *"Reducing transportation costs through incremental improvements to networks frees up resources that can then be put to other uses."*
> *(Mohring, 1961)*

More broadly, transportation networks provide value by linking together places that people wish to access (Iacono et al., 2009). The value they provide is conventionally thought of as the time saving provided by the transportation improvement and internalized by the user, which then he can allocate to other uses, such as work or leisure[1]. This assumption has proven to be difficult to demonstrate in practice, with evidence that the amount of time spent traveling by households has remained remarkably constant over long periods of time (Mokhtarian, 2004; Zahavi & Talvitie, 1980). This indicates that other forms of behavioural patterns modifications might be taking place in response to transit improvements. Iacono et al. (2009) highlight how different alternative user responses can be drawn: households might be taking advantage of the additional time savings by increasing the number of activities they participate in, or they might move to a more desired location, or they might move to a location where land is cheaper and they can consume more housing, all while maintaining the same commute length or duration. While these responses are less direct, they are nonetheless beneficial and suggest the existence of some type of transportation related benefit. The latter response suggests that patterns of land use and land value may provide clues as to how these benefits are realized. As noted by Levinson (1997), land use and transportation systems – and their associated patterns of accessibility – are characterized by feedback loops which mutually affect all of the different elements of the systems (Figure 2). According to the author, increases in the capacity of the transportation systems in response to rising demand lead

[1] Conventionally, the measure of user benefits for the evaluation of transportation improvements is a standard value of time saving as a function of local wage rates. The underlying assumption, difficult to be proven, is that time savings brought about by transportation improvement would be allocated to additional work effort.

to increases in land value, while increases in congestion causes the opposite effect. That is because travel time acts as a disincentive to consumers to choose destinations that are further away, since consumers must expend resources to access those destinations. Increases in travel time or other travel costs reduces the number of destinations that can be feasibly accessed, given the budgets households are restricted to in terms of money or time. The feedback effects continue when the increases in land value caused by increases in accessibility lead to a larger amount of development, which again begets higher land values. In the long run, these positive and negative feedback effects tend to balance each other, with land prices playing a mediating role.

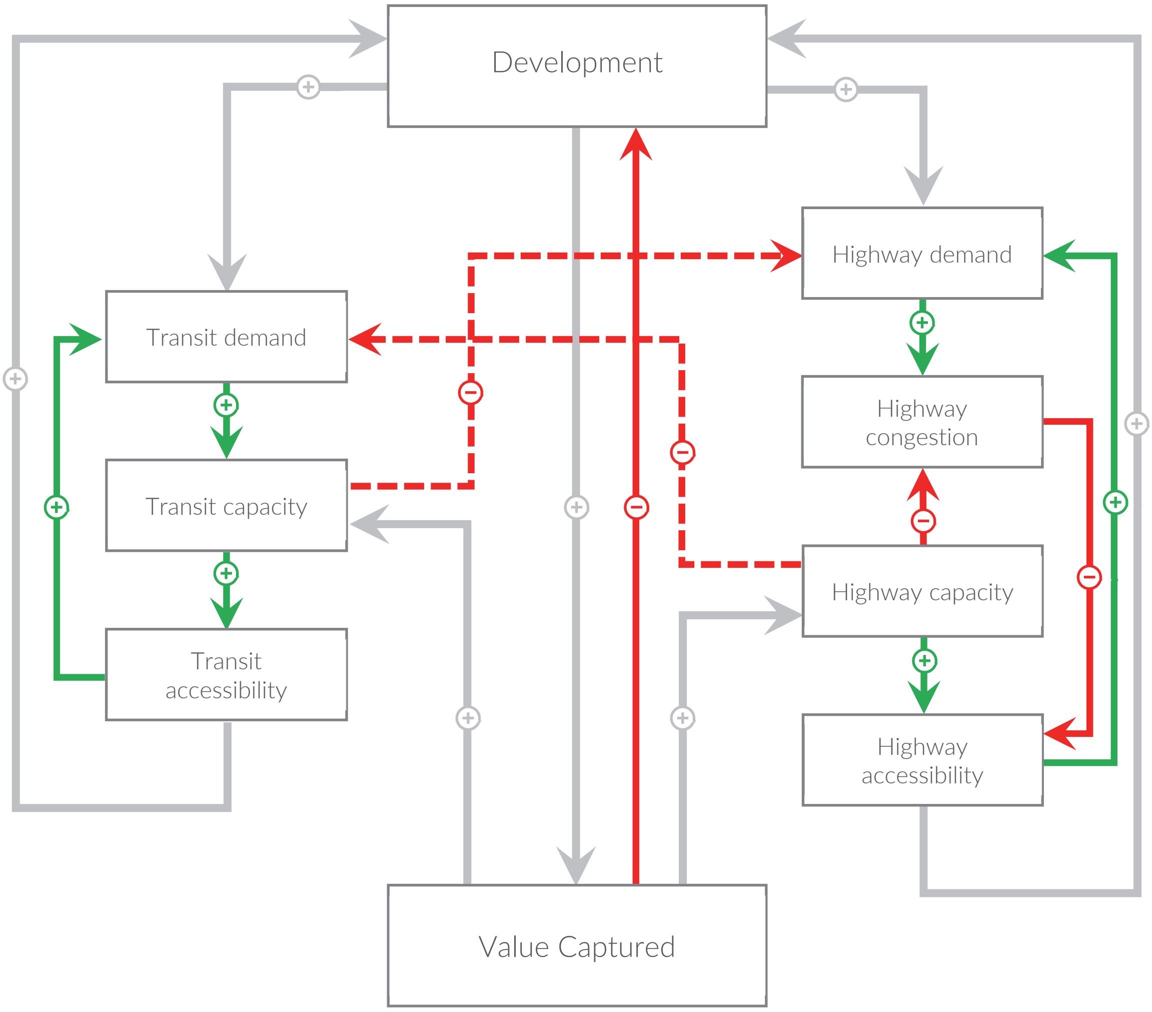

Figure 2. Feedbacks in systems of transportation and land use. Source: Levinson (1997).

To better understand the consumer's utility maximisation point of view, it is possible to draw interesting conclusions following the simple capitalization model of Agostini & Palmucci (2008), based on Alonso (1964). This model targets the problem of each consumer in the housing market, which consists in maximizing his/her own utility when choosing between different alternatives. The utility maximisation is based on the size and location of the housing unit and all other consumption goods, subject to a budget constraint that explicitly considers transportation costs and its effects on housing prices.

Briefly, the maximization looks as follow:

$$\max U(s,d,o)$$

with a budget constraint:

$$Y = P(d)s + T(d) + o$$

Where Y is the consumer's income, $P(d)$ is the price per square meter of the property related to the distance to the closest station, d is the distance of the housing unit from the closest metro station, s stands for the size of the property in square meters, $T(d)$ is a cost function of transport and o is a compound good made up of all the other essential attributes an individual values of a property. The reason why distance is included in an individual's utility function is that of capturing the inconvenient necessity for the consumer to reach the nearest station, acting with a negative effect as distance increases, hence moving the ideal housing location. Let's assume that our utility function U satisfies the following conditions: U is continuous, smooth with continuous derivatives of second order and strictly quasi-concave. Furthermore, U is increasing in s and o and decreasing in d. Additionally, $\partial P(d)/\partial d<0$ and $\partial T(d)/\partial d>0$. The first order conditions for this maximization problem are the following:

$U_s - \lambda P(d) = 0$

$U_d - \lambda(P_d m + T_d) = 0$

$U_o - \lambda = 0$

$Y - o - P(d)m - T(d) = 0$

One of the equilibrium location conditions can be obtained from the first and third equations of the previous list:

$$\frac{U_s}{U_o} = P(d)$$

This first equilibrium condition establishes that the marginal ratio the consumer is willing to accept to substitute consumption of square metres of property, *s*, with consumption of other goods is equal to the relative price. Relative prices depend on the distance, *d*, to the transport service under study.

A second equilibrium condition is obtained from the second and third equations of the same list:

$$P_d m = -\left(T_d - \frac{U_d}{U_o}\right)$$

This second condition establishes that the marginal willingness to pay per square metre of property to increase distance decreases as marginal transport costs increase and rise as marginal disutility rises. This simple model shows that, from a theoretical viewpoint, house prices should be negatively related to the distance to the nearest metro station: as distance to the nearest metro station increases, prices go down. The expected outcome is a price curve with a negative slope (Figure 3), where, as we move away from the station, prices decrease.

This price/distance relationship is not necessarily monotonically decreasing, since the metro station may potentially have counterbalancing impacts. On the one hand, the convenience of a new means of transport generates a direct positive effect by reducing transport costs for neighbourhood residents; on the other hand, the metro station produces a multitude of indirect negative effects, such as increased circulation of people, a higher noise level, increased pollution levels and negative spillover due to redistribution of economic activities (R. Cervero & Duncan, 2002). The net impact of this host of indirect effects is ambiguous and place specific, because some of them may have a positive impact on the price of the housing units nearest to the station, contributing to the price increase, while others may have a negative effect, which potentially could flip the curve in the negative environment (Figure 3). As noted by Higgins & Kanaroglou (2016) in their comprehensive and critical review of over 130 analyses across 60 studies completed in North America over the past 40 years, a significant heterogeneity is found in terms of research outcomes. Apart from illustrating that public transit networks investments do result in compact urbanisation and acknowledging that the final goal was to provide evidence for the implementation of value capture schemes for financing rail investment, their review confirms that many analyses have indeed found significant positive relationships between proximity and price. However, as with study methods, there is a dramatic range in findings, and several seemingly similar studies have drawn opposite findings, with some coming to the conclusion that transit has actually decreased land values.

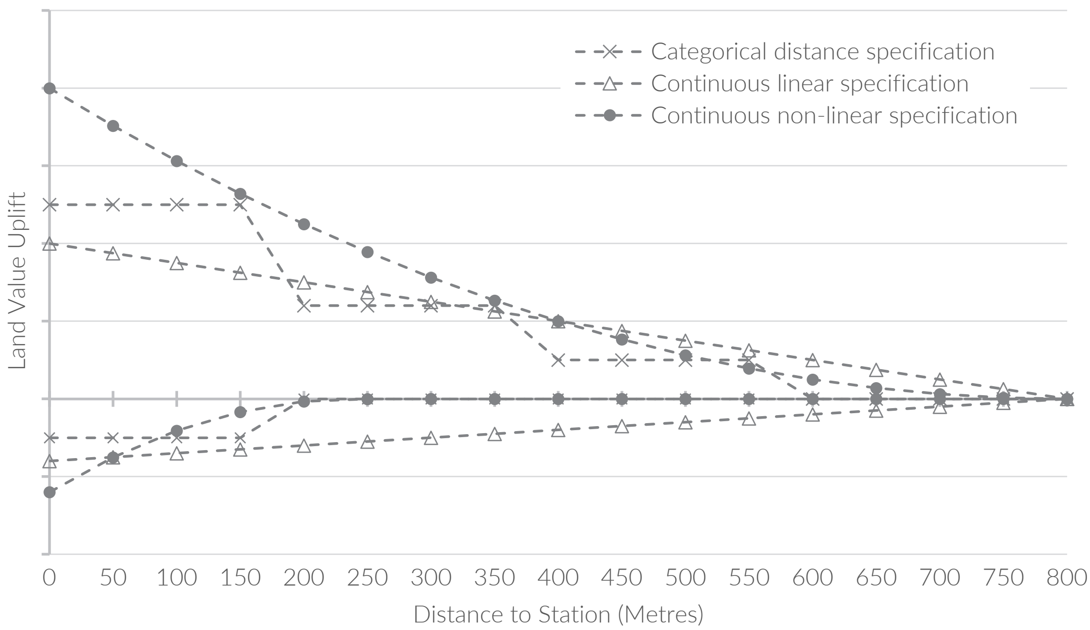

Figure 3. Positive and Negative LVU Effects by Distance Specification. Source: Higgins & Kanaroglou (2016).

Following this reasoning line, and since every transport network and city present peculiar characteristics and differences both within the system (station hierarchies, neighbourhoods' socio-economical characteristics, local scale environmental characteristics, crime density) and in comparison with other cities, an empirical analysis of the desired network is necessary to verify and test which of the assumptions holds, and if the same curve is persistent throughout the whole network or if it changes according to the inner differences highlighted above. To date, no consistent relationship between proximity to underground stations and property values has been studied and reported for the city of Milan.

1.2 Econometric analysis technique: the hedonic price method

This kind of evaluation is possible thanks to a variety of econometric and statistical methods: the hedonic price method, repeat sales methods, spatial econometric models, such as the spatial regression model (SAR), spatial error (SEM), Durbin (SDM) and autocorrelation (SAC) model and Geographically Weighted Regression (GWR), which are increasingly used by econometricians. Given the analogue choice made by the vast majority of the case studies analysed and given also the little knowledge in the field of applied statistical analysis, hedonic price method was deemed sufficient for the purpose of this study.

Models that use hedonic pricing methods (also referred to using the acronym HPM) are widely adopted for the study of the effects of transportation improvements on the value of real estate property. Regardless of whether prices for empty plots of land or improved properties are available, hedonic pricing models allow the analyst to decompose the determinants of prices into a set of attributes, each of which has an implicit price associated with it, permitting to single out the effect of that specific quality from the entire number of attributes of the property. The theory behind hedonic price method originates from Lancaster's (1966) work that linked consumer utility to the characteristics of goods, intended as the inputs in the activity of consumption. HPM assumes that a good such as a house can be considered as an aggregation of distinct components or attributes (Griliches, 1971). When consumers purchase goods in the market, such as a house, they select a commodity that maximizes each of the embodied bundles of attributes' underlying utility function (Rosen, 1974). Rosen (1974) analyses the process wherein prices reveal quality variations as relying on producers who "tailor their goods to embody final characteristics described by customers and receive returns for serving economic functions as mediaries". As explained by Limsombunchai (2004), bundles of characteristics rather than bundles of goods are ranked according to their utility bearing abilities. Attributes (for example, characteristics of a house such as number of bedrooms, number of bathrooms, number of fireplaces, parking facilities, living area and lot size) are implicitly embodied in goods and their observed market prices. The amount, or mere presence, of attributes associated with the commodities defines a set of implicit or "hedonic" prices (Rosen, 1974). The marginal implicit values of the attributes are obtained by differentiating the hedonic price function with respect to each attribute (McMillan, Reid, & Gillen, 1980). To synthesize, we can think of the hedonic price method as a form of regression modelling that tries to estimate how a wide range of independent variables affect a desired dependent variable: in our case, a regression model that seeks to assess the degree of capitalisation of different kind of house-related variable into property prices and their underlying land values. The advantage of the hedonic methods is that they control for the characteristics of properties, thus allowing the analyst to distinguish the impact of changing sample composition from actual property appreciation (Calhoun, 2001). This approach turns out to be quite useful for analysis of the effects of transportation improvements, since data are more often available for developed properties than for the value of undeveloped land (Iacono et al., 2009). In subsequent studies, we observe the integration of physical, accessibility and environmental characteristics of the property in models which address the differences in property values.

The general HPM function usually takes the form:

$$P_i = f(S, N, L, M, T, E)$$

where

P_i = estimated price of parcel i

S = vector of structural and lot characteristics (e.g. number of rooms),

N = vector of neighbourhood characteristics (e.g. school quality, crime, economic growth),

L = vector of locational characteristics (e.g. distance to CBD, distance to rapid transit facility, distance to nearest highway, accessibility to employment),

M = vector that measures proximity to nearest metro,

T = vector of time control variables,

E = vector of idiosyncratic error capturing unobserved determinants of housing prices.

Together, these variables provide a more or less complete description of a given property. The associated parameters for each variable can then be estimated to give an approximation of their implicit value, as revealed by the consumption decisions of buyers or renters of houses or commercial property.

The theoretical literature on hedonic price functions does not specify a particular functional form for the hedonic model, although many empirical studies adopt specifications that are nonlinear in prices but can be transformed to more easily estimable forms (Halvorsen & Pollakowski, 1981). On one side, this freedom is positive because it leaves the analyst the possibility to apply or discard case-specific choices, or explore new unprecedented solutions; on the other side, the lack of a common approach has been found as an obstacle when it comes to comparing different studies, since results are reached following different paths (Higgins & Kanaroglou, 2016).

Data on home sales tend to be more readily available than for other types of property, and this is where much of the evidence from hedonic price models has been accumulated. The effects of transportation improvements are usually specified in terms of the distance or travel time to some transportation facility, such as a highway link or public transit station. Where distance or travel time cannot be specified as a continuous variable, researchers sometimes adopt an approach of defining an "impact zone" within which property values are assumed to be influenced by a transportation improvement (Iacono et al., 2009).

1.3 THE EFFECTS OF PROXIMITY TO TRANSIT STATIONS ON NEIGHBOURING LAND VALUES: EMPIRICAL EVIDENCE FROM THE LITERATURE

Over the past decades, many authors have embarked on studies describing the impacts triggered by transport infrastructures projects on land values and real estate market. In the USA, the development of new rail systems in San Francisco, Washington and Atlanta during the 1970s and early 1980s brought an interest in the evaluation of the effects of these systems on adjacent land and property values. Much of this new curiosity emerged as the effect of an early review of Knight & Trygg (1977), in which the authors underline the potential for different transport technologies (heavy rail, light rail, express bus, etc.) to have different magnitudes of effect on land values and dramatic impacts on land use and development patterns in cities, though little empirical analysis existed at the time. From then on, authors have worked extensively to fill the knowledge gap between theories of land rent and land use patterns and their empirical demonstration, coming together with a multitude of different conclusions: the impacts emerged in the studies, in fact, vary in magnitude and form of the result due to a variety of reasons.

First, it is noted how different kind of transport facilities result in different land value variation outcomes, with subway systems getting the highest premia, compared to light rail and commuter rail (train) systems. Empirical studies of the impact of subway/elevated urban rail systems (often referred to as "heavy rail" or "metro" systems) almost uniformly find positive impacts on home prices or commercial property prices or rents near stations (Higgins & Kanaroglou, 2016): at the high end of this spectrum, a study by Lewis-Workman & Brod (1997) on the subway system of New York City reports a negative gradient of $75 for each additional meter of distance away from a metro station for house prices. According to Iacono et al. (2009), more generally, systems that are more extensive, more heavily patronized and that provide a greater level of accessibility tend to have greater impacts on property values.

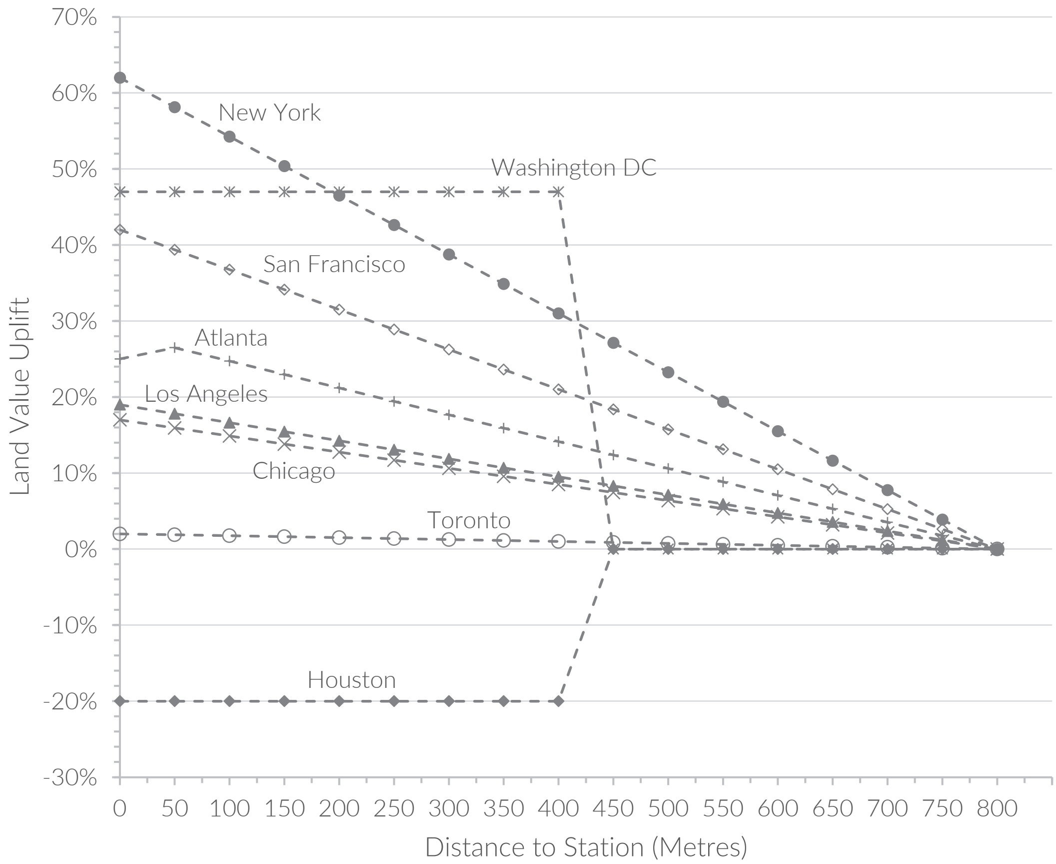

Figure 4. Land Value Uplift coefficients from study sample. Adapted from Higgins & Kanaroglou (2016).

Further, notwithstanding a general positive impact of the infrastructure project, the immediate surroundings of both the stations and the transit line (this only in the case of above-ground solutions) might receive a reduced premium on neighbouring land and property values: this is caused by the negative externalities of the project, such as noise nuisance, increased pedestrian concentrations, changing patterns of local commercial offer targeting user population and other place specific effects. Chen, Rufolo, & Dueker (1998) concluded that a same infrastructure project may generate multiple counterfactual types of externalities: in their paper, they both noted a positive effect of proximity to light rail stations in Portland and a negative effect of being near the light rail line itself, due to the noise nuisance effect of the light rail passing cars. Lastly, there is some evidence that the price effect of being near a station may also depend on socioeconomic characteristics of the neighbourhood surrounding the station itself, which may cause reduced – or even negative – land value premia. Effects of proximity to rail stations on residential property values have been found to vary by neighbourhood income in station areas (Bowes & Ihlanfeldt, 2001). Where crime rates are higher compared to other stations or areas of the city, residential property prices in the immediate vicinity of stations may be depressed, especially in lower-income neighbourhoods (Hess & Almeida, 2007).

Another crucial aspect when trying to compare different outcomes is represented by the inconsistency of model specification for estimating the proximity effect, which in turn makes comparisons across studies somewhat difficult: some studies treat distance as a discrete variable and measure effects within distance bands of a given facility while others treat distance as a continuous variable and attempt to recover rent gradients (Debrezion, Pels, & Rietveld, 2007).

In a paper titled "The anticipated capitalization effect of a new metro line on housing prices", Agostini & Palmucci (2008) studied the impacts of the opening of the line 4 on surrounding real estate values in the city of Santiago, Chile. The authors' aim was to understand how and when real estate market would transform the absorbed information about the upcoming opening of a new transit line into residential values uplifts. With the use of a unique database containing all home buying and selling transactions in the Greater Santiago area between December 2000 and March 2004, they were able to discover that the average apartment price rose between 4.1% and 7.9% after construction was announced and between 3.9% and 5.4% after the location of the stations was identified. This increase was not distributed evenly, but depended on the distance from the apartment to the nearest station: specifically, it corresponded to the changes in values for those properties located within 1 km from the upcoming metro station.

Regarding European cities, which represent a better set to be compared with the case study of this research for the general city structure and socioeconomical aspects, numerous authors have undertaken empirical analysis of the land value uplift generated by investment in subway lines in different cities. Medda & Modelewska (2009) have analysed the economic impacts of the existing metro line on housing prices in Warsaw, Poland, and predicted future uplifts in values due to the construction of the second line. The aim of their work is to measure the capitalisation benefits of the metro access, both where the subway is already operating and in the district where the new line will reach. To do so, the authors have run two distinct hedonic regression models, one for the existing line on the district of Bielany and one for the district of Targówek. Each regression contains the natural logarithm of sales prices as dependent variable, and a range of property descriptors: among them, for each apartment they calculated the direct distance, point-to-point, to the metro station and identify it as a dummy variable (1 if property is within 1 km to station, 0 if distance to station exceeds 1 km). Their assumption is that, given the similar characteristics and trends in the real estate market of the two districts, it is possible to calculate the value of house price in Targówek by introducing in the regression the Bielany coefficient for access to metro. The results show that houses located within a distance of 1 km to the nearest metro station compared with those in the same district but farther away have, respectively, a 6,7% higher selling price in the district of Bielany and a 7,13% higher predicted selling price in the district of Targówek.

Similarly, Efthymiou & Antoniou (2013) studied the interaction between transportation infrastructure and both selling and rent property values for the city of Athens, Greece. After building a dataset of residential selling and renting prices with a web-scraping technique (since real estate transaction were not available), the authors ran several different econometric analyses, including HPM. They concluded that houses located 500 metres around the metro stations have higher purchase prices on average between 6.74% and 11.66% and rental price from 4.20% to 6.21%, while those located 500metres around ISAP stations (Athens-Piraeus Electric Railways, the old urban railway of Attica) have sale prices from -10.20% to -12.24% but the effect is significantly smaller on rental (from -1.55% to -1.73%), showing that people are less willing to purchase a house – than to rent one – next to ISAP stations. In his bachelor thesis in Social Sciences at the Institute of Economic studies at Charles University in Prague, Laznicka (2016) studied the impact of metro station proximity on apartment values in Prague, Czech Republic. His research resembles the previous cases, but, concerning the goals, he also controlled for difference in difference within the same transit system by analysing individual stations' effects on real estate values in different areas of the city individually. The results show that a positive impact of metro closeness prevails in most of the examined suburb stations, while the ones located in the midway to the centre showed diverse effects on apartment prices and finally, the only station examined that is located in the centre, Staromestska, confirmed the assumption of diminishing benefit of having apartment close to the metro station in the case of the city centre.

CHAPTER 2 | THE FUNDING OF PUBLIC TRANSPORT INFRASTRUCTURES AND THE UNEVEN DISTRIBUTION OF GENERATED BENEFITS

Traditionally, there have been three main sources to finance urban infrastructure: savings of local governments – with general taxation and user fees as primary revenue sources -, grants from central government, along with supplemental methods including bonds, loans, public-private partnerships and concessions (Iacono et al., 2009). Each of these financing methods is now facing constraints. Local budgets are needed to run basic operating services and to maintain existing infrastructure. Central governments must limit grants to cities in the view of judicious fiscal management. Meanwhile, decentralization policies have moved service responsibilities downward, asking local governments to finance more of the urban capital budget with their own resources, but their local taxation revenue base is often insufficient, even just to request borrowings and fund urban infrastructure investment through debt. Furthermore, there is a growing reluctance among voters to pay higher taxes, while at the same time the operating costs of many services has increased, along with voters' expectations for amplified services (Alterman, 1988; Altshuler & Gómez-Ibáñez, 1994; Callies & Suarez, 2004; Nelson, Bowles, Juergensmeyer, & Nicholas, 2008; Rosenberg, 2006). There is a shared consensus that in the last twenty years Italian cities have faced heavy underinvestment concerning the provision of public infrastructure (Calafati, 2009), which began in 2004 and got even worse as an effect of the financial crisis of 2008 (Chiades & Mengotto, 2013; Cogno & Piazza, 2013). Between 2004 and 2012, local administrations' capital expenses have decreased by 34%, while those of just the major municipalities (accounting for over 60.000 inhabitants) have dropped by 63% (Camagni, 2014).

The concern about the increasing difficulties of the actual transportation system finance has grown over the years, while the resources to build, manage and maintain such systems have not grown correspondingly, causing the gap between costs and available resources to increase alarmingly. The ability of cities to finance the needed infrastructure provision partially depends on their ability to draw from another set of financing methods, with the aim of rebalancing the distribution of the land value uplifts between private and public sector, in favour of the latter – penalized thus far (Camagni, 2016). The set of financing methods is that of Land Value Capture (LVC), which consists on capturing a portion of the increment in property value gains resulting from a transportation improvement, to channel them into the provision of infrastructure finance (Peterson, 2009).

> *"Land Value Capture in general is a mechanism by which the agency responsible for the development of the urban transport infrastructure captures part of the financial benefits gained by land developers or the community at large. This benefit is reflected in an increase in the real property values, which can be regarded as a comprehensive index of all the benefits generated by the development, including improved accessibility and increase in business opportunities." (Farrell, Tsukada, & Kurawami, 1994)*

As the demand for land is a derived demand, its price depends on the potential benefits that it can generate for those who use it[2]. Public interventions (including those that allow transformation of land use from rural to urban, provide infrastructure, and permit higher development density) can all increase benefits for the properties impacted. This, in turn, can result in higher land prices. As this value uplift is generated solely by public decisions, investments and interventions, the public has the right to recover this value for the benefit of the community (Blanco et al., 2016).

In an age of extensive fiscal limitation, with the rising awareness that the cost of transport will not be sufficiently met by the existing financing and revenue generation methods, LVC and other alternative sources of capital for financing rapid transit that involve contributions from a range of public and private stakeholders have become increasingly attractive (Z. J. Zhao & Levinson, 2012). Land values are in fact highly sensitive to urban economic growth and infrastructure investment: *ceteris paribus*, or "all other variables held constant", housing units that are closer to public transport stations have a higher market value (Higgins & Kanaroglou, 2016; Iacono et al., 2009; Medda & Modelewska, 2009). This effect is explained by the lower cost of transport – expressed in time saved – to the main workplaces, leisure and service areas of the city, which converts into benefits that are directly capitalized into nearby land values and housing prices (Agostini & Palmucci, 2008). In fact, if transportation implies a cost for the user in terms of time

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[2] In urban economics literature, this concept is referred to as "the doctrine of the highest and best use": the market assigns the property to the use that generates the highest economic benefits, assuming that land is scarce and holding all other factors constant.

and individuals try to minimize such costs, an increase in accessibility due to a new transit line translates in improved locational qualities for the area along the transit line, and, more specifically, around its stations. The direct Land Value Uplift (LVU) generated by the construction of a new transit infrastructure can then pile up a variety of cascading positive effects which can all be priced into the urban land market, ranging from land use change (as more valuable land should, in theory, attract more intensive land use development), to a reduction in air pollution, to a pedestrian friendly Transit Oriented Development (TOD), to a higher-density mixed-use neighbourhood. Estimating LVU associated with the effects of transport developments is a crucial step for an evidence-driven policy analysis that must be able to demonstrate the robustness of its theoretical foundation in the direction of a fiscal reform which aims at introducing LVC methods as a new tool in the hands of the public sector. If it's proven that a transport infrastructure project generates positive externalities and that these effects are priced into the private land market, there is a claim for the public sector to recapture some of these LVU benefits, also referred to as the "unearned increment"[3], to partially fund the project through localized LVC policy tools (Higgins & Kanaroglou, 2016).

2.1 THE RATIONALE FOR LAND VALUE CAPTURE

Given the premises on the budget constraints that cities' administrations are facing, a key element to stimulate investment in transport infrastructure and attract investors is a conceptual shift about funding mechanisms. Land value capture finance (LVC) is a supplementary method of revenue generation for urban transport systems, which aims at recovering part or all the initial capital cost of the investment by capturing some or all the increase in land value (LVU) secondary to the increase in accessibility. The concept of LVC is sometimes referred to also as Land Value re-Capture, highlighting how this process aims at recovering an initial investment rather than capturing extra revenues. This shift can be realized by unlocking and enhancing urban assets based on their accessibility value, where accessibility is defined as "the extent to which land-use and transport systems enable individuals to reach activities or destinations by means of transport mode" (Geurs

[3] Any rise in land values – whether due to public decisions or to the general economy; stressing the fact that the rise is not due to the landowners' own initiatives and efforts. Used internationally (World Bank, UN, academic literature). (Alterman, 2012)

& van Wee, 2004). To investigate the potentials of LVC, it is necessary to incorporate accessibility within a framework of land value finance, where we can link the benefit of transport investment to its costs. Before focusing on the analysis of the different LVC methods that will be unveiled in the following paragraph, this section focuses on understanding why capturing unearned increments in land value can be an ethic solution.

Essentially, the value of land (total land value) is comprised by two components (Figure 5):

(A) The capitalized value determined by accessibility to natural and social resources in the city;

(B) The capitalized value of on-site improvements and constructions.

The capitalized land value of accessibility (A), which more broadly is the focus of this entire thesis, can further be understood as the aggregate value of three major components (Fensham & Gleeson, 2003):

(A.1) 'social' infrastructure paid for by government through tax and excise income (i.e. schools and hospitals, public transport, arterial road networks);

(A.2) 'private benefit' or 'development' infrastructure, that services individual properties paid for through local government levied user charges (i.e. local roads, reticulated water and sewerage, stormwater drainage, local parks);

(A.3) urban externalities (i.e. amenity and aspect, access to services, suppliers and markets).

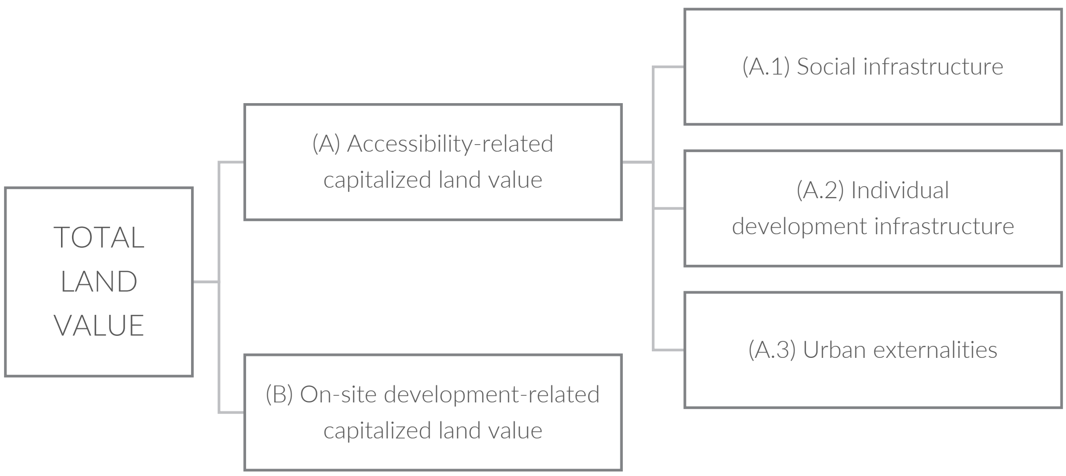

Figure 5. Total Land Value components and structure of the capitalized land value. Source: Medda (2012)

Intrinsic land value created in this way (A) represents an ‘economic surplus’ that arises independently of private landowners’ investment in on-site improvements (B). One of the main arguments addressing this as a major institutional failure of land markets is that surplus land value is a major and growing source of unearned income for certain economic actors, and acts as a profound cause of social and spatial inequalities. The origin of this reflection, still advocated by many economists to date, dates back to the 18th century, when the Scottish economist and philosopher Adam Smith (1776) first argued that position plays a crucial role in determining land rent value, identifying the cause being products’ transportation cost.

> *“The rent of land not only varies with its fertility, whatever be its produce, but with its situation, whatever be its fertility. Land in the neighbourhood of a town, gives a greater rent than land equally fertile in a distant part of the country. Though it may cost no more labour to cultivate the one than the other, it must always cost more to bring the produce of the distant land to market.”*
> (A. Smith, 1776)

Not only would his theory apply to agricultural land, but rather it was a first call to revise the relationship between public and collective effort in providing services and infrastructure on one side, and private revenue on the other.

> *“Both (urban) ground–rents and the ordinary rent of land are a species of revenue which the owner, in many cases, enjoys without any care or attention of his own. A part of this revenue should be taken from him in order to defray the expenses of the State.”*
> (A. Smith, 1776)

This assumption grew even more in popularity during the 19th century, when the attitudes toward land began to change with the wealth increasingly deriving from industrial production rather than agriculture. The philosopher and political economist John Stuart Mill, drawing on the work of David Ricardo, noted the disparity between the productive industrialist, whose wealth would generate from its abilities in managing industrial production, and the inactive landowner, whose land increased in value regardless of any input that he might make. Mill was the first who proposed the idea of taxing what came to be referred to as the “unearned increment”. Mill argued that it was totally suitable for the state to take all or part of the land value increase, because that value was being created by the state as a whole, adding that:

> *"[…] a land tax should not be regarded as a tax at all, but as a rent reserved from the beginning by the State, which has never belonged to or formed part of the income of the landlords."*
> (*Mill, 1848*)

Following on Mill's idea, Henry George, the political economist, argued that land taxes are equitable because the value of land is determined by community effort, not by individual effort:

> *"[…] public capturing of land values represents a taking by the community, for the use of the community, of that value which is the creation of the community."*
> *(George, 1879)*

Another great defender of this theory was the British politician Winston Churchill, who spoke in the House of Commons in 1909 putting this argument eloquently:

> *"Roads are made, streets are made, services are improved, electric light turns night into day, water is brought from reservoirs a hundred miles off in the mountains – and all the while the landlord sits still. Every one of those improvements is effected by the labour and cost of other people and the taxpayers. To not one of those improvements does the land monopolist, as a land monopolist, contribute, and yet by every one of them the value of his land is enhanced. He renders no service to the community, he contributes nothing to the general welfare, he contributes nothing to the process from which his own enrichment is derived."*
> *(Churchill, 1909)*

In more recent times, the evolution of this concept, particularly when related to the funding of public transit infrastructure, was theorized by Joseph Stiglitz (recipient of the Nobel Memorial Prize in Economic Sciences later in 2001) who formalized these elements into a theorem – the so-called Henry George theorem – in which he demonstrates that, under certain conditions, the total final revenue increase is equal to the total cost of a public asset (Stiglitz, 1977). This idea was stated most forcefully by Donald Shoup, who asked in his famous assertion on the urban underinvestment anomaly:

> *"Why is it so difficult to finance public infrastructure that increases the value of the serviced land by much more than the cost of the infrastructure itself?"*
> *(Shoup, 1994)*

The underlying rationale of the Smithian argument is still compelling to many, and it is often cited in support of the idea that the added value specifically created by land-use regulation and infrastructure improvement decisions should be shared with the public (Alterman, 2012). Nowadays, the indications of supranational agencies and international study centres are more and more oriented towards suggesting the local application of differentiated value recapture and value sharing practices.

> *"The unearned increment resulting from the rise in land values resulting from change in use of land, from public investment or decision, or due to general growth of the community must be subject to appropriate recapture by public bodies (the community), unless the situation calls for other additional measures such as new patterns of ownership, the general acquisition of land by public bodies"*
> *(UN-HABITAT, 1976)*

The recapture and a more equitable sharing of the LVU between private and public sector would trigger a cumulative virtuous circle: agglomeration advantages attract new activities and generate growth; growth generates revenues (company profits, wages and above all rents) from which it is possible to find the resources for the new public goods, infrastructures and services that further revive the growth process (Figure 6).

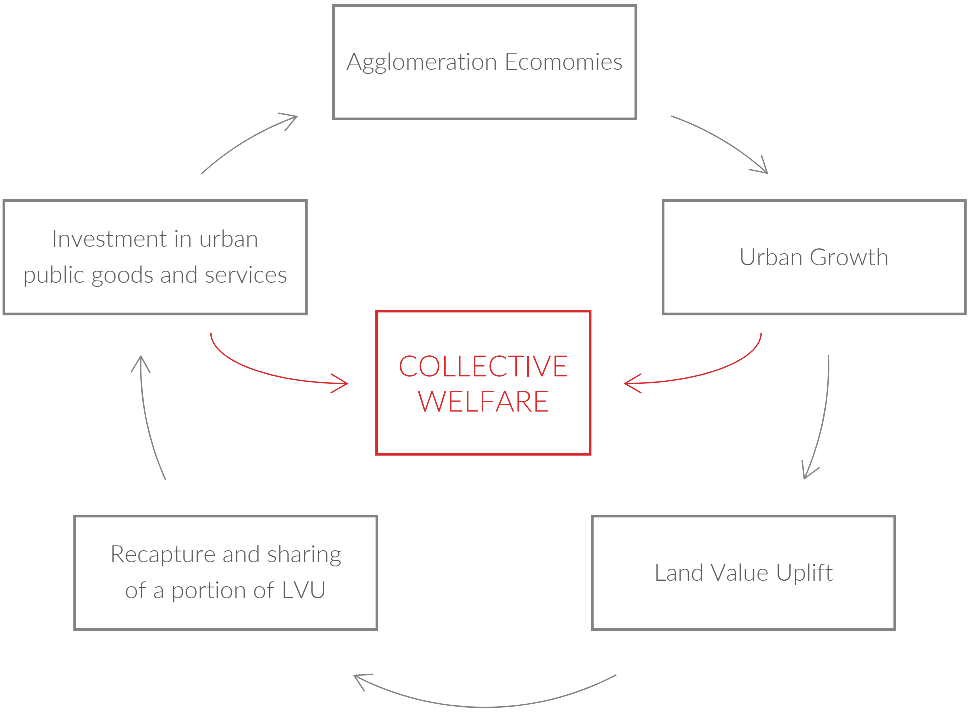

Figure 6. The virtuous circle of urban growth. Source: Camagni (2016)

2.2 The different levels of Land Value Capture fiscal policies

In practice, land value capture includes a range of mechanisms and policies, which various authorities implement and practice differently. All of these tools share one common goal, however: returning land value to the public.

Notwithstanding extensive academic literature and a long-established tradition and history of application, value capture remains an open-ended concept, variously defined and used. Some use the generic term value capture to cover any type of policy or legal instruments whose purpose is to tap any form of "unearned increment", regardless of the cause of the value rise. Others use the same term to denote only the policy instruments for capturing value arising directly from land-use regulation or public works (Alterman, 2012).

In this work, the objective is to analyse and deepen the understanding of the policy instruments and habits arising from both meanings of value capture, with the further goal of employing the most interesting findings for the case of Milan and the funding of its metro line extensions. As noted by Alterman (2012), value capture policies and instruments can be broadly divided in three main groups: macro, direct and indirect.

2.2.1 Macro value capture instruments

Macro value capture instruments occur to be embedded in some sort of overarching land policy regime, with a strong ideology to motivate them and the assumption that such regime can provide a better land and development policy than a market regime. The four major instruments, ordered by degree of intervention with private property, are:

1. Nationalization of all land
2. Substitution of private property by long-term public leaseholds
3. Land banking
4. Land readjustment.

Nationalization, after the decline of Communist regimes and failure of the underlying ideology, have been rejected in most countries.

Long-term public leaseholds substituting private property are only rarely proposed, and their prime purpose is not to capture the unearned increment anymore (Bourassa & Yu-Hung, 2003).

Differently from the previous two instruments, land banking does not negate private property: the government (often local authority) purchases land that is planned to be the object of a future urban expansion well in advance, supplies the infrastructure and leases or sells the land after its development. The sale or lease price incorporates the added value derived both from the right to develop the land and from the infrastructure provided. In the past, several central and north European countries have used this instrument extensively; however, since the 1990s, the proposal of land banking has been declining even in its bastion countries such as the Netherlands (Needham, 2007). The reasons reflect the same deep trends that have led governments to reduce their scope of direct action in many other spheres.

Lastly, land readjustment consists in a sophisticated and malleable tool that enables government authorities and landowners to collectively cooperate with the developers by pooling the land to accomplish a redevelopment project, reshuffling the current division of land plots. The investments in infrastructure and services undertaken on the pooled land are intended to increase the value of the properties in the redeveloped area; afterward, each landowner receives a smaller parcel of land that has greater value due to the improvements made, and new development rights. In one of the most successful examples of large-scale redevelopment in the 20th century, Japan's

Greater Tokyo Railway Network used land readjustment as a strategic component of its financing (Murakami, 2012). Despite its great promise, due to the complexity of its implementation, land readjustment also remains rare among advanced economies.

In all these land policy regimes, value capture is only one of several inspiring logics and goals. However, once the new land regime has been in place for a few years, it will likely develop its own economic and political dynamics, and value capture may be eroded. With time, it may be difficult to determine how much of the plus value in fact reaches the community. The linkage between these macro land policy regimes and value capture could become remote.

To summarize, three of the macro policies are echoes from past regimes and are unlikely to be revived today; the fourth one is the most interesting, yet it is rather cumbersome in practice and for this reason rarely proposed. This leaves more ground for the investigation of direct and indirect value capture instruments.

2.2.2 Direct value capture instruments

Instruments for direct value capture are policies whose goal is to capture all or some of the added value of a property under the explicit rationale that it is a legal or moral obligation for landowners to contribute a share of their community-derived wealth to the public pocket (Alterman, 2012).

Direct value capture is intended as a wealth redistribution instrument, hence often regarded as a tax which requires legislative authority. This rationale, of a tool that seeks to redistribute wealth, stands in its own right and does not need to seek any additional justification.

Following Alterman (2012) classification, direct value capture may be divided into two subtypes, and the second subtype is further divided into two subtypes (Figure 7):

(A) Capture of the unearned increment:
Where the value rise is not linked to a specific government decision but rather to general economic or community trends.

(B) Capture of betterment:
Where the value rise is directly caused by a specific government decision related to physical development.

The concept of betterment, too, may be further divided into two subtypes of decisions. Confusingly, both are often denoted by the same term: *betterment*.

(B.1) Betterment arising from public infrastructure works:
The value rise is due to positive externalities from a government decision to approve or execute public infrastructure, parks, or other services.

(B.2) Betterment arising from land use regulation:
The value rise is due to a land-use planning or development-control decision.

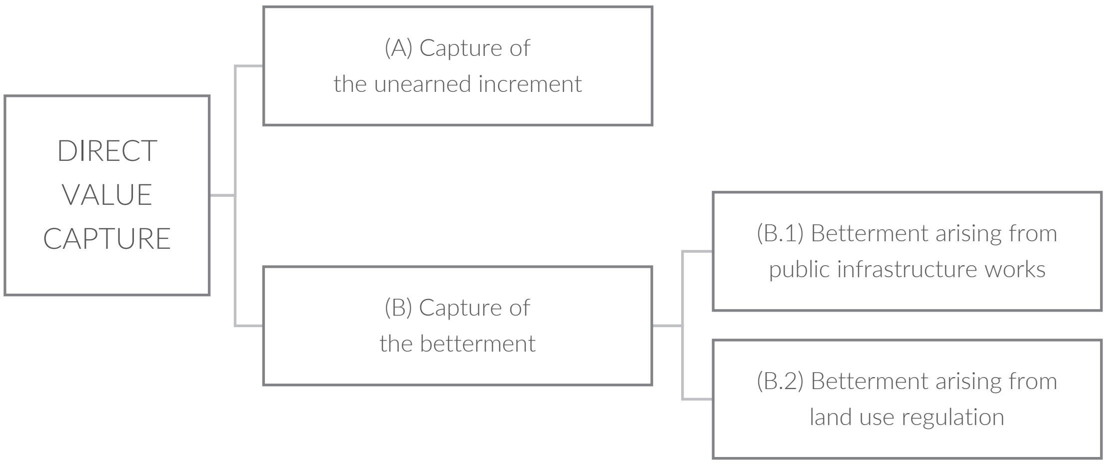

Figure 7. Types of direct value capture. Adapted from Alterman (2012)

Capture of the unearned increment (A) may take many forms, most usually as a tax. It can be proposed as a capital gains tax on land or real property, an unearned increment tax upon transfer of title, sometimes time-adjusted to curb speculation, or an annual property tax that is closely tuned to the rise in property values. Many are the countries that propose taxation of the unearned increment around the world, which can offer procedural standards. The USA host the examples provided by the states of Vermont and Pennsylvania (Daniels, Daniels, & Lapping, 1986; Gihring, 1999). Valuable experiences can also be found in Asia, more precisely in Taiwan (Lam & Tsui, 1998), Hong Kong, and Singapore (Hui, Ho, & Ho, 2004). For the purpose of this thesis, it does not seem necessary to further investigate and deepen this kind of value capture solution more extensively.

The infrastructure-based betterment capture instruments (B.1) are the oldest type of direct value capture method. Due to the fact that public works have always been a government duty, long before any land-use planning law, this kind of specific value capture tools were originally proposed to capture value increases in properties neighbouring newly built public infrastructure. As many authors highlight (Alterman, 2012; Booth, 2012; Iacono et al., 2009) linking value rise to the execution of public works is not easy. The reasons are many, and include: difficulties of demonstrating the causal relationship to the infrastructure works; difficulties in defining the geographic extension of the value rise impact; and difficulties in levying the charge at a time frame reasonably close to the completing of the infrastructure, because the capitalization has usually not yet occurred at that point in time. Yet this idea never completely faded, nor did it get abandoned. In fact, there are plenty of examples of explorative researches and reports coming from the recent years: in 2004 the Scottish government commissioned a report on whether betterment could be captured from value increase directly due to new transport facilities (GVA Grimley, 2004); scholars like Peterson (2009), who wrote for the World Bank, and Medda (2010), who participated in a conference titled "*Financing affordable housing and infrastructure in cities: towards innovative land and property taxation*", reported on similar initiatives in both developing countries and more advanced economies. Initiatives of this kind are unrelated to capture of betterment based on land use regulation and find their rationale only in capturing the infrastructure-based betterment value. Despite the difficulties in applicating such ideas, more recently even the United Nations suggested exploring these hypothesis to help the funding of future cities' infrastructures, especially in developing countries where the public authority has limited capital savings (UNECE, 2017).

Betterment capture policies modelled on land-use regulations (B.2) may target different land-use planning and development-control decisions. In most cases, administrations target only a few of the procedural steps that link an empty plot of land to its final built aspect, is to say either in the planning or in the permitting process. This kind of value capture policies are applied in many countries all around the world, with different cultural background and juridical structure. Among the most advanced and with a longer dating use of such technique, countries like the United Kingdom, Israel and Poland lead the rest, comprising of Australia, Austria, Canada, Finland, France, Germany, Greece, the Netherlands, Sweden, and the United States (Alterman, 2010). If well implemented, one of the key features and the greatest outcomes of re-capturing the added value at an early stage is the ability to obtain such land value uplift directly from the developer – which is the real gainer of the process – rather than from the future property owner. As highlighted by Camagni (2016) in fact, real estate contractors are the category that most decisively gains from the building process when there is a lack of an adequate and fair fiscal system.

2.2.3 Indirect value capture instruments

Indirect value capture instruments are radically different from the macro and direct ones concerning the rationale motivating them. In fact, they do not seek to capture the added value simply because it is unearned, but rather to generate revenues for specific public services. Their goal is usually more pragmatic and less ideological. Furthermore, they are usually practiced at a local government level, making them an easier, more flexible solution in terms of fiscal administration, and an ever-evolving category of policies that varies greatly among countries and localities (Alterman, 2010). In order to fight legal and political challenge, indirect value capture instruments are proposed and applied across countries under a set or combinations of different rationales (Healey, Purdue, & Ennis, 1996):

- Cost recovery: indemnification of direct public investments public services made necessary at the particular project. In cases where the law requires that a direct betterment levy be capped at the cost of public services, the instrument becomes a hybrid between direct and indirect value capture (the recent English Community Infrastructure Levy has this rationale).
- Shortage of resources for various public services within or beyond the project area.
- Internalization of negative externalities such as noise, radiation, or pollution caused by the project.
- Mitigation of impacts on the natural environment or on historic buildings.
- Mitigation of perceived social injustices such as social exclusion or higher housing prices.

Daily application of indirect instruments is often ambiguous about which of the different rationales is being applied in a specific case. Indirect instruments are also heterogeneous in how the contribution is delivered and which beneficiaries are targeted for contribution: some are in money, others in kind whereby the developer constructs a public service, delivers mitigating technologies, supplies land, or builds housing. The next paragraph identifies and analyses the different indirect value capture instruments, focusing on the targeted beneficiaries.

Because the indirect instruments are usually locally determined and may not require explicit legislation, they have several advantages over direct betterment capture:

- They can more easily go under the radar of party-political debates and can therefore better survive changes in party ideology and voter resistance to new taxes.
- They can more easily be justified to the project's consumers and to the general public if they can be linked to the burden that the project places on the public.
- They are more flexible for financing changing public needs because they are usually applied only when development is ripe.
- They can be fine-tuned to be politically more acceptable when socio-political positions change in the community
- They may be adjusted to accommodate the changing economics of real estate so as not to drive away development.

Yet, indirect capture instruments are not a panacea. They are often applied case by case, without ensuring equality among landowners. These instruments are therefore open to political and legal challenges regarding bias and favouritism (Alterman, 2010).

2.3 Land Value Capture, tools and experiences

To better understand where all the different value capture policies that are applied around the globe can be placed in a conceptual framework of transportation finance, this section focuses on their classification. The aim is to review the main methods based on accessibility that allow for the capture of the windfall from an increase in land value.

The first part of the section identifies the relationship between the different beneficiaries that, directly or indirectly, benefit from the construction of a new transport infrastructure and the tools and policies applied for the recapture of the value uplifts. In the second part, the most significant among such policies are deepened in a more systematic and detailed manner, together with real life application examples. The ultimate goal is to provide a solid theoretical ground acting as a base camp for decision makers who want to make direct application or further use of the LVC know-how resulting from the set of experiences.

2.3.1 The different targets of Land Value Capture

According to the principle that the cost of transportation for a contributor should be proportional to the benefits received, a variety of transportation finance tools may be considered to match the different categories of transportation beneficiaries with the different ways of assessing such benefits: Table 1 shows how, after identifying different sets of beneficiaries, namely:

- The general public
- Restricted non-user beneficiaries
- Users of transportation infrastructure

specific finance instruments can be designed to match unique combinations of types of benefits and types of costs to be recovered.

As a general deduction, improvements in transportation infrastructure generate benefits for the community as a whole, because upgraded infrastructure may bring general economic or social gains which are consequently highlighted by – and capitalized through – the general tax base growth. This is the reason behind the common practice of financing transportation projects through the allocation of government general funds – from all levels of government: national, regional and local – that come from the general tax base. Isolating this "general benefit", however, is hard to do in practice, since it is nearly impossible to separate the general public benefit from the individual benefits received by the population.

At the other end of the spectrum, users of transportation facilities – namely, transit passengers – are those who enjoy the direct benefits of a transportation investment. Given the ease of isolating this group of beneficiaries, special revenues for transportation can be implemented: tickets, fares or permits fall under this category, representing both the easiest tool to think of and the most widely applied. The generated revenues from transit passengers' tickets are mainly utilized to run operation and maintenance cost, while only a small portion can be used to partially recover initial capital costs, making this financing solution insufficient to fully finance and develop a public transit infrastructure project. As noted by Iacono et al. (2009), the intermediate category between the general public and transit passengers identifies a restricted set of beneficiaries that experience sustained location-based value from transit upkeep, gaining added benefits from the construction of new transit.

Beneficiaries		Measurement of Benefits	Transportation Finance Instruments	Associated Cost Recovery	
				Capital cost	O & M Cost
General public		General tax base growth	General fund allocation; Earmarked property tax; Transportation sales tax.	Fully	Fully
Restricted non-user beneficiaries	Property owners	Land-value growth	Land-value Taxes	Fully	Fully
		Assessed special benefits	Betterment Levies / Special Assessment Districts (SAD)	Fully	Partially
		Property tax growth	Tax Increment Financing (TIF)	Fully	Partially
		Transportation utility	Transportation Utility Fees (TUF)	Partially	Fully
	Developers	Off-site development opportunities	Development Impact Fees (DIF)	Fully	Partially
		Off-site benefits	Negotiated Exactions	Fully	No coverage
		On- or off-site development privileges	Joint Development (JD)	Fully	Partially
		On-site development opportunities	Air rights	Fully	Partially
Users of transportation facilities	Transit passengers	Ridership	Fare, ticket or permits	Partially	Fully

Table 1. Land value capture instruments by beneficiaries. Source: Iacono et al. (2009)

This value goes over and above the one which they derive either as part of the larger general public or as riders, and, most importantly, these beneficiaries often do not contribute to paying for the costs of the infrastructure or service in proportion to the benefit they receive. Location value capture mechanisms allow these location beneficiaries of transit to help pay for it. The subset is composed by property owners and developers, who appreciate different land value uplift associated benefits, which are capitalized in different moments and which can be targeted for specifically designed value capture financing tools.

Particularly, for the subset of property owners, whose land value gains can be measured in different ways, to date there is a variety of land value capture strategies that can be applied:

- Land-Value Taxes (LVT), also referred to as split-rate property taxes, may be levied to capture the general increase in the price of land created by the provision of public transport facility and its related enhanced accessibility. LVT assesses land value rather than property value and focuses on landowners.

- Betterment Levies and Special Assessments financing (also referred to as Betterment Tax) may be levied if the direct benefits for some properties due to transportation improvements can be clearly identified and measured within a Special Assessment District (SAD);
- Tax Incremental Financing (TIF) may be used because improved transportation facilities will contribute to the growth of property tax within a TIF district;
- Transportation Utility Fees (TUF) may be collected if the utility of transportation improvements is measured with the proxy of property types or sizes.

Regarding developers, aiming to capture the value of enhanced development rights:

- Development Impact Fees (DIF) or impact taxes pay for enhanced off-site infrastructure;
- Negotiated Exactions (NE) require developers forfeit part of their lands in exchange of the off-site transportation benefits; or
- Joint Development (JD) involves collaboration with the public sector to simultaneously improve transportation while developing land;
- Air Rights (AR) allow development on top of existing or new transportation facilities in exchange for a financial contribution or future additional property and income taxes;

It is important to highlight that transit network improvements may create value in many different ways simultaneously, and, depending on the fiscal strategy, multiple instruments of value capture can be jointly applied. Furthermore, it is important to understand that it is not necessarily desirable for the public authority to capture all of the location-based benefit of transit (Salon, Sclar, & Barone, 2019). In fact, it is in the interest of both the transit agency and the city to leave some windfall value on the table to incentivize developers to construct higher density development near transit. In Paris the newspaper Le Monde criticized a recent plan for attempting to capture so much of the value that it might depress development (Jérôme, 2014).

Finally, the last column of Table 1 shows the suitable cost types that can be financed by each transportation finance instrument. Ideally, cost types should be matched with the timing of transportation benefits. Typically, direct users of transportation facilities receive the bulk of their benefits through the use of facilities, and thus the corresponding special revenues are most suitable for operation and management (O&M) costs. The growth of general tax base occurs through the life cycle of a transportation facility, and thus the corresponding general fund revenues are suitable for both capital cost and O&M cost. For value capture beneficiaries (property owners and developers), their value gains due to enhanced locational advantages are mostly realized upon the completion of transportation facilities, and so the corresponding value capture strategies may be used more often for capital cost. For example, negotiated exactions are typically used for the capital cost only as a way to reduce the fixed-cost for the right-of-way. Transportation Utility Fees, however, are more closely related to the daily usage of facilities and thus TUF may be more suitable for O&M cost. It should be noted that any financial instrument can be used for any a cost occurring at any time with appropriate planning and use of debt and annuity instruments. An agency could use ongoing revenue to pay back debt acquired to pay for capital costs, or could charge a one-time fee to fund an annuity to pay for ongoing costs. This is somewhat more complicated than the pay-as-you-go mechanism many jurisdictions prefer to reduce transaction and interest costs, and also dissociates benefits from costs (Iacono et al., 2009).

2.3.2 Land Value Capture policies and their application around the world

In this section some of most interesting solutions among the many value capture policies are explained more thoroughly. A specific attention is given to those policies that are seen as potential candidates for a future application in the city of Milan, mainly focusing on the techniques that would enable the recovery of the initial capital investments needed to update and further expand the provision of efficient public transport infrastructure in the city.

Land Value Tax (LVT)

Land Value taxes are generally aimed at capturing the value created by the provision of public services and goods, including increased accessibility generated by the improvement of transit infrastructure. Conventionally, property and land are taxed simultaneously through the property tax. Taxing land and property together, though, presents some limitations, and a better solution would be to separate the tax on land from the tax on improvements: buildings' value is based on the effort and expense the owners have incurred to construct them, while – as we have seen – the parcel of land underneath the building has a value based on surrounding improvements the community as a whole has made. Raising the tax on land allows the community to keep a greater portion of the value generated, while corresponding decrease in the tax on improvements allows property owners to keep more of the value they have created for themselves. As noted by Iacono et al. (2009), under a conventional property tax mechanism, owners have a disincentive to improve their property, since doing so would be reflected in higher property taxes, while they are able to benefit at the expense of the community when their land value increases based on infrastructure projects or improvements to nearby properties. If the levy on land itself were increased, land owners would have an incentive to develop their property for the highest and best economic purpose. This theoretically would discourage the speculative holding of vacant parcels, as the higher tax would cause owners to develop or sell to someone who would. With a corresponding decrease in the levy on buildings, property owners would be able to commit more funds toward development, without having to account for as great a rise in property tax. Thus, urban development would occur in a more orderly, compact way, and would be less likely to skip over parcels held out of development in speculation. A tax on buildings is considered distortionary because it reduces the quantity of building from that which would occur in a free, untaxed market. As shown in the first chart of Figure 8, taxing buildings causes the demand for their construction to decrease by the amount of the tax. Building supply then meets demand at a lower price point, and part of the tax burden falls on the producers of buildings. In contrast, a tax on land is not distortionary because the supply of land cannot change in response to a higher tax rate. As the second chart indicates, a tax on land will cause the demand for land to decrease by the amount of the tax but

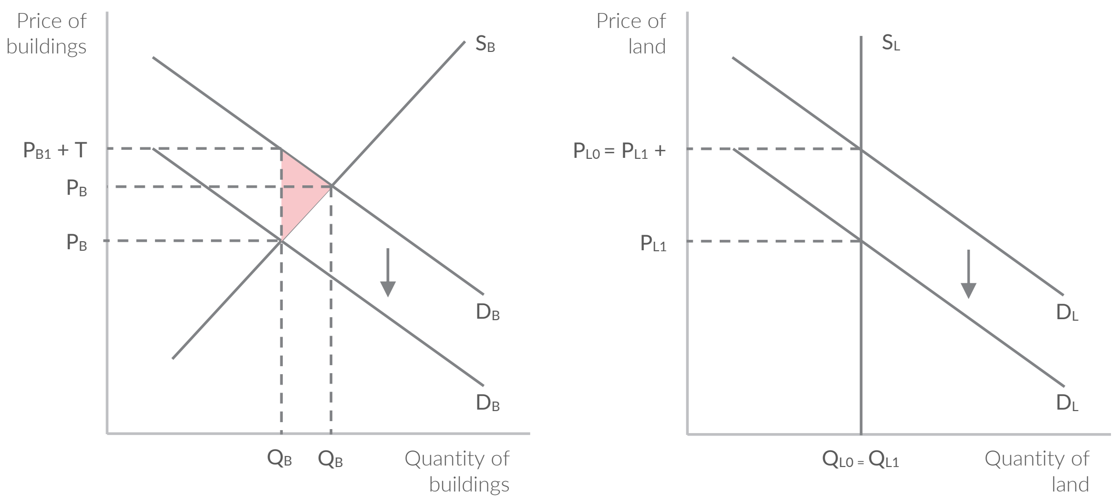

Figure 8. Effects of the tax on improvements and of the tax on land. With a tax on buildings, demand decreases, causing price and then supply to decrease. On the contrary, the supply of land is perfectly inelastic and remains constant: if land is taxed, demand decreases, causing lower prices. Source: King & Nesbit (2007)

not the supply, resulting in lower land prices. Reducing the tax on buildings improves efficiency, while raising the tax on land to maintain revenue neutrality does not cause a corresponding efficiency loss.

Taxing land values separately from the value of the built property (also known as the "split-rate" property tax) was first theorized by Adam Smith back in 1776:

> *"Ground–rents are a still more proper subject of taxation than the rent of houses. A tax upon ground–rents would not raise the rents of houses. It would fall altogether upon the owner of the ground–rent, who acts always as a monopolist, and exacts the greatest rent which can be got for the use of his ground."*
> (A. Smith, 1776)

Since then, a number of administrations have embarked in the application of a split-rate tax, in which land and buildings are valued and taxed separately.

Currently in Italy a conventional tax on both land and building is applied, with the name of IMU (Imposta Municipale Unica), and – given the prerequisite of owning a building, building land or agricultural land – it is due to the municipal administration. With the law 147/2013, the tax is abolished for any "main residence" without any logical rationale (Camagni, 2016), with the exclusion of those classified with the cadastral category A/1 Stately homes, A/8 Villa and A/9 Castle or palace with artistic or historical value.

Iacono et al. (2009) explain that at a local level – where it would not be expected to serve as a replacement for national income or state sales taxes – taxing land and improvements separately is a viable alternative. The split-rate tax could be levied at a rate that allowed landowners to retain a portion of the profit from their holdings. The land tax rate could be high enough to allow the tax on buildings to be eliminated, or the tax on buildings could be maintained at a lower rate. The differential between land and building tax rates under such a split-rate tax can, and has, varied widely with each application. A differential of zero would amount to a conventional property tax, and a pure land tax can be thought of as a split tax with a rate differential of 100%.

The land value tax is most often used at the municipal level, because local governments levy the majority of property taxes and have the most control over the regulation of land use. For administrative and political reasons, it is easier to implement a land tax in place of a property tax than a sales or income tax. Existing land value taxes have not been targeted toward transportation funding specifically, but were envisioned simply as an additional way to raise revenue and facilitate development. The area encompassed by the tax would necessarily be somewhat large, and as it decreases, the land tax jurisdiction begins to more closely resemble a special assessment district. At the local level, split-rate property taxes have been extensively studied, especially since the 1970s when Pittsburgh revised its tax code and many of the other cities with a split-rate tax first enacted it. In a paper by Dimasi (1987), increasing the land rate relative to the building rate was found to decrease rents and housing prices both overall and in each development ring, and increase population density at all distances from the city centre. Resident welfare in terms of affordable housing and wage level was found to optimize when land was taxed at three times the rate on improvements (a 75% rate differential).

In their thorough analysis of land value taxes, the authors conclude that pure land value taxation is more effective than conventional property tax at capturing value accruing to a property from external sources, while leaving the portion of value created by the efforts of the owner untaxed. A split-rate tax is a less drastic step toward this goal. It relates the costs of community improvements more closely to the benefits than the conventional property tax, although the conventional tax is a better reflection of a landowner's ability to pay. Applied to transportation projects, the owners of adjacent parcels would pay a larger share of the costs of infrastructure improvements than the owners of faraway properties that would benefit less.

The success of land value taxation as a value capture strategy depends on several factors. The efficiency must be evaluated in terms of the effects on economic development and the connection between the benefits realized and the costs borne. Measurements of the distribution of the costs and benefits among geographic areas and demographic groups can be used to indicate whether the system treats all members of the community equitably. The amount of revenue generated can be evaluated as a proportion of value captured and as a proportion of costs recovered, and can be compared to the cost of the project to determine adequacy.

The political and administrative feasibility also must be addressed, less as measures of effectiveness than as potential barriers. As long as assessments are kept up to date, the increased value would be automatically captured in the property tax bill and no additional fees would need to be assessed. Maintaining the assessments accurately and updating them frequently are the largest barriers to successful land value taxation, as the value of land independent from any developments is difficult to determine. Public acceptance is most likely if the split-rate tax is phased in gradually and does not coincide with a tax increase. Additionally, such a change in tax strategy may be more attractive to the public if it is proposed in conjunction with a specific infrastructure improvement project. More detailed research and analysis would need to be conducted in any location considering such a switch to determine accurate land values on which to base the tax, and to establish who the winners and losers of the shift would be.

Summarizing, a pure tax on land is possible, though rarely used. While land value taxes are desirable from the standpoint of economic efficiency and sustainability, they would most likely be slightly regressive in terms of ability-to-pay. Further, land value taxes may prove politically challenging due to high visibility and potential unpopularity (Iacono et al., 2009).

Betterment Levies and Special Assessment Districts

Betterment Levies (in the UK) and Special Assessment Districts (in the USA) are among the most straight-forward policies in trying to apply the Land Value Capture principles. They consist in a "compulsory charge imposed by a government on the owners of a selected group of properties to defray, in whole or in part, the cost of a specific improvement or services that is presumed to be of general benefit to the public and of special benefit to the owners of such properties" (IAAO, 1997).

When the British enacted the first national town planning act in 1909, they embedded in it an infrastructure-based betterment levy, and, until the early 1980s, Britain exhibited pendulum-like shifts in policies about compensation and betterment as power changed hands between Labor and the Conservatives (Alterman, 2012). The various policies adopted and repealed represent a large range of rates of recoupment, all addressed to fund the central government: from the 50 percent levy on betterment arising from the approval of a land-use plan of the 1909, to the 100 percent of the post-World War II "development charge", abolished in 1953 by the Tories and supplanted in 1967 by a 40 percent betterment-like levy when the Labor returned to power until 1971. The 1976 Development Land Tax act (DLT) instituted an 80 percent charge on the betterment value, and this time the municipalities were allowed to keep some of the tax revenues, but most still went to central government. Lastly, in 2004 the Labor government commissioned the Barker Report, which recommended reintroduction of a mandatory national betterment levy to be called the Planning Gain Supplement that would have captured 20 percent of the increase in land values resulting from the grant of planning permission.

This set of policies has also been adopted in Spain, Argentina, Colombia and, more generally, most Latin American countries, where a similar solution called "contribución por mejoras" was adopted. Despite betterment levies being broadly considered impractical, technically cumbersome, beyond local capacity to implement, and unpopular, the Colombian case represents a positive example and contradicts these allegations, suggesting that the resistance is grounded more on prejudice, ideology, or lack of information. This instrument not only has a long history of continued (albeit irregular) application, but also a record of raising substantive revenues to fund public works. Bogotá currently has about $1 billion worth of investment in public works from this levy, and eight other smaller cities combined have another $1 billion (Borrero Ochoa, 2011). In more recent years, other nations like Israel and Poland have adopted similar strategies and have recurred to policies aiming to capture the betterment (Alterman, 2012).

In the USA, Special Assessment District (SAD) are widely applied with the aim of capturing revenues to improve public infrastructure in a specific district, where – on top of the usual property tax – an additional special levy is imposed on the value uplift generated by the new infrastructure. During the 1980s, Southern California Regional Transit District (SCRTD), now the Los Angeles Metropolitan Transit Authority (LAMTA), used SADs around four metro stations to finance their construction (Rolon, 2008). In Miami and Tampa, SADs helped finance a portion of their downtown people mover systems (US Department of Transportation, 1984). Through the 1990s, SADs remained a viable strategy for financing rail stations, with the opening of the New York Avenue Metro station in Washington, DC in 2000 (Iacono et al., 2009). More recently, cities such as Seattle, Portland and Charlotte have used special assessment districts along urban corridors to finance streetcar and light rail infrastructure.

Tax Increment Financing (TIF)

Another LVC solution is represented by Tax Increment Financing (TIF), which is aimed at capturing the value of benefits received by property owners due to the improvements received by a neighbourhood or an area of the city. Public improvements, such as development of a business park, better highway access, or improved transit infrastructure, tend to cause the property value within the district to rise over time. These rising property values also result in increased property tax receipts (Weber & Goddeeris, 2007). TIF anticipates the use of these future increases in property taxes generated by new development to finance the initial costs of the development itself: this assumption underlines the two founding concepts of TIF.

The first principle is the use of property tax increments to capture the value of investments made in an area. Importantly to note, the property tax increment is created by the growth in the assessed property value or business activity caused by the improvement in the area, and not through an increase in property tax rates. As the total assessed property value in a TIF district rises above a fixed baseline, the tax on the difference between the new and the baseline assessed values (incremental tax revenue) is diverted to pay for the public sector improvements made within the TIF district and to stimulate private investment (B. Smith, 2006). The public improvements are paid for through debt issued by the public sector (municipalities or local development authorities), which is repaid using the increment in tax revenues within the designated area.

The second principle is the use of future property tax revenues resulting from a development that would not occur otherwise. This enables local governments to either pay for improvements to a site designated for TIF activities themselves or subsidize developers to make these improvements and use the future growth in property tax revenues to pay off the ongoing economic development expenditures (Weber & Goddeeris, 2007).

As highlighted by Iacono et al. (2009), TIF finds its support in the basic tenets of microeconomics, which theorize that the incentives given through TIF result in higher property values. From a developer's perspective, investments and risks associated with development are only justified if the initial investments are low or if estimated returns outweigh the investments. TIF reduces initial private sector investment through incentives such as site preparation, which increase the returns on investment in such areas and boosts demand for property in the area.

Weber & Goddeeris (2007) point out that TIF is essentially a tool for harnessing future revenues to pay for current expenditures. It is a reallocation of property tax revenues from a city's general fund to a smaller, more local jurisdiction. TIF is often misunderstood as having an additional tax burden associated with it. However, residents and property owners in the area where TIF is implemented pay only their normal tax burden. Weber & Goddeeris (2007)further argue that all property owners within the district may benefit from the TIF-financed infrastructure improvements. TIF is also considered a self-financing method to pay for development projects as it uses increases in property tax revenues arising from the new development's future, and presumably higher value to finance the project. Therefore, government officials need not impose a new tax and can instead use their local tax base to generate development by reallocating local revenues. Once the accumulated debt is extinguished, the TIF tool ceases to exist and the additional revenue generated by the project gets capitalized and shared by both the private owners and the public sector through an adapted property tax system.

This tool seems very appealing in theory but presents some limitations in practice. First and foremost, to avoid that a municipality utilizes TIF not for the necessary development of a project or an area but simply because it is forecasted that property values will rise in the future, it is required that the local government endorses that no growth is expected "but for" the use of TIF: it is then difficult to demonstrate the causality between the latter statement and the effective future happenings, and this opens up to political issues and legal disputes (Dye & Merriman, 2000). Furthermore, geographical restrictions are needed to ensure that benefits generated from the TIF district accrue to the appropriate stakeholders and do not disproportionately benefit those outside the TIF district's boundaries, nor do they unduly limit benefits to a narrow area. This particular issue makes this tool particularly effective when the investment occurs in an homogeneous and easily definable neighbourhood or zone.

However, when well designed and implemented, TIF has proven to be a successful strategy in generating significant amount of revenues to fund projects. In the USA, the city of Minneapolis and Chicago were able to generate enough revenue not only for project construction or improvement but also for operation and maintenance.

Development Impact Fees and Negotiated Exactions

In the second group of LVC policies, the one addressing the issue of capturing the value of enhanced development rights from developers, a variety of different methods is available. Development Impact Fees and Negotiated Exactions are two of them and can be found under the combined name of Development Exactions. They consist in monetary exactions charged to a developer as a condition of approval for a development project, with the aim of addressing a share of the off-site infrastructure costs to the new development. Development exactions are a value capture solution that recover the cost new development imposes on the transportation system through the beneficiary-pays principle, internalizing the costs of new development on the transportation system. The result is that the cost of new infrastructure is apportioned to developers of new housing or commercial space, so they pay their way for access to the system. In this way, developers are required to contribute to public facilities, relieving local governments of pressure to provide infrastructure to serve new development (Iacono et al., 2009). Exactions are imposed during the development review process and determine how the developer should fund, build, and/or dedicate facilities required for their new tenants. Developers have come to accept these exactions as a part of the development process (Frank & Rhodes, 1987).

Impact fees are used in areas formalized by a state-enabling act, while negotiated exactions are agreements between local jurisdictions and developers (Iacono et al., 2009). Impact fees are one-time, predetermined assessments levied on new development to offset the impact of the development on the capital cost of providing regional services and infrastructure. Negotiated exactions are contributions from a private entity to provide land or facilities to serve public infrastructure needs created by new development and are made as a condition of approval. Negotiated exactions are based on the power of political stakeholders while impact fees are objectively based on quantitative criteria. The political negotiation process that underlies negotiated exactions is flexible and does not imply a specific outcome: both developers and public officials may exert power during the negotiation process depending on financial, legal, regulatory, and/or public requirements. This political influence in negotiation make the results of negotiated exactions uncertain, and the share of costs recovered from this process is subject to political considerations. Impact fees in contrast are formulaic and the value of cost recovery is recognized by standard criteria (Frank & Rhodes, 1987). Because impact fees are based on formulas while negotiated exactions vary, impact fees promote transparent government policies that are standard depending on the type of structure built. For this and other reasons, Impact Fees are found predictable and practical cost-recovery mechanisms for new development (Iacono et al., 2009).

Joint Development

Joint Development is a public-private partnership designed to decrease the costs of constructing or operating public transportation improvements through creative public-private financing arrangements (National Council for Urban Economic Development, 1989), and, focusing on public transit, can further be defined as a formal agreement or arrangement between a public transit agency and a private individual or organization that involves either private sector paying to the public sector or private sector sharing capital costs with the public sector, in mutual recognition of the enhanced real-estate development potential created by using a public transit facility (Landis, Cervero, & Hall, 1991). Joint Development falls under the cap of value capture strategies because private benefits created through infrastructure improvements are partially captured through explicit joint development agreements to support the initial cost of the improvements. In this sense, successful joint development projects may help alleviate funding shortages and may improve market efficiency by better linking costs and benefits of transportation improvements (Z. J. Zhao, Das, & Larson, 2012).

Theoretically, joint development may be applicable to all types of transportation improvement that lead to higher property values or enhanced development potential. However, most examples in the literature pertain to public transit or urban roads in high-density development areas, where land value impacts are easier to identify (Z. J. Zhao et al., 2012). Options to increase private contribution, such as joint development, are viewed as important ways to decrease project costs, mitigate public risk, and increase the quality of transportation infrastructure (US Department of Transportation, 2004).

Joint Development has found a particularly fertile environment in Asia, where it has been most widely used in the construction of public transport facilities. In Hong Kong for example, the Metropolitan Transit Railway Corporation (MTRC) uses a joint development method they call the rail-property (R+P) model. Using this model, MTRC purchases development rights from the Hong Kong Government (the majority shareholder of MTRC) at a “before rail” price, and sells these rights to a selected developer at an “after rail,” and significantly higher, price. The difference between the “before rail” and “after rail” price covers the cost of railway investments. In this way, MTRC takes advantage of market-driven property appreciation to finance railway services (Robert Cervero & Murakami, 2008; Hong & Lam, 1998).

A land readjustment version of the joint development is employed in Japan. After organizing property owners into a cooperative, a development agency – that can either be public or private – is authorized to develop the properties, with the agreement to return smaller but fully serviced parcels to the landowners when the development is complete. This can also include transportation infrastructure projects. To compensate for the development services, the developer then retains a part of the new property parcels. In Tokyo, Tokyu Corporation, a private railway operator and real estate developer, completed the Tama Den-en Toshi development, a planned community serviced by a rail line, using the land readjustment model. Tokyu Corporation and its affiliated companies then promoted the area's development through selling land, constructing housing, and attracting shopping centers and schools. The project is viewed as one of the most successful land development initiatives undertaken by a private Japanese company, requiring no direct government subsidy (Farrell et al., 1994; Kuranami, Winston, Kimura, & Rose, 2000; Tsukada & Kuranami, 1990).

To conclude, this section has covered the description of the most interesting land value capture solutions, with the intention of highlighting the complexity and the depth of the fiscal side of the issue. However, if the intention was to propose a fiscal reform, each policy should be further analysed to fully comprehend the practical functioning, the potential, the limits and the opportunities that each of them underpins. In fact, all of the instruments, policies, taxes and fees that have been described in this section, when well designed, directly incorporate market principles of financing and support efficient operation of the urban land market. When poorly designed, on the contrary, they can distort both financial and land markets or become means of circumventing the market entirely in favour of direct planning solutions or private financial deals.

CHAPTER 3 | THE CASE STUDY

The Metropolitan city of Milan is Italy's most thriving and successful urban area. Thanks to its favourable location and geographical characteristics, the city was able to develop from being a highly productive agricultural land in the middle age and renaissance period, to an industrial city between the eighteenth and twentieth centuries, to a financial and service sector metropolitan city well integrated in the contemporary globalized economy.

Its capacity to attract young professionals and, more generally, workers seeking for better opportunities, both from nearby towns and further regions, does not surprise: the city acts as a catalyst for inward flows of commuters and new residents, thereby generating an increasing demand of transportation and housing.

Furthermore, the widening of the workforce's area of origin has resulted in increased distance between place of residence, work and basic services (most importantly among others, education and health), resulting in increased travel distance, congestion and travel time on one side, and increased demand for urban and suburban provision of transit infrastructure and public transport on the other.

3.1 MILANO AND ITS TRANSIT SYSTEM

To answer this need, the city of Milan offers its citizens a dense public transport system, essentially based on city buses, trams, the metro and regional scale trains. If buses and trams can be considered the fine-grain level of public transport, whereas regional trains, on the other side, the rough-grain level of interconnection with the metropolitan area, then the metro system undoubtfully plays the role of connecting those two elements inside the urban sphere, with an eye on the peripheries and a strong linkage with the most important cultural and financial nodes of the city.

As we mentioned, bus and trams cover and connect most of the urban area, but with specific conditions to respect and characteristics that hence occur: their routes and stops are usually calibrated at a neighbourhood scale in a way that stops are located every 150-200 m one from another. This condition enhances the specific capillarity of reach of this mean of transportation, maximizing the coverage area, but with the drawback of reducing the relative speed of travel, hence increasing time travel and reducing the ratio of travelled distance/time. Furthermore, in the case of buses without a dedicated lane (which represent the vast majority in the city of Milan, especially in the peripheries), the need to share the road with a multitude of private vehicles makes public transport vulnerable to delays caused by traffic congestion, especially during peak hours, which represents a daily trend all across the city.

To try and mitigate this long-standing condition and improve overall transport efficiency, over the past few decades Regione Lombardia (the administrative body in charge of the regional government) has developed and financed a well-integrated system of suburban trains that connect the city of Milan with all the surrounding municipalities, with the aim of reducing the share of regional commuters driving private vehicles on the urban city streets. The core and the flagship of the suburban train system is represented by the "passante ferroviario" (Figure 9), an underground railway connecting the north-west side of the city with the east side which is used by six different suburban lines (S1, S2, S5, S6, S12 and S13). Obviously though, the suburban train system is mostly aimed at metropolitan scale travels, with the rare exception of urban trips that find their origin and destination along the "passante ferroviario" urban stations.

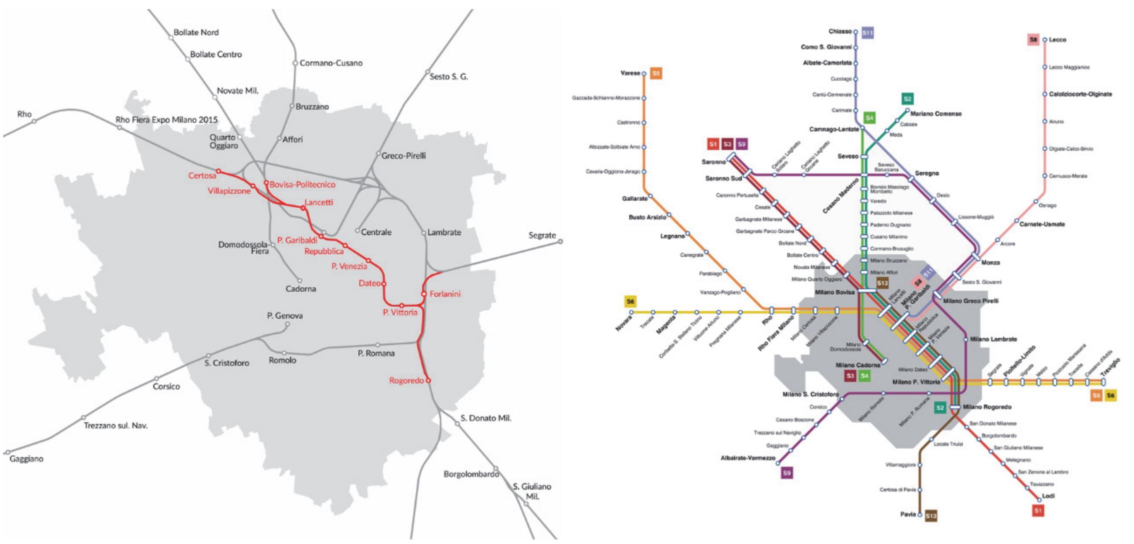

Figure 9. Representation of the "passante ferroviario", in red on the left, inside the railway system. Source: Wikimedia Commons

As stated above, the intermediate element of the transportation system in the city of Milan is represented by the metro, which plays the crucial role of connecting the fine grain bus and tram networks, the peripheries of the city, the most important regional and national scale transportation nodes (Stazione Centrale, Stazione Milano Garibaldi, Stazione Milano Rogoredo) and the socio-cultural nodes of the city (Duomo, San Babila, Sant'Ambrogio, Porta Venezia just to name a few). The origin of the metro network of Milan (Metropolitana di Milano) dates back to '50's of the past century, when the first project was effectively approved and financed (after several failed attempts before the world conflict began). Works began in 1957, and on November 1st, 1964 the first of the existing four lines – the M1 red line – started operating, followed in 1969 by the opening of the M2 green line. During the '70's and the early '80's the investments focused on extending the existing lines, while at the end of the '80's and the early '90's the third line, the M3 yellow line, was built and began operating. During the first decade of this millennium all three lines were further extended, and in the meanwhile the city of Milan received a contribution for the construction of two additional lines, the M4 blue line and the M5 lilac line, after winning the bid for the Universal Exposition EXPO (held in 2015). The latter was inaugurated in 2013 and completed by the end of 2015, while the M4 is still under construction and is planned to start operating – at different stages – between 2021 and 2023.

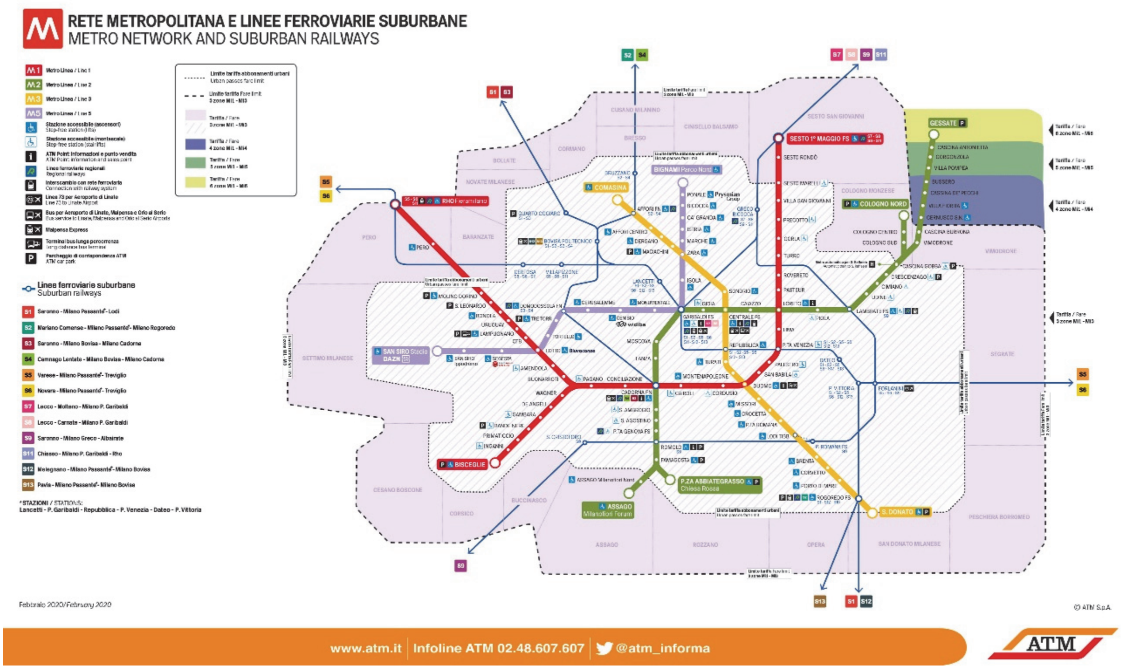

Figure 10. The existing metro and suburban railways network. Source: ATM

To date (Figure 10), the underground system comprises four different lines with 106 stations, of which: 7 provide transfer from one line to another (namely: Centrale M2-M3, Duomo M1-M3, Loreto M1-M2, Cadorna M1-M2, Lotto M1-M5, Garibaldi M2-M5, Zara M3-M5); 5 offer transfer with national and regional level railway lines (Centrale, Garibaldi, Lambrate, Rho Fieramilano, Rogoredo); and another 8 stations provide linkage with just regional railway lines (Affori FN, Cadorna, Domodossola, Porta Romana, Porta Venezia, Repubblica, Romolo, Sesto 1° Maggio FS). When the construction works will end, the new M4 blue line will be roughly 15 km long, running from the south-west side of the municipality, the railway station Lorenteggio-San Cristoforo, to the Linate airport on the east side of the city, passing through the city centre. It will run through a total of 21 stations (Figure 11), 15 of which will be brand new and only devoted to this metro line, while in 6 cases the M4 will be integrated with existing stations: the existing metro stations of Sant'Ambrogio (M2 green line), Sforza Policlinico (M3 yellow line) and San Babila (M1 red line), as well as some of the existing "passante ferroviario" stations, Dateo and Forlanini FS, and the head railway station of Lorenteggio-San Cristoforo; this connection with both the upper level element of the metropolitan transportation system – the suburban railway system – and 3 out of 4 of the existing metro lines, should guarantee a deep integration in the city's public transport system. The expected annual ridership is 87 million passengers, and the total estimated cost is about €1819 million: €958 million granted by the Italian government, €461 million by private investors and €400 million from the municipal government of Milan (Comitato Interministeriale per la Programmazione Economica, 2013).

Figure 11. Scheme of the upcoming M4 blue line. Source: ATM.

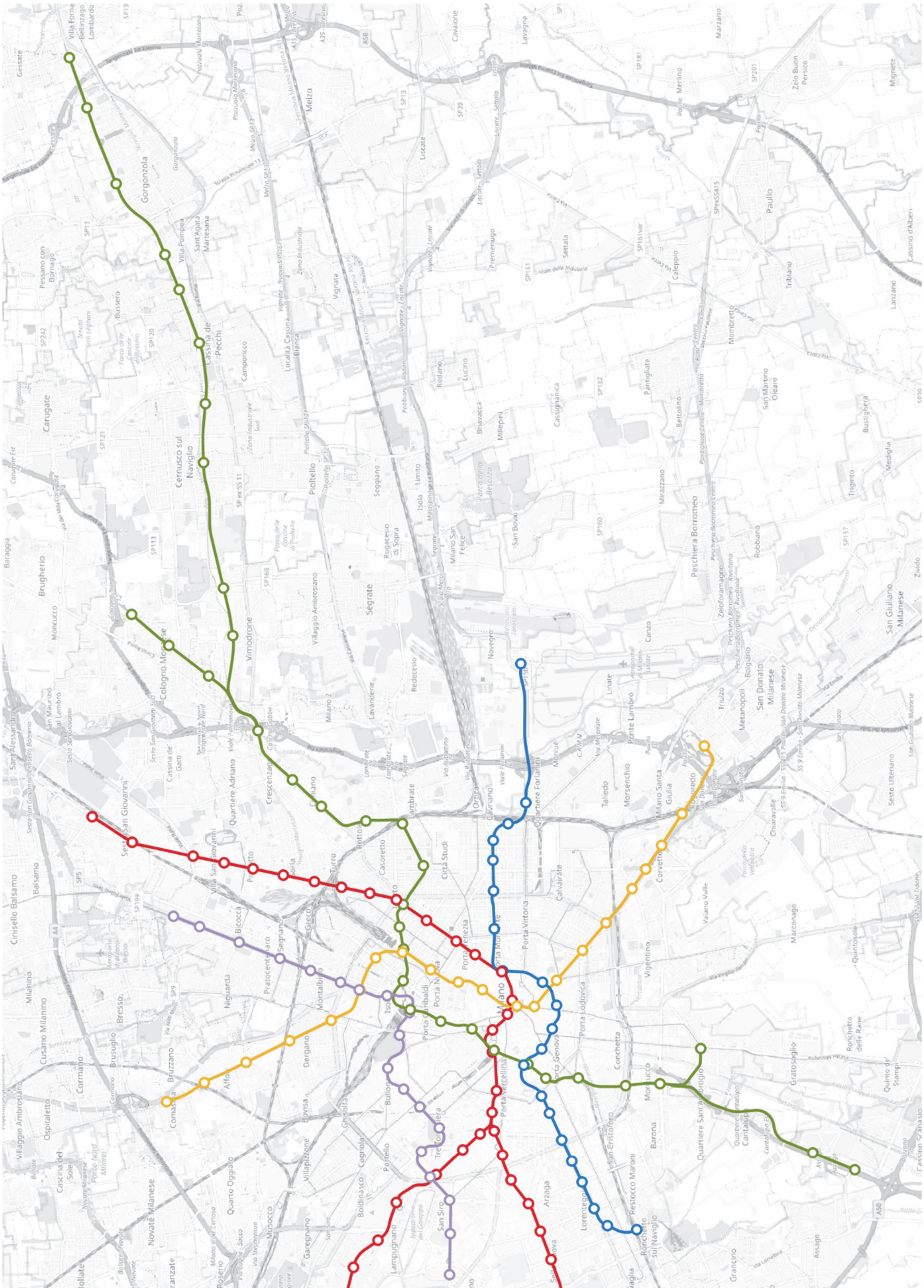

Figure 12. Scheme of the Metropolitana di Milano in its 2023 future complete layout. Produced by the author.

3.2 The residential market in Milano

During the last decade, Milan has suffered, like many other European and World cities, the negative effects of the global financial crisis which burst in September 2008 with the bankruptcy of Lehman Brothers. These financial crisis negative effects, diffused in all markets, severely hit a sector like that of real estate which, more than others, depends on financial credit for the proper inner nature of the goods that are exchanged therein. The 2011 report on real estate market of the major Italian cities edited by Nomisma highlights a better holding of cities compared to smaller towns in the residential sector. The demographic factor seems to be the main support of the demand in such cities. The report also sets at September 2, 2008, the turnaround of residential prices in the 13 major Italian cities. All in all, the crisis has produced limited effects in the Italian and Milanese markets, if compared to those of other national and international contexts (Gaeta, 2012). Families' propensity to save, and consequently the greater solidity of mortgage guarantees; a higher proportion of families owning the first home, which acts as a flywheel for extensions and replacements; and finally, the greater volatility of savings investment alternatives are all factors that contributed to giving relative stability to the real estate market in times of crisis.

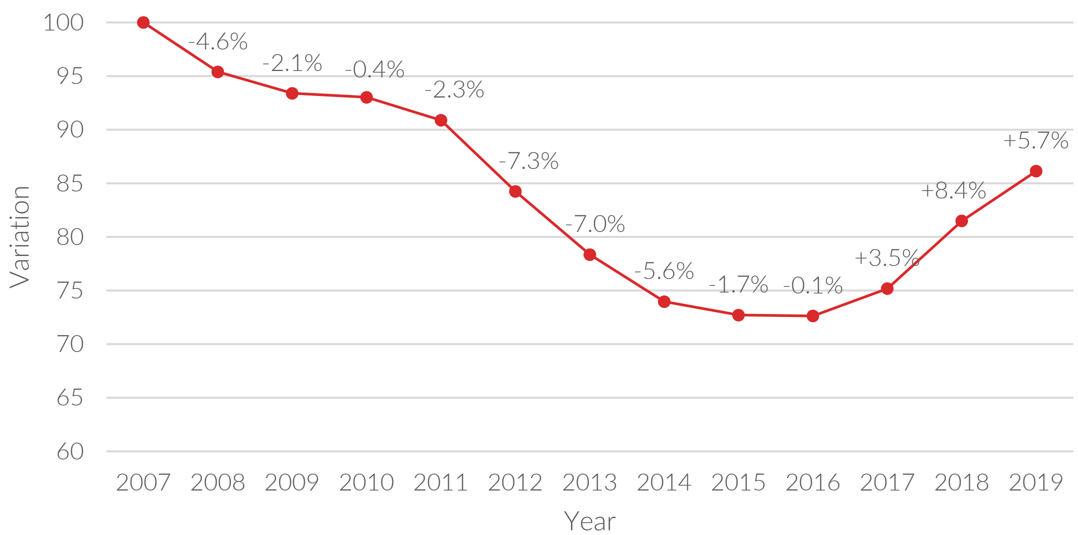

Figure 13. Residential market fluctuations in Milan between 2007 and 2017. Produced by the author using Tecnocasa data.

Furthermore, when compared to the rest of the Italian cities, the flection has hit the city with minor strength. According to a report by Tecnocasa, which analysed the evolution of the real estate market between 2007 and 2017, among Italian major cities Florence, Milan, Palermo, Rome and Verona are those which have lost less when compared to the national average. In particular, Milan is the city who leads the rest, with a -26.3% when compared to 2007 (Figure 13), followed by Florence (-28.3%), Rome (-35.8%), Verona (-36%) and lastly Palermo (-39.3%), while Genova has been the city that suffered most (-53.5%). Moreover, the crisis affected all macro areas of the city indistinctly.

3.2.1 The geography of Milanese housing market

The Milanese housing market can be described through different geographies, that nonetheless share the recognition of a strong monocentric and radiocentric urban structure. The most influential representations of this market show the subdivision of the city in concentric rings and a further division in microzones with homogeneous characteristics.

OSMI Borsa Immobiliare Milano (subdivision of the Milan Chamber of Commerce), distinguishes four concentric rings, named as follow: "centro storico" (historic centre); "bastioni" (bastions); "circonvallazione" (ring road); "decentramento" (decentralization). The three latter are then divided in sectors (north, south, east, west), resulting in a total of thirteen macro sectors that represent the fundamental spatial coordinates of the market. These macro sectors are further subdivided in 65 "microzones" with homogeneous values, meaning that each and every subzone is characterized by an inner homogeneous real estate price dynamic, even if belonging to different cadastral categories. The geography of the subzones in fact doesn't change with the functional destination of the buildings. This way, the Milanese urban market is segmented in numerous micro-markets, especially highlighting how locational characteristics play a crucial role in determining real estate values (Gaeta, 2012). The subzones have limited dimensions in the historic centre, that is inside the Navigli ring, where 8 of them are contained. The subzones dimension grows for the 9 microzones included in the second ring, for the 14 that are inside the third ring and, lastly, reaches its peak for the 34 final peripherical subzones. Similarly, the Italian revenue agency (agenzia delle entrate, under the Ministry of Economy and Finance) provides, through the Real Estate Market Observatory (Osservatorio del Mercato Immobiliare) service (Figure 14), an analogue analysis criterion composed of four concentric rings (historic centre, centre, semicentre, periphery) and a further sector in the southern side of the municipality classified as rural area, further divided into 41 micro areas with homogeneous characteristics.

As far as housing typologies and their location, Milan offers a vast heterogeneity and a spread out distribution. Clearly, the historical centre is the area that hosts some of the oldest buildings, dating from a wide range of historical periods (broadly, from the renaissance onwards) which have, on average, a higher value, both for their location and for the cultural significance they inherited (Fascia B in Figure 14).

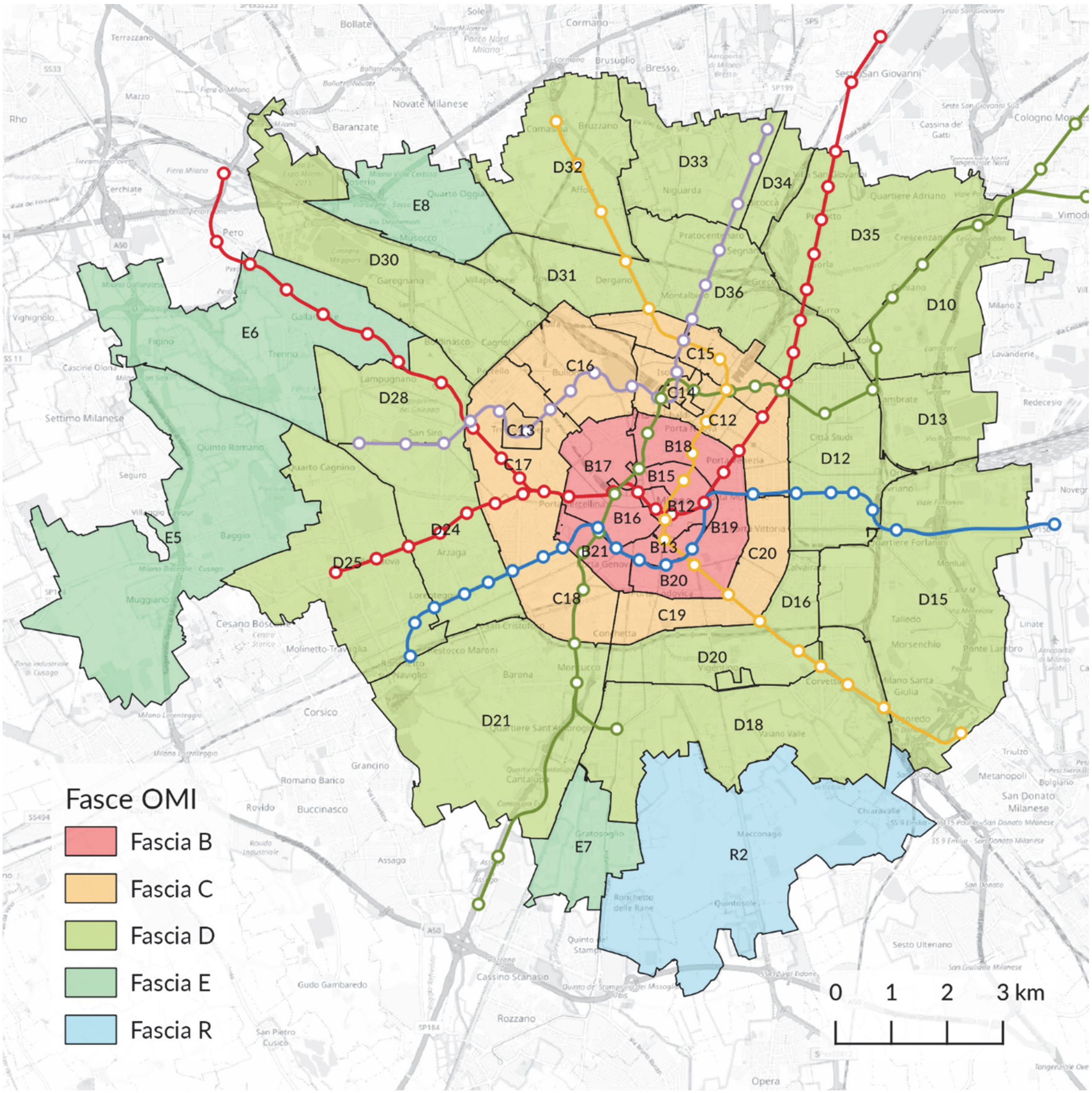

Figure 14. Real estate market homogeneous areas. Produced by the author on data from Agenzia delle Entrate, Osservatorio del Mercato Immobiliare

Residential units located in the band immediately adjoined, referred to as "cerchia dei bastioni" (Fascia C in Figure 14), host similar characteristics: this area is highly appreciated by the upper middle class for its quieter atmosphere, luxurious historical and contemporary apartments, vibrant social environment and great accessibility to both the outward linkages and the inner city transport network. Then, as we move towards the outskirts of the city, prices tend to decrease for a variety of reasons: on average, lower prestige of the architectural qualities of the buildings, lower quality of the urban environment, poorer accessibility, lower density of services, although these trends are not proportionally distributed throughout all the subzones. Focusing on accessibility, it is interesting to note how in the semesterly report by the study centre of Tecnocasa (a leading company in the real estate market), where they analyse the variations in prices in every area of the city, the arrival of the new metro is considered as a crucial factor in motivating the rise in the prices:

> *"Sul rialzo dei prezzi nei mesi precedenti aveva influito l'arrivo della metropolitana e la vicinanza alla Darsena e alla zona della moda. […] Si cercano prevalentemente trilocali e l'aspetto più importante è la vicinanza alla metropolitana e alle attività commerciali. […] Tra i quartieri interessati corso XXII Marzo, dove c'è attesa per la linea 4 della metropolitana e per le aree verdi che dovrebbero sorgere non lontano dal complesso di Porta Vittoria.*
>
> *The arrival of the underground, together with the proximity to the Darsena and the fashion district influenced the price rise of the previous months. […] Users are mainly looking for three-room apartments and the most important aspect is the proximity to the subway and commercial activities. […] Among the districts concerned Corso XXII Marzo, where there is waiting for the subway line 4 and for the green areas that are planned to be located not far from the Porta Vittoria complex."*
> *(Ufficio Studi Gruppo Tecnocasa, 2019)*

This confirms the intuition at the base of the research question of this thesis, and motivates the further empirical analysis that will be unveiled in the next chapter.

CHAPTER 4 | DATA AND METHODOLOGY

4.1 FINDING A DATASET

What might merely seem a necessary but rather simple task of selecting the right set of data, can actually be understood as a rather instrumental passage for the positive conclusion of this work; finding a dataset that would fulfil the complete set of requirements for the purpose of this research was, in fact, far from an easy task. To investigate the role of proximity to metro stations as a determining price factor and price predictor, it was soon understood that aggregated values of price per square meters in a given zone, area or street were not sufficient. In fact, the research question moves further, asking to determine if and how accessibility to metro stations affects real estate prices, and this variable should not be treated as an aggregated value (at least in a first moment of data generation; we will see how, in specific cases, aggregating classes with common characteristics can be a useful technique in speeding up the process and making the results look clearer). Moreover, to extract and highlight the importance of one independent variable (in our case, distance to the closest metro station) from a dependent variable (price per square meter), it is necessary to provide or generate a complete set of other independent variables that would help us explain our dependent variable. Several similar research studies were analysed, and the independent variables available for Milan were compared to those used by the authors of such studies to build a robust framework of analysis.

As a consequence of all these assumptions, a research began, looking for a database with the following characteristics:

- Individual observations of real estate transactions
- Each observation must have an address or X,Y location
- Each observation must store an extensive variety of variables
- The set of variables should be as similar as possible to those of the case studies analysed
- The observations variables should be equally populated throughout the database, to make each observation comparable with respect to all other observations
- The time span between the first and the last recorded observation should be as long as possible, and possibly happening during as many of the 6 phases of the new line

construction (general layout, specific announcement, basic engineering project, start of construction, opening, operating consolidation).

Easy in theory, not so easy in practice. A database with such characteristics presents a series of issues that makes it hard to find. First of all, privacy issues: knowing the address, one could link sensitive information to individual property owners. Therefore, this kind of databases is hard to spot online. Secondarily, such databases are often built by real estate companies which invest a lot of resources in its development and rely upon them to analyse the market and decide where and how to move their steps to build future strategies. In a highly remunerative field like that of real estate, the information stored in such databases are the seam of gold of the companies and will not be easily given for free. In the research of the database, many real estate companies were contacted to ask for a collaboration for study purposes: of all the companies, Tecnocasa was the only one who replied positively – specifically in the person of Fabiana Megliola, Responsible of the Study Office of the Tecnocasa Group for Italy –, but could only provide a database of aggregated values and average price yearly fluctuation for a limited variety of areas for the city of Milan. In the same line of research, the "Direzione Centrale Servizi Estimativi e Osservatorio Mercato Immobiliare" of the Agenzia delle Entrate, under the Italian Ministry of Finance was contacted. In this case, the database provided consisted of aggregated values of price per square meter for each street of Milan, but in their reply it was clearly stated that "the detail of the data referred to the single household unit is not available", probably because this work didn't meet the criteria to be eligible for the free sharing of such detailed information. While getting more and more aware of the difficulties emerging in finding the right database, the option of independently building a database through the so-called *"web scraping"* technique was investigated. This technique consists on setting up a web-based software that would read, organize and download in CSV format the real estate offers that can be found online on a variety of real estate announcements websites, both user populated or managed by real estate companies. After understanding that this option would result in a database with many limitations (a limited number of observations; a short time span, only beginning when the tool would be put to work; the awareness that the offer prices are commonly higher than the transaction values, leading to misjudgement; multiple offers for the same observation throughout time, with dropping prices as time passes and the property doesn't get sold), the idea was soon dropped. Lastly, after spending months without much luck in the research of a database that would solve the issue of providing all the necessary characteristics in order to analyse distance at the micro-individual level rather than the macro-aggregated one and go on with the rest of the research, the right set of data was found. Under the guidance of professor Roberto Camagni, the correct dataset was found in the hands of professor Marzia Morena and her research team. The dataset consists on the detailed version of the one previously provided by the "Direzione Centrale Servizi Estimativi e Osservatorio Mercato Immobiliare" of the Agenzia delle Entrate, and it was delivered to professor Morena and her research team for a different research purpose.

The following empirical analysis hence draws on data from the database on real estate values generated by "Direzione Centrale Servizi Estimativi e Osservatorio Mercato Immobiliare (OMI)" of the "Agenzia delle Entrate", under the Italian Ministry of Economy and Finance (Ministero dell'Economia e delle Finanze), which is supposed to be highly reliable and precisely populated. The data set comprises of 7018 observations of residential transactions dating from the year 2006 to the year 2017, and it accounts for 122 different variables. Each observation came with its address, making it relatively easy to obtain latitude and longitude location for each observation, which was needed to calculate distance to the nearest metro station. The first attempt was to read the address line using the "Geocoding" plugin software, running on OpenStreetMaps database in the QGIS software, but the georeferenced result was poor due to the incomplete or mismatching database of civic numbers and street names stored by OpenStreetMap. From this acknowledgment, it was understood that a complete dataset with street name, civic address and latitude and longitude information was needed. The complete database was found online on the Comune di Milano webgis page (https://geoportale.comune.milano.it/sit/open-data/) where a set of files referred to addresses and toponymy are freely available. The two databases were then combined in Microsoft Excel software, and, after minor matching adjustments, through the application of the VLOOKUP[4] formula it was finally possible to pair each observation address to the corresponding X, Y coordinates. Despite the better result compared to that of OpenStreetMap, some of the observations resulted being not detailed enough with incomplete or mismatching addresses. The

[4] In its simplest form, the VLOOKUP function says:

- what you want to look up – in our case, the address in the OMI dataset
- where you want to look for it – in our case, in the Comune di Milano dataset
- the column number in the range containing the value to return – in our case, latitude and longitude
- return an Approximate or Exact match – indicated as 1/TRUE, or 0/FALSE)

most common problems appeared to be the lack of civic number or street name from the database of origin, or the misspelled street names. After fixing the naming mismatches that could be found and fixed, and removing the apartments with missing civic numbers or imprecise location coordinates, the database comprised a total number of 4976 observations, now with longitude and latitude stored as variables as well. The dataset was then ready to be further geographically analysed in a GIS environment and to be populated with the missing and necessary location based variables.

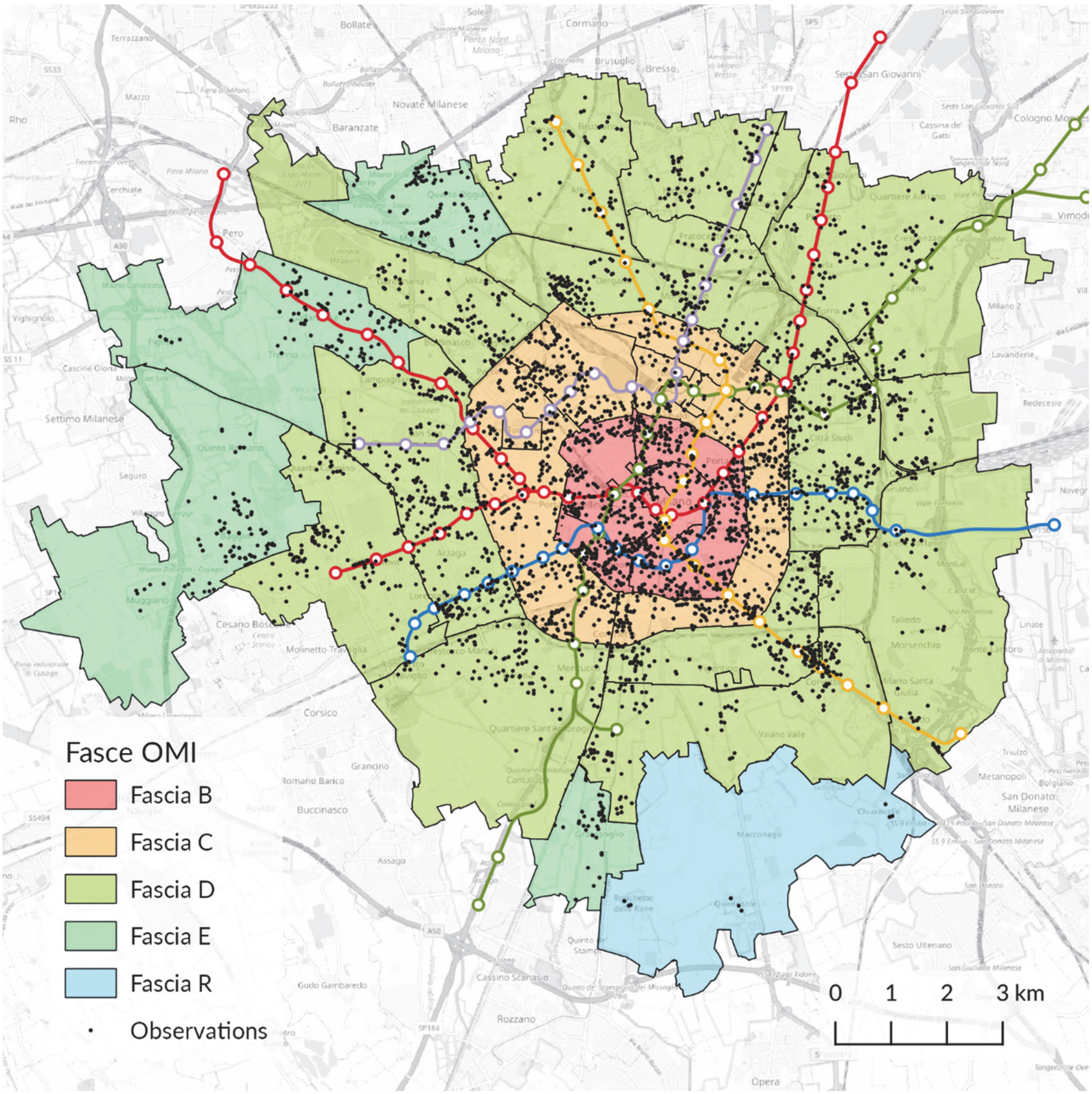

Figure 15. Distribution of the observations across the municipality of Milan. Produced by the author on data from Agenzia delle Entrate, Osser-vatorio del Mercato Immobiliare

At this stage, the coordinates of the observations were known, just like those of the metro stations. The next step was then to calculate the distance between each of the observations and its closest metro station, as well as to others amenities that may influence prices, such as schools, supermarkets, shopping areas, green areas, pharmacies, clinics and universities, which are often chosen as additional independent locational variables in studies of this kind.

4.2 Measuring accessibility: fixed-distance buffer vs street network distance

Most public transport users access transit stops or stations by walking, particularly in urban areas. It has been demonstrated that walking distance is a critical factor in the choice of public transport use. Coverage analysis enables one to evaluate pedestrian accessibility to the bus stops or stations on the network and it can be understood as a measure of accumulated opportunities (Gutiérrez & García-Palomares, 2000; Jones, 1981; Koenig, 1980; Pirie, 1979).

Distance coverage or service areas are commonly delineated by GIS through the creation of buffers (circular bands) around the point of interest, drawing a circle by using a set threshold of distance as radius, a technique based upon Euclidean (straight-line) distance (Murray, 2001; Murray, Davis, Stimson, & Ferreira, 1998); this is the case, for example, of the PGT of the Comune di Milano (Figure 16, Figure 17). A second, less utilized method to operationalize the task is based on calculation of distances (network distance) or travel times (isochrone) along the street network. Choosing one method or the other can significantly affect the final result.

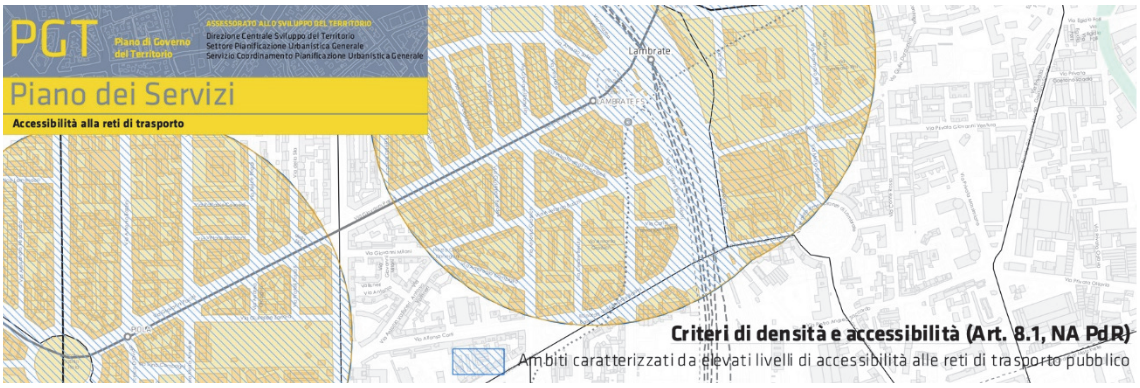

Figure 16. Extract of the plan "Accessibilità alle reti di trasporto" (accessibility to transport network) from the Piano dei Servizi (service plan) of the decayed Piano di Governo del Territorio of the Municipality of Milan, with a highlight on the representation of the accessibility to the public transport network of the city: "areas with high accessibility to public transport network". Source: Piano di Governo del Territorio 2012, Comune di Milano

The buffer method is widely applied in transportation and urban planning: the logic behind it assumes that walking distance for a user accessing a service or a station is the same as the Euclidean distance, or – at least – that its approximation is enough. When estimating walking proximity, 5 minutes or 10 minutes are used as threshold walking times depending on the scale of the service, accounting respectively for 400m and 800m. These thresholds represent psychological limits for the public transport user and influence the use of public transport.

The Piano di Governo de Territorio "MILANO 2030", for example, when indicating the areas characterized by high levels of accessibility in the Norme di Attuazione (implementation rules), applies the buffer method.

Figure 17. Extract of the plan "R02 Indicazioni Urbanistiche" (planning indications) from the Piano delle Regole (rule plan) of the Piano di Governo del Territorio in force of the Municipality of Milan. The blue line incorporates "areas with high accessibility to public transport network". Source: MILANO 2030 - Piano di Governo del Territorio (2019), Comune di Milano

In fact, even the areas only partially within the accessibility boundaries are to be considered in the same manner as those fully incorporated.

> *"art. 17 Criteri di densità, accessibilità*
>
> *1. All'interno del Tessuto Urbano Consolidato, sono individuati con apposita grafia gli ambiti caratterizzati da elevati livelli di accessibilità alle reti di trasporto pubblico nella Tav. R.02.*
>
> *2. Le aree interessate da tali ambiti sono da intendersi quelle anche solo parzialmente comprese all'interno degli areali rappresentati sulla tavola R.02 e riferiti alle sole stazioni e fermate esistenti o in fase di realizzazione, con possibilità di aggiornamento.*
>
> *[…].*

art. 17 Density and accessibility criteria

1. Within the Consolidated Urban fabric, the areas characterized by levels of accessibility to the public transport networks are identified with a specific handwriting in Table R.02.

2. The areas comprised in these contexts are to be understood as those even only partially within the limits shown on table R.02 and referred to only the stations and stops included or under construction, with the possibility of updating.

[…].”

Art. 17, Norme di Attuazione, Piano di Governo del Territorio MILANO 2030

Specifically, in the case of the Piano di Governo de Territorio “MILANO 2030” this threshold is set to distinguish between areas that have a higher building permit index from those that have a lower building permit index:

“art. 6 Indice di edificabilità territoriale

[…]

3. Entro gli ambiti caratterizzati da elevati livelli di accessibilità, di cui all’articolo 17, così come identificati sulla Tav. R.02, il suddetto Indice di edificabilità Territoriale massimo è elevato a 1 mq/mq […].

art 6. Territorial building index

[...]

3. Within the areas characterized by high levels of accessibility, as referred to in article 17, as identified on Table R.02, the aforementioned maximum territorial building right index is raised to 1 mq/mq […].”

Art. 6, Norme di Attuazione, Piano di Governo del Territorio MILANO 2030

This approach is defensible in cases like this (Figure 17, Figure 18), where the buffer method is applied inclusively to provide extended rights (specifically, raising building permits index from 0.35 mq/mq to 1 mq/mq), while it presents drawbacks and room for contentions (and, potentially, legal disputes) in other situations where accuracy is crucial, like for example in the case of the application of a new land value capture policy based on accessibility indexes. In cases like the latter, which is also the one of the objectives of this work, the need to provide extensive evidence when measuring accessibility motivates for a deeper methodological effort.

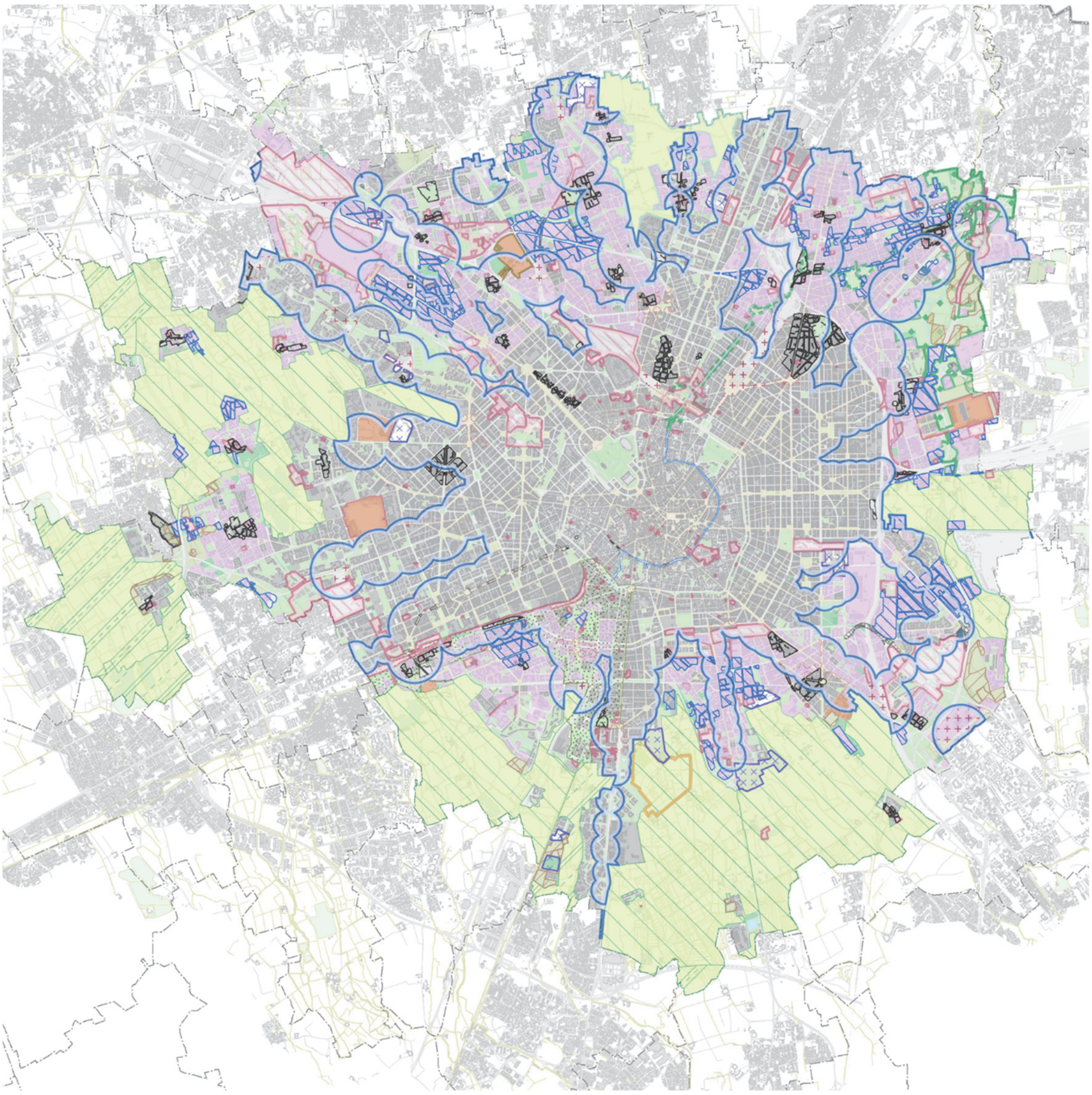

Figure 18. Overlook of the complete plan "R02 Indicazioni Urbanistiche" (planning indications) from the Piano delle Regole (rule plan) of the Piano di Governo del Territorio in force of the Municipality of Milan. The blue line incorporates "areas with high accessibility to public transport network". Source: MILANO 2030 - Piano di Governo del Territorio (2019), Comune di Milano

The preference of using Euclidean distances over real walking distance finds its justification on the advantage of its simplicity, thanks to the ease of its elaboration, and the need for approximation of certain processes. But this, inevitably, happens at the cost of inaccuracy as the actual walking distance is longer, owing to the 'crookedness' of streets (F. Zhao, Chow, Li, Ubaka, & Gan, 2003). Since pedestrians follow the street network layout as they move throughout the city, and only rarely can they move from point A to point B following a straight line, the result is that – no matter the threshold distance used – distances calculated using Euclidean distances are always shorter than network distances, and researchers agree in stating that the first method underestimates the results (Gutiérrez & García-Palomares, 2008).

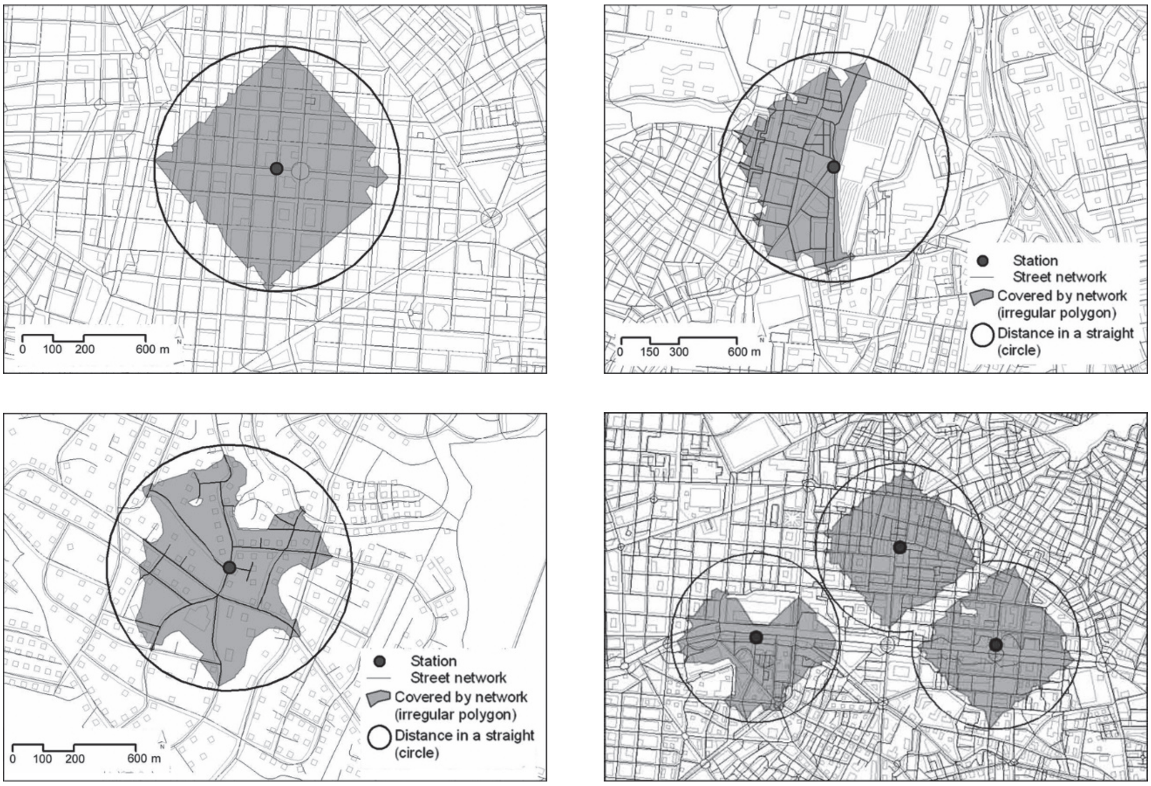

Figure 19. The influence of different factors (urban network patterns, barriers and closeness between service areas) over miscalculations of coverage areas. Source: Gutiérrez & García-Palomares (2008)

To avoid the underestimation occurring when using the straight-line method, it is possible to calculate distances along the street network, simulating the actual routes covered by pedestrians (Horner & Murray, 2004; Hsiao, Lu, Sterling, & Weatherford, 1997; O'Neill, Ramsey, & Chou, 1992). With this method, when calculating a coverage area as within reachable distance from the starting point, the result is not a circle, rather an irregular polygon that includes all branches of streets located within a network distance threshold (Figure 19). For example, the top-right image in Figure 19 represents coverage area of a suburban rail station calculated both with the straight-line Euclidean method (buffer) and through the street network (irregular polygon). The rails of the station produce a barrier effect, which results in a smaller coverage area when calculations are made through the street network.

Following this rationale, other than drawing service areas from a service point to its surroundings, it is also possible to calculate the distance between any two points both with a straight line Euclidean method (where one point corresponds to the centre of the circle and the second sits on the circumference, at a radius distance from the centre) and the street network method (by calculating the sum of the street segments needed to move from point A to point B). Habitually, even for an accessibility evaluation like the one needed for this thesis, the common practice would be to calculate the distances between each observation and the closest metro station on a straight line (Higgins & Kanaroglou, 2016), given the operational difficulties of the street network method. Conscious of the limits of this simplistic approach, with the aim of delivering the most accurate analysis and despite the awareness of the technical difficulties to put in practice the network analysis method, the decision for the development of this study was to use the network distance method for its ability to deliver a higher accuracy. To test whether this assumption holds, both methods were run, and the results compared to be fully aware of the implications that each choice underpins.

4.2.1 Measuring distances between housing observations and metro stations applying the Euclidean and the street network method

In order to understand the actual difference between using one method or the other for the calculation of the distance between each observation and its closest metro station, both solutions were operationalized. Furthermore, a secondary objective was to test whether the closest station as measured with the euclidean method would correspond to the closest station as measured with the network distance.

To do so, the first step was to calculate the Euclidean distances in GIS environment between each observation and the three closest metro stations, assuming that the closest station to each observation as measured using the network distance would be one among the three closest stations on a linear distance. The software utilized for this task was QGIS, which hosts a plugin that computes distances between points on a straight line: the result was a table with the 4976 observations and, for each, the 3 corresponding closest metro stations and the relative distance stored in individual columns.

The second part of the analyses consisted of setting up a method to operationalize a batch origin-destination calculation following road patterns, drawing from the knowledge acquired through the literature, specifically from Laznicka (2016) who highlights how:

> *"[…] in order to obtain real undistorted distance, the true walking distance was collected by conversion of both stations and apartments coordinates to their addresses using the reverse geocoding program (Batch reverse geocoding) and secondly calculating the distance between them using Microsoft Excel and Visual Basic, with the usage of Google Maps APIs (Application Programming Interface)."*
> *(Laznicka, 2016)*

This method uses the power offered by Google servers to operate batch searches on the Google Maps search engine, as if many individual searches of directions from point A to point B were run simultaneously. Putting this method to work is rather complex and requires technical knowledge on how to activate and use a Google API key and, most importantly, how to code in Visual Basic for Applications (VBA) inside the Excel environment. After some trial and error, the application was able to compute the desired calculations: by the simple click of the "Get Distances" button (Figure 20), the VBA code would interrogate the Google Maps search engine, which in turn would send the desired origin-destination information (namely distance and time of travel) based on the specified travel mode – for which, for the purpose of the study, walking was deemed more appropriate. The results were then organized and paired with the corresponding observations, and together with the Euclidean method results they were then ready to be investigated and analysed.

	A	B	C	D
1				
2	Get Distances	Google API Key		
3		Travel mode (driving or walk	walking	
4				
5	Origine			
6	45.48453032, 9.20346353	Centrale Fs M2		
7				
8	Destino	Distanza Origine-Destino (in metri)	Tempo di percorso (secondi)	Tempo di percorso (hh:mm:ss)
9	45.4797356386999, 9.20440499222			0:00:00
10	45.4857858426999, 9.20747022864999			0:00:00
11	45.4801974170183, 9.20162111774494			0:00:00
12	45.489802797, 9.20338934818			0:00:00
13	45.4898869913999, 9.20322382102			0:00:00
14	45.4877682374999, 9.20276496026			0:00:00
15	45.4791743203366, 9.20285998345496			0:00:00
16	45.4886150952999, 9.20923985926999			0:00:00
17	45.4919366254, 9.20685845441			0:00:00

	A	B	C	D
1				
2	Get Distances	Google API Key		
3		Travel mode (driving or walk	walking	
4				
5	Origine			
6	45.48453032, 9.20346353	Centrale Fs M2		
7				
8	Destino	Distanza Origine-Destino (in metri)	Tempo di percorso (secondi)	Tempo di percorso (hh:mm:ss)
9	45.4797356386999, 9.20440499222	656	492	0:08:12
10	45.4857858426999, 9.20747022864999	442	325	0:05:25
11	45.4801974170183, 9.20162111774494	609	464	0:07:44
12	45.489802797, 9.20338934818	797	592	0:09:52
13	45.4898869913999, 9.20322382102	796	591	0:09:51
14	45.4877682374999, 9.20276496026	466	342	0:05:42
15	45.4791743203366, 9.20285998345496	782	581	0:09:41
16	45.4886150952999, 9.20923985926999	727	539	0:08:59
17	45.4919366254, 9.20685845441	1033	786	0:13:06

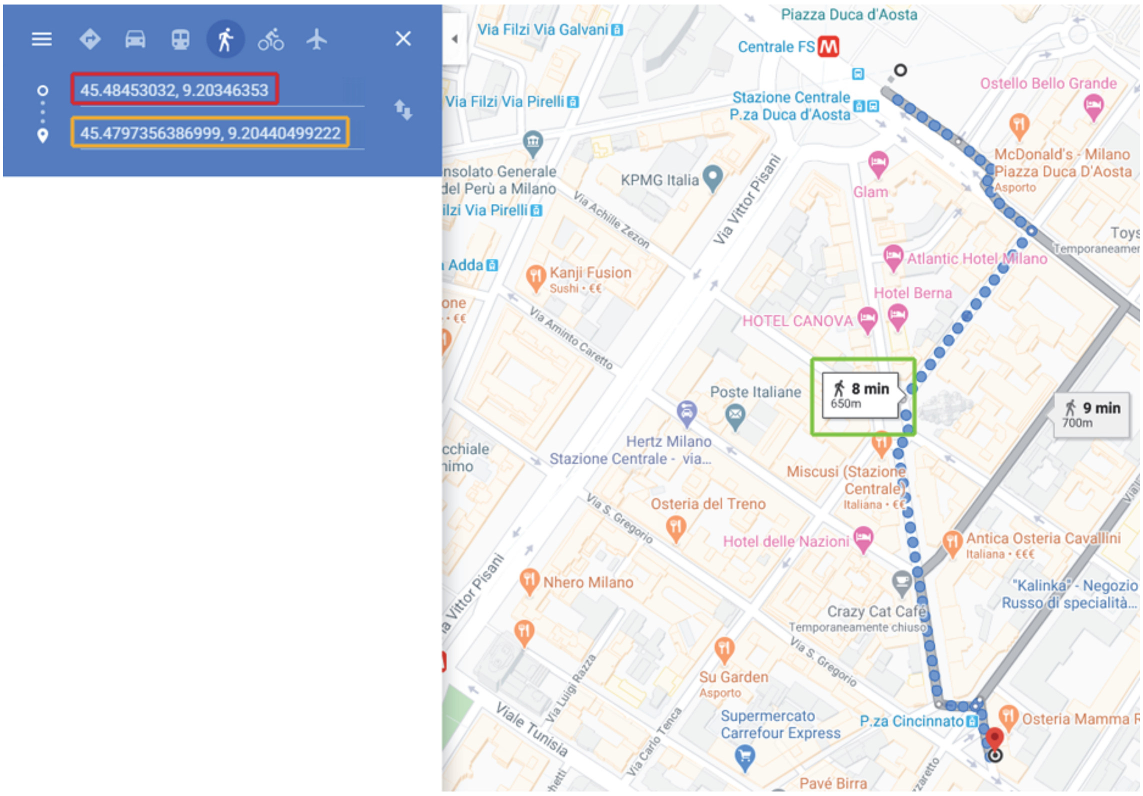

Figure 20. An example of a batch computation of network distances, with a manual testing online. Produced by the author

The analysis of the results of the distance computations confirms both hypothesis that emerged at the early phases of the " distance to the metro" variable populating stage. Out of all the 4976 observations, 4316 of them (87%) are found to be matching in terms of the closest metro station, no matter which technique of distance calculation is used; in 532 cases (11%) the closest station measured with the network distance analysis corresponds to the second closest station as measured with linear distance, and in 147 cases (3%) it actually corresponds to the third closest station in linear terms (Figure 21), highlighting how the linear distance method leaves room for misjudgement.

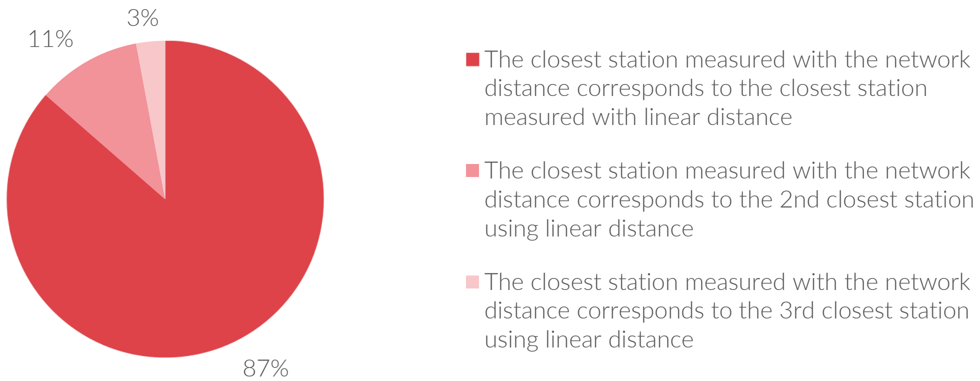

Figure 21. Correspondence between distance measure techniques. Produced by the author

Secondly, and most importantly, the actual measures between the closest station on a linear distance and the closest station on a network distance were compared. The results are shown in Figure 22, where the X-axe indicates the size of the underestimation occurring when the linear distance is preferred, while the Y-axe indicates the percentage of observations in each underestimation category. The graph highlights a quasi-normal distribution (slightly positively skewed with the tail to the right) indicating that the analysed phenomena is statistically consistent. The results indicate that, on average, the approximation caused by the use of the Euclidean distance provokes an underestimation of the actual walking distance of 19.9%: to put it clearer, on average, drawing a straight line between the observation and its closest metro station shortens the actual path by almost 20%. Two thirds of the observations fall in the range 10%-30%, and the peaking case has an underestimation of 76.9% (Figure 23). Many aspects may affect the underestimation results: absolute distance between the points, urban patterns, natural or artificial barriers. A further investigation of this topic, though, goes beyond the interests of this study.

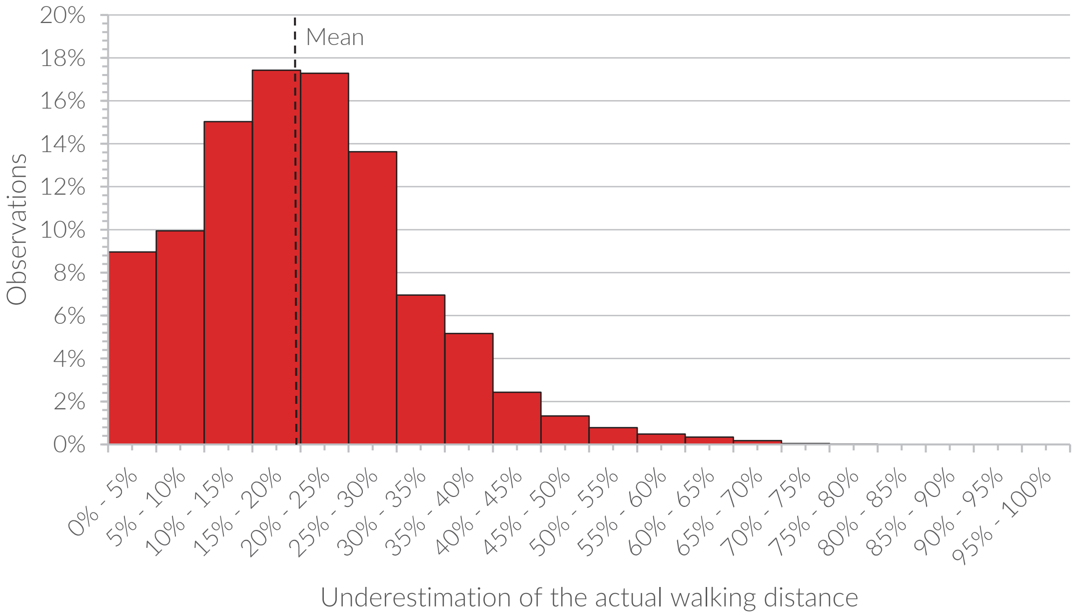

Figure 22. Underestimation of the actual walking distance occurring when the linear method is used to compute the distance between each of the 4976 observations of the study and their nearest metro station. Produced by the author

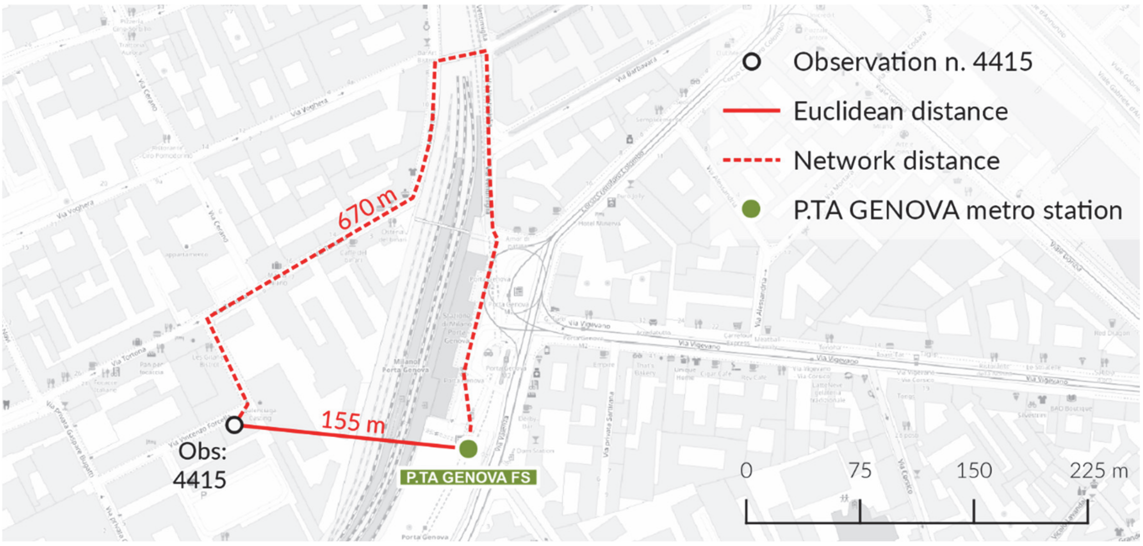

Figure 23. An example of the different results provided by the two alternative methods. Produced by the author

Despite the awareness that these findings are only related to what can be considered a minor technical aspect, they nonetheless highlight how choosing one technique of analysis over another can have important implications on the data being generated and, consequentially, on the overall quality of the final outputs of a research.

4.3 Description of the data

After the addition of the distance to the metro variable and of other location related variables with the use of the GIS software, the population of the dataset with the geographically related variables was complete. The next step was to build a Hedonic Price Model. The model was developed using the software RStudio.

Table 2 shows the summary statistics of the variables used in the estimation. The final selection, after the necessary elimination of observations with missing values or evident errors previously unidentified, comprises a total of 4700 observations. The dependent variable is the natural logarithm of the apartment price per square meters, measured in euros. The use of the natural logarithm is justified by the distribution of the data: as evidenced by the literature on statistical analysis, when running a linear regression (like the case of a hedonic price model), it is suggested that the data would follow a normal distribution. By choosing the logarithmic form, the data histogram takes the conventional "bell shape", describing a normal distribution (as opposed to the right-skewed distribution of the normal form of "Price per sqm" in Figure 24).

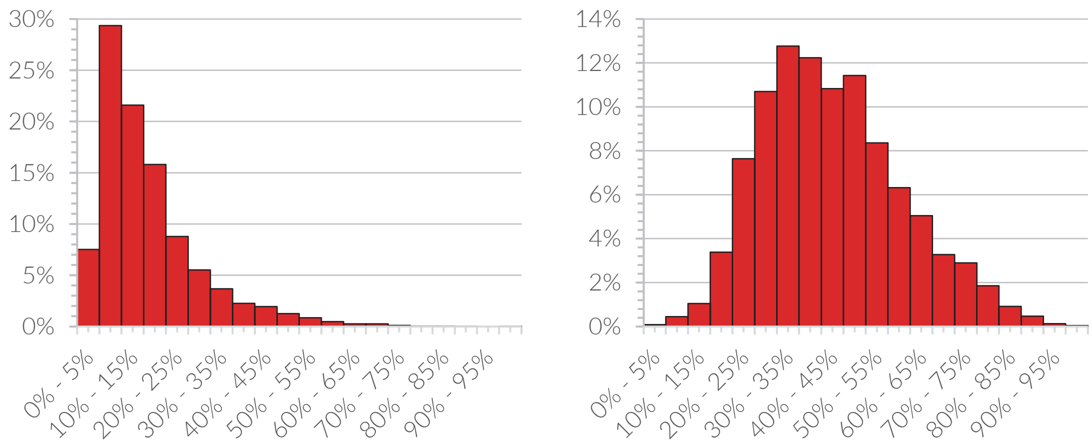

Figure 24. Distribution of observations: Price/sqm vs. Ln(Price/sqm). Produced by the author

The explanatory variables fall into three groups of variables. The first group of variables consists of time control variables, the second set covers the structural characteristics related to each apartment and the corresponding building, the third comprises neighbourhood characteristics, the fourth captures access to public and semi-public goods and, more broadly, location-related variables that are thought to potentially influence house prices, while the last one is the group of our observed variable, distance to the metro, expressed in different ways.

Variable	Type	Mean	Std.Dev	Min	Median	Max	N. Valid	% Valid
Price €/sqm	Real-valued	3922.87	2243.36	222.08	3290.76	36764.71	4700	100
Year of sale	Categorical	2012.15	2.8	2006	2012	2017	4700	100
Semester of sale	Categorical	1.48	0.5	1	1	2	4700	100
Month of sale	Categorical	5.64	3.62	1	6	12	4700	100
Cadastral Category	Categorical	2.81	0.57	1	3	6	4700	100
Year built	Categorical	1955.17	63.26	1020	1960	2015	4700	100
Age of the building	Real-valued	3922.87	2243.36	222.08	3290.76	36764.71	4700	100
Renovation	Binary	0.16	0.37	0	0	1	4700	100
Year of renovation	Categorical	2001.02	10.84	1920	2004	2017	757	16.11
Size (square metres)	Real-valued	91.37	48	16	79	568	4700	100
No. rooms	Count	5.01	2	1	4.5	23.5	4700	100
One-roomed flat	Binary	0.01	0.1	0	0	1	4700	100
Two-roomed flat	Binary	0.07	0.25	0	0	1	4700	100
Three-roomed flat	Binary	0.17	0.38	0	0	1	4700	100
Four-roomed flat	Binary	0.29	0.45	0	0	1	4700	100
More than four-roomed flat	Binary	0.47	0.5	0	0	1	4700	100
No. bathrooms	Count	1.3	0.55	1	1	5	4700	100
More than one bathroom	Binary	0.25	0.43	0	0	1	4700	100
Basement	Binary	0.44	0.5	0	0	1	4700	100
Attic	Binary	0.06	0.24	0	0	1	4700	100
Balcony	Binary	0.41	0.49	0	0	1	4700	100
Terrace	Binary	0.05	0.22	0	0	1	4700	100
Floor	Categorical	3.09	2.28	0	3	23	4700	100
Elevator	Binary	0.91	0.28	0	1	1	4700	100
Elevator if Floor>2	Binary	0.96	0.2	0	1	1	4700	100
Last floor	Binary	0.05	0.22	0	0	1	4700	100
Fascia OMI	Categorical	2.42	0.93	1	3	5	4700	100
Zona OMI	Categorical	20.28	10.96	1	20	41	4700	100
Distance to the CBD (Duomo)	Real-valued	3963.36	2093.63	193	3735.5	10593	4700	100
Supermarket within 400 m	Binary	0.7	0.46	0	1	1	4700	100
Kindergarten within 400 m	Binary	0.68	0.47	0	1	1	4700	100
Elementary school within 400 m	Binary	0.43	0.49	0	0	1	4700	100
Middle school within 800 m	Binary	0.89	0.32	0	1	1	4700	100
Highschool within 800 m	Binary	0.66	0.47	0	1	1	4700	100
Presence of any of the schools	Binary	0.95	0.22	0	1	1	4700	100
University within 1200 m	Binary	0.41	0.49	0	0	1	4700	100
Euclidean distance to closest metro station at time of sale	Real-valued	780.57	638.99	19	546	3947	4700	100
Network distance to closest metro station at time of sale	Real-valued	999.38	832.51	21	710	5958	4700	100
Network distance to closest metro station (100 m bands)	Categorical	2.58	2.74	0	2	8	4700	100

Table 2. Summary statistics. Produced by the author

Time control variables:

- *Year of sale* – categorical variable indicating the year of the transaction, ranging between 2006 and 2017;
- *Semester of sale* – categorical variable indicating the semester of the transaction;
- *Month of sale* – categorical variable indicating the month of the transaction.

Structural characteristics of the apartment and the building variables:

- *Cadastral Category* – categorical variable distinguishing among the different residential cadastral categories: A/1 Stately homes ("abitazioni di tipo signorile"), A/2 Civil homes ("abitazioni di tipo civile"), A/3 Economic homes ("abitazioni di tipo economico"), A/4 Popular housing ("abitazioni di tipo popolare"), A/5 Ultrapopular housing ("abitazioni di tipo ultrapopolare"), A/7 Single detatched houses ("abitazioni in villini");
- *Year built* – categorical variable indicating recorded year of construction of the building;
- *Age of the building* – real-valued continuous variable storing the difference between year of sale and year built;
- *Renovation* – binary variable indicating whether the apartment had been renovated (value 1) or not (value 0);
- *Year of renovation* – categorical variable year of the renovation;
- *Size (square metres)* – real-valued continuous variable representing apartment floor area in square meters;
- *No. rooms* – count variable indicating the number of rooms;
- *One-roomed flat* – binary variable indicating whether the apartment is a one-roomed flat ("monolocale", value 1) or not (value 0);
- *Two-roomed flat* – binary variable indicating whether the apartment is a two-roomed flat ("bilocale", value 1) or not (value 0);
- *Three-roomed flat* – binary variable indicating whether the apartment is a three-roomed flat ("trilocale", value 1) or not (value 0);
- *Four-roomed flat* – binary variable indicating whether the apartment is a two-roomed flat ("quadrilocale", value 1) or not (value 0);
- *More than four-roomed flat* – binary variable indicating whether the apartment has got more than four rooms (value 1) or not (value 0);

- *No. bathrooms* – count variable indicating the number of bathrooms;
- *More than one bathroom* – binary variable differentiating apartments with one bathroom (value 0) from those with two or more bathrooms (value 1): essentially, this variable is a corollary of the previous, and assumes that the premium related to having more bathrooms is capitalized when the second bathroom is added, loosing meaning from there on;
- *Basement* – binary variable indicating the presence of the basement;
- *Attic* – binary variable indicating the presence of the attic (1 if present, else 0);
- *Balcony* – binary variable indicating the presence of the balcony (1 if present, else 0);
- *Terrace* – binary variable indicating the presence of the terrace (1 if present, else 0);
- *Floor* – categorical variable indicating floor of the apartment with 0 as the ground floor;
- *Elevator* – binary variable indicating the presence of the elevator (1 if present, else 0);
- *Elevator if Floor>2* – binary variable indicating the presence of the elevator if the apartment is located at the third floor or higher: essentially, this variable is a corollary of the previous, and assumes that the relative premium generated by the presence of the elevator only accounts for those apartments located at high floors (if the building has the elevator, but the apartment sold is at the ground, first or second floor – or if the building doesn't have the elevator – the value returned is 0, else 1);
- *Last floor* – binary variable indicating whether the apartment is located at the last floor of the building (usually considered a favorable position due to enhanced privacy).

Neighbourhood characteristics variables:

- *Fascia OMI* – categorical variable indicating in which of the 5 sectors of Milan identified by the Osservatorio del Mercato Immobiliare (Fascia B, Fascia C, Fascia D, Fascia E, Fascia R) the apartment is located;
- *Zona OMI* – categorical variable indicating in which of the 41 homogeneous microzones identified by the Osservatorio del Mercato Immobiliare the apartment is located.

Location-related variables:

- *Distance to the CBD (Duomo)* – real-valued continuous variable indicating the distance to the Central Business District, or, better, from the center of the city, approximated to the Duomo di Milano and calculated using the network distance method;

- *Supermarket within 400m* – binary variable indicating the presence of supermarkets within 5 minutes of walking distance from the observation using the network distance method (1 if present, else 0);
- *Kindergarten within 400m* – binary variable indicating the presence of kindergartens within 5 minutes of walking distance from the observation using the network distance method (1 if present, else 0);
- *Elementary school within 400m* – binary variable indicating the presence of elementary schools within 5 minutes of walking distance from the observation using the network distance method (1 if present, else 0);
- *Middle school within 800m* – binary variable indicating the presence of middle schools within 10 minutes of walking distance from the observation using the network distance method (1 if present, else 0): the distance threshold changed to 800m according to the supposed change in walking patterns of a user population composed by grown up kids;
- *Highschool within 800m* – binary variable indicating the presence of highschools within 10 minutes of walking distance from the observation using the network distance method (1 if present, else 0);
- *Presence of any of the schools* – binary variable indicating the presence of any of the schools listed above (1 if present, else 0);
- *University within 1200m* – binary variable indicating the presence of universities within 15 minutes of walking distance from the observation using the network distance method (1 if present, else 0): again, a distance threshold increase is assumed to better capture the displacement patterns of a user population mainly composed by young adults.

Distance from transport variables:

- *Euclidean distance to closest metro station* – real-valued continuous variable indicating the linear distance to the closest metro station expressed in metres;
- *Network distance to closest metro station* – real-valued continuous variable indicating the network distance to the closest metro station expressed in metres;
- *Network distance to closest metro station (100m bands)* – categorical variable indicating in which of the alternative 8 bands of 100m around the metro station the apartment is

located (1 for the band “0-100”, 2 for the band “101-200” and so on, where the reference group 0 contains all observations further than 800m from the closest station).

The next step was to estimate the necessary house price equation to run a hedonic price method.

4.4 MODEL ESTIMATION

Drawing from chapter 1.2, in order to run a hedonic price model for the selected observations, it is necessary to estimate a HPM function. The function used for this purpose takes the form

$$Ln(P_i) = f(T, S, N, L, M, E)$$

where

$Ln(P_i)$ = natural logarithmic form of the estimated price per square meter for the observation i

T = time control variables,

S = structural characteristics of the apartment and the building,

N = vector of neighbourhood characteristics,

L = vector of locational characteristics,

M = vector that measures proximity to nearest metro,

E = vector of idiosyncratic error capturing unobserved determinants of housing prices.

The results of the equation are shown in the next chapter.

CHAPTER 5 | RESULTS OF THE RESEARCH

This chapter reports the results of estimating the HPM equation to determine the effect of metro station accessibility on apartment values. In the first place, the aim is to discover whether, in the city of Milan, the closeness to the metro stations is positively associated with real estate residential values, and, in case of a positive answer, the degree and distribution of such effect. As a further goal, the second part of the chapter is dedicated to the study of the anticipated capitalization effects potentially generated by the upcoming metro line 4 on residential market.

5.1 HYPOTHESIS TESTING N.1: THE RELATIONSHIP BETWEEN REAL ESTATE VALUES AND DISTANCE TO THE METRO

To test the first of the two hypothesis, different linear models are estimated:

- *Model 1* – the standard form, as shown in the generic equation, which takes the form of a log-level equation and where the dependent variable is the natural logarithm of the price per square metre while the independent variables are not further mathematically adjusted;
- *Model 2* – a log-log equation, where also the independent variable storing the network distance to the closest metro station is transformed into its natural logarithm to better solve distributional implications (as suggested by DiPasquale & Wheaton, 1996);
- *Model 3* – a polynomial equation of 2nd degree, since it is expected that the price gradient is not constant and decreases as distance increases;
- *Model 4* – a polynomial equation of 3rd degree, to further explore whether additional unexpected effects can be captured in a finer grain detail;
- *Model 5* – a log-level equation where the distance variable is transformed into different binary variables indicating distance bands to the closest metro station (0-100m, 101-200m, 201-300m and so on). The threshold is set at 800m.

As seen in the first chapter (1.3), the results emerging from studies of this kind can vary widely: while the majority of the studies analysed in the literature witness a generally negative correlation between distance to the transit station and house prices (as distance decreases, prices increase), there are cities where this is not the case and prices either don't get influenced by the presence of transit (with positive and negative externalities counterbalancing and, finally, cancelling each other out) or, no less, they decrease with increased accessibility. For Milan, given the general understanding of the city as it is, characterized by a strong economy, a centripetal force that attracts flows and a healthy real estate market, prices would increase as distance to the metro stations decrease.To begin, a generic model (referred to as *"Model 0")* was run with as many of the variables from Table 2: due to multicollinearity issues, in fact, not all of the variables could be included. This is because pairs (or groups) of variables indicating similar phenomena are mutually exclusive, and only one at a time can be included:

- *"Size (square metres)"* and *"No. rooms"*, which essentially describe the same characteristic (in different terms, the size of the apartment): since the distinction among different *"No. rooms"* apartments is also captured by the binary variables *"One-roomed flat", "Two-roomed flat"*, *"Three-roomed flat"*, *"Four-roomed flat"*, *"More than four-roomed flat"*, the decision was to drop the variable *"No. rooms"*
- *"Fascia OMI", "Zona OMI"* and *"Distance to the CBD (Duomo)"*, among which *"Zona OMI"* was deemed more representative and richer in explanatory potential: in Milan, it is not always the case that distance to the centre acts as a major factor in determining the land rent characteristics of a neighbourhood (as an example, keeping in mind Figure 14, think about *"Città Studi D12"* and *"City Life C13"*: they have similar distance to the city centre, but face a completely different real estate market). Furthermore, this variable underpins other omitted variables that are common to all observations within a neighbourhood and that are otherwise hard to identify and would be left behind (for example, walkability of a neighbourhood, quality of the urban environment, noise nuisance at the micro scale, etc…)

After running the model and eliminating the outliers that most heavily influenced the outcome, the first results emerged, as shown in Table 3. To further refine the model and improve its overall efficacy, the variables from *"Model 0"* that resulted being least significant were removed using the manual F-test-based backward selection technique. This method requires multiple steps, where at each of the steps only the least significant variable is removed, until all remaining variables are found to be significant at a pre-specified cut-off ($p<0.05$ here). The model emerging from this process takes the name of *"Model 1"* and can be found in Table 3 for comparison with *"Model 0"*.

Dependent Variable: *Ln(price/sqm)*	*Model 0*		*Model 1*	
Cat A/2	-0.2887	***	-0.2808	***
	(-0.0348)		(-0.0343)	
Cat A/3	-0.3999	***	-0.3920	***
	(-0.037)		(-0.0364)	
Cat A/4	-0.4585	***	-0.4512	***
	(-0.041)		(-0.0405)	
Cat A/5	-0.4631	***	-0.4568	***
	(-0.0869)		(-0.0866)	
Cat A/7	-0.3677	***	-0.3707	***
	(-0.0599)		(-0.0596)	
Age of the building	-0.002	***	-0.0020	***
	(-0.0005)		(-0.0005)	
Age of the building^2	0.00001	**	0.00001	**
	(-0.000003)		(-0.000003)	
Renovation	0.034	***	0.0348	***
	(-0.0095)		(-0.0095)	
Size (square metres)	-0.0003	*	-0.0003	*
	(-0.0001)		(-0.0001)	
One-roomed flat	0.0897	**	0.0997	**
	(-0.0341)		(-0.033)	
Two-roomed flat	0.0595	***	0.0670	***
	(-0.0165)		(-0.0148)	
Three-roomed flat	0.038	**	0.0451	***
	(-0.0119)		(-0.0098)	
Four-roomed flat	-0.0097			
	(-0.0096)			
More than one bathroom	0.0638	***	0.0664	***
	(-0.0105)		(-0.0103)	
Basement	-0.0314	***	-0.0290	***
	(-0.0079)		(-0.0072)	
Attic	-0.0217			
	(-0.014)			
Balcony	0.001			
	(-0.0079)			
Terrace	0.0055			
	(-0.0157)			
Elevator if Floor>2	0.0434	**	0.0447	**
	(-0.0164)		(0.0164)	
Last floor	0.0338	*	0.0338	*
	(-0.0144)		(0.0144)	
Supermarket within 400 m	0.0144	.		
	(-0.008)			
Kindergarten within 400 m	-0.0161	*		
	(-0.0079)			
Elementary school within 400 m	0.0093			
	(-0.0074)			
Middle school within 800 m	-0.0109			
	(-0.0113)			
Highschool within 800 m	0.0258	**	0.0244	**
	(-0.0092)		(0.0091)	
University within 1200 m	0.03	**	0.0312	**
	(-0.0114)		(0.0114)	
Network distance to metro	-0.00003	***	-0.00003	***
	(-0.00001)		(0.00001)	
Constant	9.3567	***	9.3349	***
	(-0.0734)		(0.0712)	
Time variable (year of sale)	Yes		Yes	
Neighbourhood variable (Zona OMI)	Yes		Yes	
Adjusted R-squared	0.7852		0.7850	
F-statistic	220.7	***	245.5	***
Observations	4690		4690	

*** p<0.001, ** p<0.01, * p<0.05, . p<0.1. Standard errors in parentheses

Table 3. Model 0 and Model 1. Produced by the author

The results from Table 3 are encouraging. The coefficients of the variables related to the characteristics of the units generally have the expected signs and reflect the expected differences. After running M*odel 0*, certain variables that are not found to be significant are dropped in order to increase the overall performance of the model. With this process, we lose those variables that cannot be trusted, such as *Four-roomed flat*, *Attic*, *Balcony*, *Terrace*, *Supermarket, Kindergarten, Elementary school* and *Middle school.* According to the model, these variables do not generate any kind of direct effect on average price per square metres.

The coefficients of cadastral categories reflect the average change in price for the units of each category when compared to the control class *A/1 Stately homes*: the model estimates that the average price per square metre of *A/2 Civil homes* is 28% lower than that of the control group (holding all other variables constant, which from now on is assumed for every commented coefficient); likewise, the price for *A/3 Economic homes* is 39.2% lower, and further reduces by 45.1% and 45.6% for *A/4 Popular housing* and *A/5 Ultrapopular housing*, while *A/7 Single detatched houses* are estimated to receive an average price reduction of 37%. Furthermore, all of the coefficients of the cadastral categories are significant at $p<0.001$, meaning that we can safely trust the outcome.

The *Age of the building* and *Age of the building*^{2} variables tell us that, on average, an increase in the age of the apartment corresponds to a decrease in price, although the slope tends to reduce as the age of the building increases, which can be explained by the fact that old buildings may as well be positively associated with historical or monumental value. Similarly, the *Renovation* variable highlights how, if the apartment has been recently renovated, its value is, on average, 3.4% higher than apartments which have not been renovated.

The *Size of the apartment* is slightly negatively correlated with average price per square metre, probably due to the fact that bigger houses are generally harder to sell. On the contrary, *One-roomed flats* and *Two-roomed flats* are highly requested in the Milanese market, and the model certifies this notion, concluding that the price per square metre of the former group of apartments is, on average, 9.9% higher than the rest of the apartments, while the premium is of 6.7% for *Two-roomed flats* and of 4.5% for *Three-roomed flats.*

Apartments with a *Basement* tend to have lower average prices per square metre compared to those without a basement: this is easily explained by the computational methodology of the Italian system when it comes to calculating the price of an apartment unit, which considers any surface of the house as part of the total size, hence sharing the same price per square metre, but with lower coefficients for the additional surfaces like *Basement, Attic, Terrace* and *Balcony* (whose are is generally multiplied by 0.35 or 0.4); as a result, an apartment with any of the aforementioned additional surfaces faces a lower overall price per square metre.

For the apartment units located at high floors, the presence of the *Elevator* is found significant and positively correlated with price (this variable can potentially hide a further unexpressed variable, which is the overall quality of the building, since buildings without elevators tend to be older and more neglected). Similarly, being located at the *Last floor* is found significant and positively correlated with price, highlighting how an increase in privacy (and, potentially, panoramic view), is positively valued.

The results for access to some public services and goods are not altogether satisfactory. Variables like the different schools (apart from *Highschools*) and the presence of supermarkets are not found to be significant: this can be explained by the high capillarity of such services, which in turn reduces their importance when real estate market customers are facing the decision of selecting the location of the apartment they want to buy. Indeed, the presence of *University* is found to be significant and positively correlated, suggesting that units located in proximity of such attractive poles usually face a high demand composed of students families, investors who want to rent them to students, and, potentially, university professors and university-related workers.

Lastly, the variable that is the main interest of our study. As expected, the coefficient of the *Distance to the closest metro station* is significant and with the expected negative sign, meaning that for each additional unit increase (one metre) of distance to the closest metro station, the price per square metre will decrease by 0.003%: to better explain it, it is possible to multiply the distance by 100, coming to the conclusion that each additional 100m of distance to the metro station reduce the price by 0.3%.

This is a comforting result, which confirms the underpinning hypothesis and sets the direction for further considerations and findings. In fact, it is assumed that the closeness to the stations might act as a magnet in all its aspects, is to say with both attractive and a repulsive forces combined reflecting the positive and negative externalities produced, and with fading impacts as distance increases. These two considerations in particular are poorly described by a linear model coefficient like that of *Model 1*. For this reason, alternative models are presented in Table 4.

Dependent Variable: *Ln(price/sqm)*	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Cat A/2	-0.2808 ***	-0.2822 ***	-0.2803 ***	-0.2802 ***	-0.2772 ***
	(-0.0343)	(0.0343)	(0.0343)	(0.0343)	(0.0343)
Cat A/3	-0.3920 ***	-0.3933 ***	-0.3918 ***	-0.3918 ***	-0.3888 ***
	(-0.0364)	(0.0343)	(0.0364)	(0.0364)	(0.0365)
Cat A/4	-0.4512 ***	-0.4528 ***	-0.4515 ***	-0.4515 ***	-0.4495 ***
	(-0.0405)	(0.0343)	(0.0405)	(0.0405)	(0.0406)
Cat A/5	-0.4568 ***	-0.4579 ***	-0.4567 ***	-0.4568 ***	-0.4631 ***
	(-0.0866)	(0.0343)	(0.0866)	(0.0866)	(0.0867)
Cat A/7	-0.3707 ***	-0.3745 ***	-0.3708 ***	-0.371 ***	-0.3735 ***
	(-0.0596)	(0.0343)	(0.0596)	(0.0596)	(0.0597)
Age of the building	-0.0020 ***	-0.002 ***	-0.0021 ***	-0.002 ***	-0.002 ***
	(-0.0005)	(0.0343)	(0.0005)	(0.0005)	(0.0005)
Age of the building^2	0.00001 **	0.00001 **	0.00001 **	0.00001 **	0.00001 **
	(-0.000003)	(0.0343)	(0.000003)	(0.000003)	(0.000003)
Renovation	0.0348 ***	0.0343 ***	0.0344 ***	0.0344 ***	0.0352 ***
	(-0.0095)	(0.0343)	(0.0095)	(0.0095)	(0.0095)
Size (square metres)	-0.0003 *	-0.0003 *	-0.0003 *	-0.0003 *	-0.0003 *
	(-0.0001)	(0.0343)	(0.0001)	(0.0001)	(0.0001)
One-roomed flat	0.0997 **	0.0974 **	0.0991 **	0.099 **	0.101 **
	(-0.033)	(0.0343)	(0.033)	(0.033)	(0.033)
Two-roomed flat	0.0670 ***	0.0675 ***	0.0668 ***	0.0669 ***	0.0681 ***
	(-0.0148)	(0.0343)	(0.0148)	(0.0148)	(0.0148)
Three-roomed flat	0.0451 ***	0.0456 ***	0.045 ***	0.045 ***	0.0456 ***
	(-0.0098)	(0.0343)	(0.0098)	(0.0098)	(0.0098)
More than one bathroom	0.0664 ***	0.0663 ***	0.0665 ***	0.0665 ***	0.066 ***
	(-0.0103)	(0.0343)	(0.0103)	(0.0103)	(0.0104)
Basement	-0.0290 ***	-0.0284 ***	-0.0291 ***	-0.0291 ***	-0.0281 ***
	(-0.0072)	(0.0343)	(0.0072)	(0.0072)	(0.0072)
Elevator if Floor>2	0.0447 **	0.0453 **	0.0453 **	0.0454 **	0.0469 **
	(0.0164)	(0.0343)	(0.0164)	(0.0164)	(0.0164)
Last floor	0.0338 *	0.0338 *	0.034 *	0.034 *	0.0345 *
	(0.0144)	(0.0343)	(0.0144)	(0.0144)	(0.0144)
Highschool within 800 m	0.0244 **	0.0233 *	0.0231 *	0.0231 *	0.0231 *
	(0.0091)	(0.0343)	(0.0091)	(0.0091)	(0.0091)
University within 1200 m	0.0312 **	0.0338 **	0.0322 **	0.0324 **	0.0356 **
	(0.0114)	(0.0343)	(0.0114)	(0.0114)	(0.0114)
Network distance to metro	-0.00003 ***		-0.000053 ***	-0. 000057 *	
	(0.00001)		(0.00001)	(0.00003)	
Natural logarithm of network distance		-0.0242 ***			
		(0.0343)			
Network distance^2			1E-08 .	1E-08	
			(3.85E-09)	(1.489E-08)	
Network distance^3				-5E-13	
				(2.30E-12)	
Network distance band 0-100 m					0.0251 .
					(0.03027)
Network distance band 101-200 m					0.0521 ***
					(0.01903)
Network distance band 201-300 m					0.0632 ***
					(0.01465)
Network distance band 301-400 m					0.0759 ***
					(0.01388)
Network distance band 401-500 m					0.0599 ***
					(0.01496)
Network distance band 501-600 m					0.0375 **
					(0.01515)
Network distance band 601-700 m					0.0238 **
					(0.01642)
Network distance band 701-800 m					0.0131 *
					(0.01871)
Constant	9.3349 ***	0.9758 ***	9.34 ***	9.341 ***	9.262 ***
	(0.0712)	(0.0764)	(0.07124)	(0.0713)	(0.072)
Time variable (year of sale)	Yes	Yes	Yes	Yes	Yes
Neighbourhood variable (Zona OMI)	Yes	Yes	Yes	Yes	Yes
Adjusted R-squared	0.7850	0.7849	0.7851	0.7850	0.7851
F-statistic	245.5	245.5	242.3	238.8	223.4
Observations	4690	4690	4690	4690	4690

*** p<0.001, ** p<0.01, * p<0.05, . p<0.1. Standard errors in parentheses

Table 4. Alternative regression models to better describe the effect of proximity to metro stations on housing prices. Produced by the author

A first quick consideration when comparing the models in Table 4 is that, in general, all of the models can be considered to be solid and reliable, thanks to the constant significance of the variables that are maintained all across the models (namely, time control variables, structural characteristics, neighbourhood characteristics and locational characteristics), which do not change when applying the necessary adjustments on the metro distance variable. Furthermore, high *Adjusted R-squared* values with almost identical scores and generally high *F-statistics* value, suggest that all prediction models have a good fit with the observations' dataset, explaining around 78.5% of the variations of price per square metre.

Model 2 differs from Model 1 in that the distance to the metro station is transformed into its natural logarithm to better solve distributional implications (as suggested by DiPasquale & Wheaton, 1996; Figure 25). Note that when adding an additional logarithmic form variable, the model constant adapts to the new mathematical form, without further implications. Although describing spatial implications in a rather artificial way, the log-log model better explains the fading effects occurring as distance increases. The interpretation of the *Log(Distance)* variable coefficient, in fact, must be read as follow: for every one percent increase of the distance to the metro station, the price per square metre decreases by 0.024%, meaning that the variation in price does not follow a linear relationship with distance.

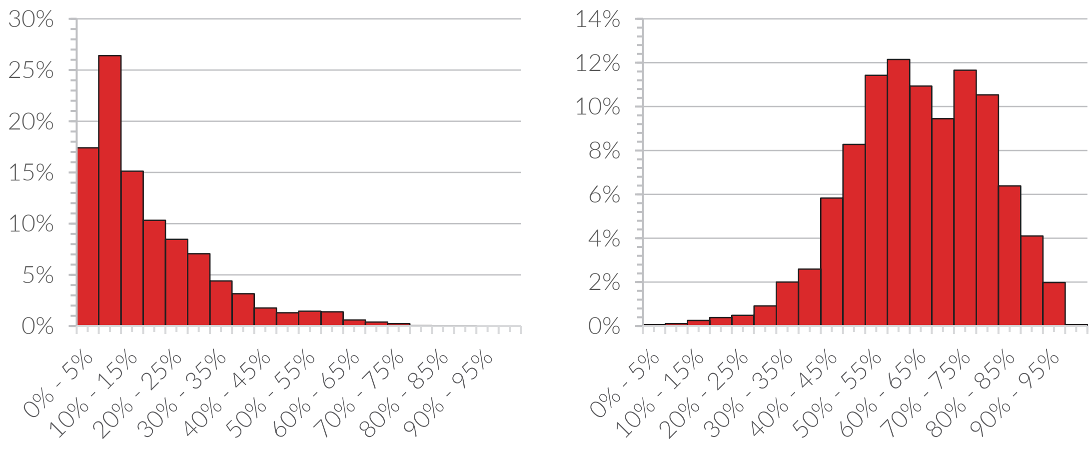

Figure 25. Distribution of observations: Distance from closest metro vs. Ln(Distance from closest metro). Produced by the author

Similarly, Model 3 tries to provide the same answer by squaring the distance variable and combining its coefficient with that of the linear model. The result highlights that the negative coefficient of the main variable is maintained, and – as expected – the squared coefficient has the positive sign, signifying that, as distance to the metro increases, the accessibility related effect is reduced. The limit of this model is the lower significance of the squared variable.

Model 4 finds its rationale in the aim to test whether the assumption that the immediate surroundings of the metro stations might face more negative than positive externalities holds. To do so, a further variable is added which is the cubic form of the distance to the metro station. The expectations are not satisfied, since the coefficients loose significance and they are not able to describe multiple patterns.

A final Model 5 is then tested to study the cumulative impact of positive and negative externalities brought about by the accessibility to the metro stations. To operationalize it, distance to the closest metro is transformed into a set of different dummy variables indicating different accessibility bands around the stations (0-100m, 101-200m, 201-300m, and so on): ideally, grouping the observations in smaller batches and separating them helps identifying finer grain changes. For each class, the coefficient is the net result of the sum of positive and negative externalities together.

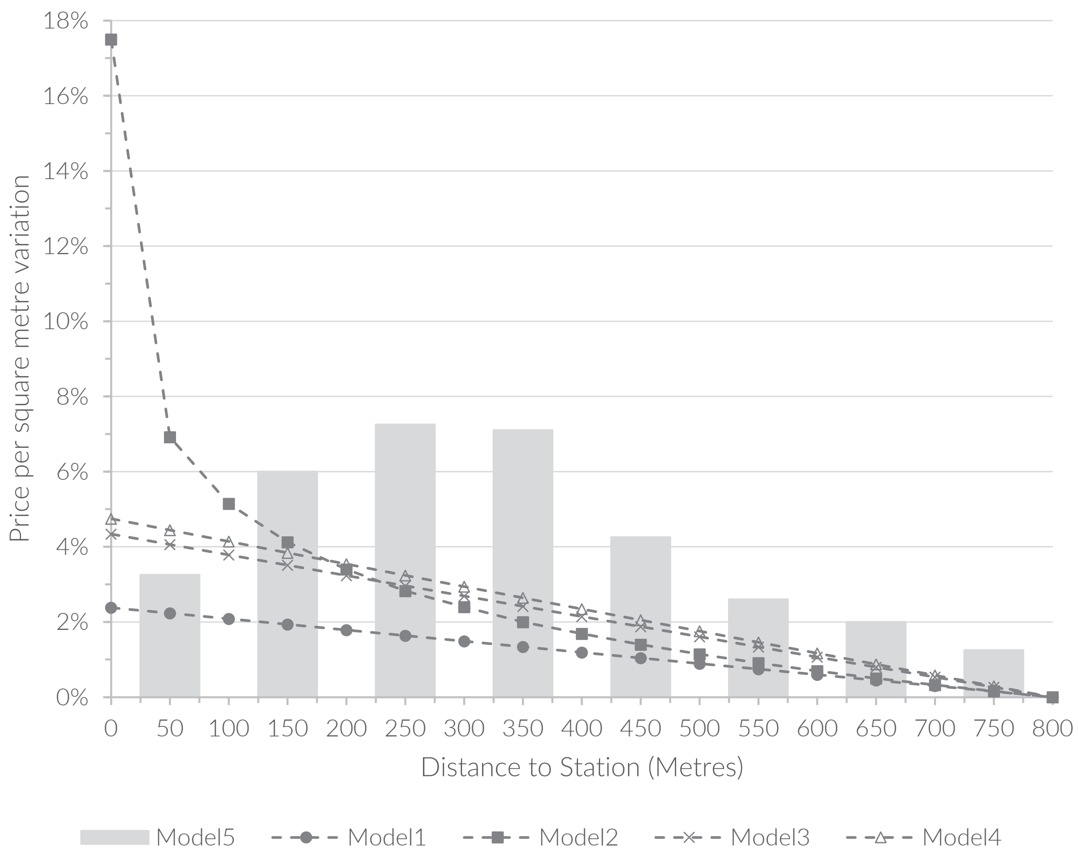

Figure 26. Comparison of the 5 Models developed thus far. Produced by the author

The resulting significance is not ideal, but it is deemed acceptable for the purpose of this empirical research. The coefficients of this last model show how, in the immediate proximity of the stations, price per square metre is high, but further increases as we slightly move to the consecutive bands up to 400 metres (Figure 26); then, prices start to decline again until the threshold of 800 metres, which the literature considers as the limit for pedestrian accessibility.

Model 5 explains that the variation is not uniform and accounts for counterbalancing externalities, making it hard to be univocally modelled. The lack of unavailable information on other factors that might negatively influence these results (such as crime rate and distribution, noise rate and distribution, density of commercial activities, average income per capita) make this kind of model the better solution to observe how both positive and negative effects influence house prices in different accessibility distance bands. These findings are among the most interesting of the study and are in line with what has been observed in other cities (Figure 27).

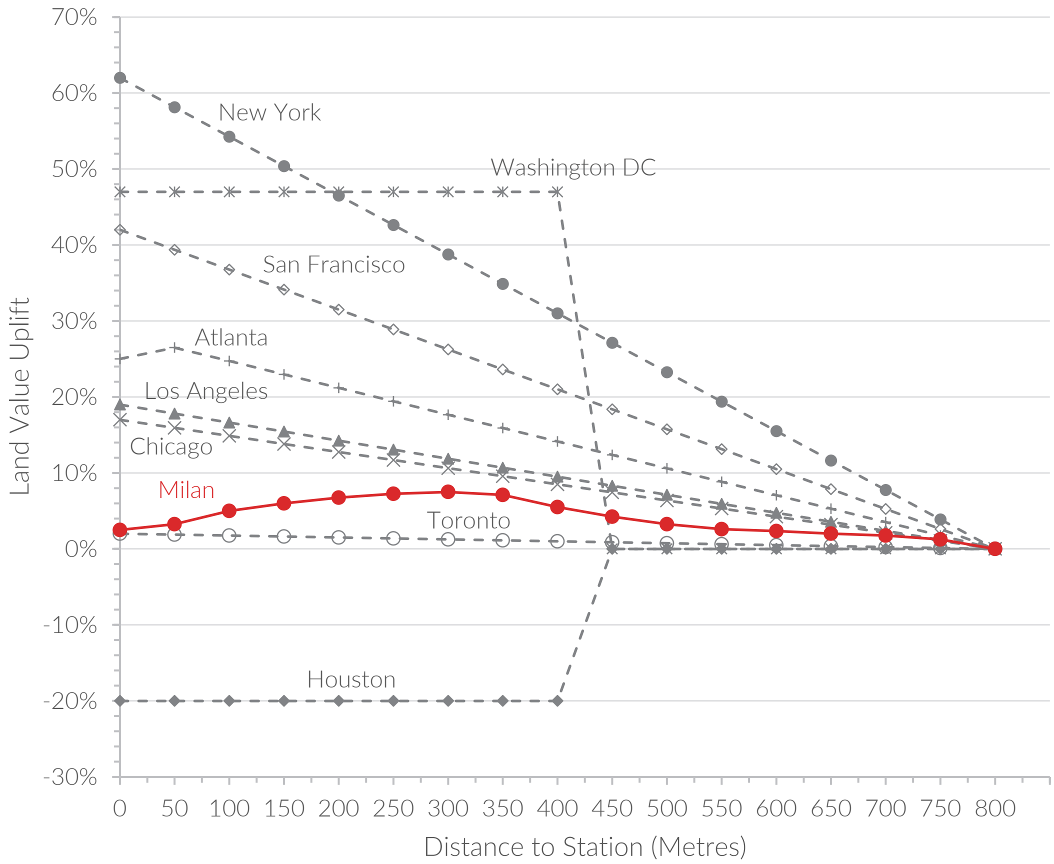

Figure 27. Land Value Uplift in Milan compared to that of other cities. Adapted from Higgins & Kanaroglou (2016).

5.2 HYPOTHESIS TESTING N.2: THE ANTICIPATED CAPITALIZATION EFFECTS

As mentioned, this section focuses on the exploration of the hypothesis that the upcoming metro line 4 may trigger an increase in real estate value along the line, even before it will begin operating. Studying whether a potential anticipated capitalization is occurring can help the implementation of further policy objectives and anticipate the recovery of the initial public investment.

In the time span of the observations that are used in the study, four out of five of the total future lines have gone through construction processes: the M2 Green line was completed in 2011 with the addition of a new branch with two stops in the south-western side of the city, namely Assago Milanofiori Nord and Assago Milanofiori Forum; the M3 Yellow line was completed in 2011 with the opening of the last four stations in the north-western side of the city, specifically Dergano, Affori Centro, Affori FN and Comasina; the project of the M5 Lilac line was officially approved in 2006, and in 2007 the construction works began and lasted until the end of 2015, when the last of the stations, Tre Torri, was opened; the project of the M4 Blue line was financed in 2010, with the contract officially assigned at the beginning of 2011 and the construction sites operating from the next year.

Year	House data	M1 Red	M2 Green	M3 Yellow	M5 Lilac	M4 Blue
2006	•				t = 3	
2007	•				t = 4	
2008	•					
2009	•					
2010	•					t = 2
2011	•		t = 6	t = 6		t = 3
2012	•					t = 4
2013	•				t = 5	
2014	•					
2015	•				t = 6	
2016	•					
2017	•					

General layout: t = 1; Specific announcement: t = 2; Basic engineering project: t = 3; Start of construction: t = 4; Opening: t = 5; Completion: t = 6.

Table 5. Timeline of the metro lines during the time span of the real estate observations. Produced by the author

In this complex framework, the idea is to identify, for each individual line, those observations that have been registered with a date prior to the opening of any of the newly built stations, and for which any of the newly built station is (or will be, upon completion of the works) the closest to reach, as measured in network distance. This group of observations is then further narrowed down, with the selection of only those observations located within 800 m from the stations (the standard threshold used in the literature for maximum walking reachable distances). A second condition is then applied, excluding the observations that experience only a limited distance reduction of less than 200m to the closest metro station compared to the existing conditions: the underlying assumption is that, if the new station doesn't provide a significant locational advantage because of the existence of a similarly distant existing station, the expected capitalization is heavily reduced. After the identification of the observations that should theoretically more directly benefit from the opening of the new stations, the aim is to develop a model in which the price per square metre of the selected observations would be compared with that of the rest of the observations. The interaction of the "advantage" variable with the year variables, should permit us to detect any potential anticipated capitalization effect year by year, line by line.

To investigate this hypothesis, three different models are estimated, starting from the results highlighted in the previous section. The M2 Green line is excluded from this specific test, because the newly built stations of Assago Milanofiori Nord and Assago Milanofiori Forum are located in areas where residential development is not present, hence none of the mentioned stations is the closest to reach for any of the 4690 observations.

- *Model 6* – a log-linear equation, starting from *Model 1*, to study the potential anticipated effect of the completion of the M3 Yellow line between the years 2006 and 2011;
- *Model 7* – a log-linear equation, starting from *Model 1*, to study the potential anticipated effect of the construction of the M5 Lilac line between the years 2006 and 2015;
- *Model 8* – a log-linear equation, starting from *Model 1*, to study the potential anticipated effect of the construction of the M4 Blue line between the years 2010 and 2017;

The prospects from these models are that, as time approaches the year in which each station begins operating, prices would increase around those stations more than they would do elsewhere in the city, witnessing a price premium derived by the upcoming arrival of a new transportation service. This would be the empirical demonstration of home buyers and sellers' expectations, which are widely theorized in the literature and hypothesized by real estate agencies in daily life, as mentioned, for example, by Ufficio Studi Gruppo Tecnocasa (2019) in their reports.

Dependent Variable: *Ln(price/sqm)*	*Model 1*		*Model 6*		*Model 7*		*Model 8*	
Cat A/2	-0.2808	***	-0.2805	***	-0.2785	***	-0.2848	***
	(-0.0343)		(0.0342)		(0.0342)		(0.0343)	
Cat A/3	-0.3920	***	-0.3922	***	-0.3897	***	-0.395	***
	(-0.0364)		(0.0363)		(0.0363)		(0.0364)	
Cat A/4	-0.4512	***	-0.4506	***	-0.4502	***	-0.4533	***
	(-0.0405)		(0.0405)		(0.0405)		(0.0406)	
Cat A/5	-0.4568	***	-0.4546	***	-0.4513	***	-0.4595	***
	(-0.0866)		(0.0866)		(0.0865)		(0.0867)	
Cat A/7	-0.3707	***	-0.3684	***	-0.3683	***	-0.3725	***
	(-0.0596)		(0.0595)		(0.0595)		(0.0596)	
Age of the building	-0.0020	***	-0.002	***	-0.0021	***	-0.002	***
	(-0.0005)		(0.0005)		(0.0005)		(0.0005)	
Age of the building^2	0.00001	**	0.00001	**	0.00001	**	0.00001	**
	(-0.000003)		(0.000004)		(0.000003)		(0.000004)	
Renovation	0.0348	***	0.0338	***	0.0352	***	0.0346	***
	(-0.0095)		(0.0095)		(0.0095)		(0.0095)	
Size (square metres)	-0.0003	*	-0.0003	*	-0.0002	*	-0.0003	*
	(-0.0001)		(0.0001)		(0.0001)		(0.0001)	
One-roomed flat	0.0997	**	0.0997	**	0.0971	**	0.1029	**
	(-0.033)		(0.033)		(0.033)		(0.0332)	
Two-roomed flat	0.0670	***	0.0664	***	0.0667	***	0.0678	***
	(-0.0148)		(0.0147)		(0.0147)		(0.0148)	
Three-roomed flat	0.0451	***	0.0442	***	0.0445	***	0.0451	***
	(-0.0098)		(0.0098)		(0.0098)		(0.0098)	
More than one bathroom	0.0664	***	0.0668	***	0.0666	***	0.0668	***
	(-0.0103)		(0.0103)		(0.0103)		(0.0104)	
Basement	-0.0290	***	-0.0294	***	-0.0291	***	-0.0293	***
	(-0.0072)		(0.0072)		(0.0072)		(0.0072)	
Elevator if Floor>2	0.0447	**	0.0457	**	0.0432	**	0.0442	**
	(0.0164)		(0.0164)		(0.0164)		(0.0164)	
Last floor	0.0338	*	0.0345	*	0.0345	*	0.034	*
	(0.0144)		(0.0144)		(0.0144)		(0.0144)	
Highschool within 800 m	0.0244	**	0.0238	**	0.0229	*	0.0254	**
	(0.0091)		(0.0091)		(0.0091)		(0.0092)	
University within 1200 m	0.0312	**	0.0309	**	0.032	**	0.0297	**
	(0.0114)		(0.0114)		(0.0114)		(0.0114)	
Network distance to metro	-0.00003	***	-0.00003	***	-0.00004	***	-0.00003	***
	(0.00001)		(0.00001)		(0.00001)		(0.00001)	
Advantage from the upcoming line			0.3558	**	-0.1921		-0.1562	
			(0.1312)		(0.2234)		(0.1643)	
Advantage * 2007			-0.141		0.1912		0.2051	
			(0.1682)		(0.2269)		(0.1706)	
Advantage * 2008			-0.1416		0.1797		0.2044	
			(0.168)		(0.2263)		(0.1748)	
Advantage * 2009			-0.1557		0.2006		0.1762	
			(0.1792)		(0.226)		(0.1747)	
Advantage * 2010			N.D.		0.2276		0.2023	
			N.D.		(0.2261)		(0.171)	
Advantage * 2011			N.D.		0.3003		0.1882	
			N.D.		(0.2245)		(0.1672)	
Advantage * 2012			N.D.		0.2819		0.1717	
			N.D.		(0.2254)		(0.1677)	
Advantage * 2013			N.D.		0.1587		0.2027	
			N.D.		(0.226)		(0.1709)	
Advantage * 2014			N.D.		0.2062		0.2091	
			N.D.		(0.2259)		(0.1699)	
Advantage * 2015			N.D.		0.2469		0.2738	
			N.D.		(0.2256)		(0.1744)	
Advantage * 2016			N.D.		0.2311		N.D.	
			N.D.		(0.2262)		N.D.	
Advantage * 2017			N.D.		0.1877		N.D.	
			N.D.		(0.2295)		N.D.	
Constant	9.3349	***	9.334	***	9.349	***	9.354	***
	(0.0712)		(0.0711)		(0.0717)		(0.0727)	
Time variable (year of sale)	Yes		Yes		Yes		Yes	
Neighbourhood variable (Zona OMI)	Yes		Yes		Yes		Yes	
Adjusted R-squared	0.7850		0.7854		0.7860		0.7849	
F-statistic	245.5		233		211.1		214.9	
Observations	4690		4690		4690		4690	

*** p<0.001, ** p<0.01, * p<0.05, . p<0.1. Standard errors in parentheses

Table 6. Regression models to test the anticipated capitalization effect for each of the lines interested by an extension. Produced by the author

The results emerging from the models, though, are not found explanatory. None of the models is in fact able to describe any relationship between prices and waiting time prior to any of the upcoming line extension or station opening. The causes of this failure to demonstrate empirical evidence should be thoroughly investigated, but, at a first glance, different alternative aspects may play a crucial role in the lack of results.

First, the limited amount of observations per line, per year. Once filtered according to the needs of the sub-study, not many observations are eligible for testing the hypothesis, which may lead to poor computational model capability. *Model 6*, which tests the relationship between waiting time and prices along the line 3 extension, can only make use of 14 observations out of 4690 to test this specific assumption: between 2006 and 2011 in fact, the available observations within 800m to any upcoming metro station and, contemporarily, located at least 1000m away from the – back then – closest existing metro station, are only 4 in 2007, 4 in 2008, 3 in 2009 and 3 in 2010, making any statistically relevant model hard to structure. Similarly, *Model 7* and *Model 8* are developed comparing respectively 567 (12.1%) and 258 (5.5%) observations to the study group.

Second, difficult modelling of the assumptions. In order to detect which of the observations is eligible for this sub-study, a simple differentiation is run, separating the observations that would receive a locational advantage from the opening of the new station from those that would not. This is right in absolute terms, but leaves space for misjudgements in relative terms. One could argue that the 800m threshold is too narrow to test the locational advantage, or, oppositely, that it incorporates too many observations. More extensively, the notion of "advantage" itself can be questioned: how should we consider any observation for which a new line's station doesn't represent an absolute advantage in reduced distance, but that nonetheless adds an extra line as an option to be used? What is the relative importance of the accessibility to the metro station in different areas of the city? Is it the same for an observation to be located at distance *n* from any station, no matter if located in the city centre or in the periphery? Assuming the unobserved error arising from this last assumption to be geographically evenly distributed, it may become problematic when the model targets variations occurring along a line extension which does not develop all across the city but only in its periphery (like the case of *Model 6* along the final branch of the M3).

Lastly, it is possible that market awareness does not form in a precise and determined moment, rather gradually throughout time. This assumption, which would be nonetheless difficult to demonstrate in practice, would make the original hypothesis hard to test using a simple temporal dummy variable.

Chapter 6 | Findings and conclusions

This research has tried to unveil the relationship between land values and transportation infrastructure, with the stated goal of demonstrating and assessing the degree of capitalization of the consequent effects into private real estate market in the city of Milan through an econometric analysis. The conclusions resulting from the empirical research may be used to provide evidence for a potential fiscal reform, which would be based on the ideals of a policy reassessment that embraces Land Value Capture strategies as the structuring backbone of the fiscal future for the city of Milan.

6.1 Findings

This work starts with a brief exploration of the theories on land rent formation, which constitute the base of any research in the field of applied urban economy, and of the techniques of analysis able to prove their occurrence through an empirical study. The aforementioned theories are first analysed through the lens of their historical evolution in relation with urban transit infrastructure and the consequent knowledge accumulation provided by the vast available academic literature, and subsequently verified through the evidence provided by several papers and studies which focus on the empirical testing of such theories.

The body of the work is centred around the empirical study of the relationship between land values and transportation infrastructure in the city of Milan. The stated goal is to provide econometric evidence of the magnitude and sign of such relationship. Drawing from the knowledge provided by the scientific literature on econometric analysis, the empirical testing of land rent theories is possible thanks to a set of econometric techniques and models that are able to extract the coefficient of any attribute of a property from the bundle of attributes that collectively form the property's overall value. Through this process it is hence possible to isolate and determine the relative importance of such attribute when compared to the final value of a good, being *residential prices per square metre* the dependent variable and *accessibility to metro stations* the embedded attribute which is the focus of this research. Since the vast majority of studies provided by the literature applies the Hedonic Price Model, this method is deemed appropriate for the hypothesis assumptions testing at the origin of this investigation on the city of Milan. When analysing the impact of metro accessibility on land values in Milan, the main obstacle is the collection of data. Data on real estate transactions is in fact hard to find for a series of reasons, ranging from high economic value of the data itself to privacy issues. Thanks to prof. Morena and her team, a reliable dataset is finally obtained. This dataset is composed of 4700 residential transactions occurred between 2006 and 2017, storing a series of attributes which would then be used in the HPM model. The reliability of the dataset is certified by the original source of the data, namely "OMI – Direzione Centrale Servizi Estimativi e Osservatorio del Mercato Immobiliare, Agenzia delle Entrate" under the Italian Ministry of Finance.

Furthermore, since HPM studies operationalize accessibility indirectly through measures of proximity to rapid transit access as an approximation for underlying accessibility benefits, a further study on the different approaches on how to calculate distance from each observation to the closest metro station is run. This study compares the traditional Euclidean distance method, widely utilized by most planning bodies to determine areas of interest of a given service or facility, with a more rigorous method independently elaborated based on theories of network distance. Both measures are independently calculated: the first, Euclidean distance, is obtained using QGIS software with a plugin that computes distances between points on a straight line; the latter, network distance, is obtained through an experimental technique independently developed which uses the combined computational power of Excel and GoogleMaps servers, which are put in communication through VBA and Google API Key, making it possible to run origin-destination calculations in bulk. The findings of this study within the study show that the traditional Euclidean distance method underestimates real distances by an average of 20 percent, and that for the 14 percent of the observations the closest metro station measured with the network distance method does not correspond with the closest metro station measured with the Euclidean measure. A brief comment on these findings is that the widespread use of the Euclidean method comes at the cost of an approximation that can potentially significantly distort and bias the outcome; on the contrary, the independently developed technique proves to be an efficient and reliable method for the cases where greater precision is needed. For the HPM analysis of this research, the latter was deemed more appropriate and the variable *distance to the closest metro* was populated with the values obtained using the custom network distance technique.

Therefore, the effective empirical application of the Hedonic Price Method is developed for the city of Milan, with the aim of testing two of the essential hypothesis questions. First: does real estate market capitalize accessibility-related effects related to the metro network in the city of Milan? Second: at what stage of the infrastructure construction is this value capitalized? The results emerging from the econometric regression provide a statistically relevant answer to the first question, while they leave room for further investigation regarding the second hypothesis. The results demonstrate a positive correlation between decreasing distance to the metro station and increasing prices in private real estate market, with values peaking between 200m and 400m away from the stations. This can be explained by the diminishing influence of the negative effects related to the immediate vicinity to the station, which on the contrary are evident for observations located at shorter distances (such negative effects are difficult to isolate in a statistically significant manner, resulting to be incapsulated together with the vicinity to the metro station itself). The control variables used to isolate the variable of interest generally provide a constructive support; the control variable group comprises 23 different variables controlling for different relevant clusters of aspects, namely structural characteristics of the apartment and the building, neighbourhood characteristics, locational characteristics and time control characteristics. The independent variable of interest is *distance to the nearest metro* as a proxy for accessibility. The Hedonic Price Model built on the 4700 residential transaction observations witnessed by the high values of Adjusted R-squared of about 0.78, this with all regression assumptions tested (linear relationship between independent and dependent variable, homoscedasticity of the results, absence of multicollinearity and absence of autocorrelation of the variables). The choice of using the neighbourhood variable *Zona OMI* in place of the more generic *Distance to the CBD (Duomo)* resulted in improved overall model fitting, confirming that Milanese neighbourhood are not uniformly arranged from a geographically point of view. One potential drawback of choosing this variable, however, is the partial encapsulation of the independent variable that the model wants to study and isolate. In fact, grouping variables by the neighbourhood they belong to can, on one side, help absorbing shared underpinned variables that are otherwise hard to identify and would be left behind (for example, walkability of a neighbourhood, quality of the urban environment, noise nuisance at the micro scale, etc…); on the other side though, it could partially absorb other measured variables that are already present in the dataset, like distance to the closest metro (think about a neighbourhood that is centred around a metro stop: accessibility is encapsulated both in the distance variable and, partially, in the overall neighbourhood attribute): this in turn could potentially reduce the strength of the accessibility coefficient. The results from the different models, however, didn't highlight any decrease in significance of the *distance from to the metro* variable. On the other hand, the acknowledgment of the existence of many more independent variables that could influence prices and that can hardly be measured led the choice to include the *Zona OMI* variable: this is testified by the overall improved model significance when the *Zona OMI* variable is included in the regression equation.

Although not being the main goal of this research, a secondary interest is to link theory, econometric evidence and policy indications on the basis of the interpretation of the empirical results. Drawing from the analysis of the alternative financing sources of urban transit infrastructures that go under the cap of Land Value Capture techniques, whose aim is to highlight the potential alternative solutions to the current difficulties that public bodies encounter in meeting the necessary capital needs to finance important infrastructure investments, and acknowledging the empirical results emerging from the econometric analysis, a series of broad but decisive indications are presented in the next paragraph. The outcomes emerging from the empirical research confirm that there is room for action in the direction of an LVC-oriented fiscal reform.

6.2 Policy recommendations

The empirical analysis demonstrates the existence of a relationship between accessibility and residential real estate values. This consideration is of fundamental importance and opens the door to policy recommendations thoughts in the direction of an LVC oriented fiscal reform.

Starting from this consideration, and drawing from the description of the LVC fiscal policies in chapter two, a side interest of this work is to suggest guiding principles to explore the potentiality of recapturing part of the initial investment in public transit infrastructure through LVC fiscal policies in Milan. A fiscal reform that would embrace LVC principles through the application of some of the policies outlined in chapter two, would reduce the public transit investment's burden on the public, and would contribute to the development of a more equitable fiscal management that would be able to keep funding further public investments. As noted by different authors (Alterman, 2010; Fensham & Gleeson, 2003; Germán & Bernstein, 2016) the application and use of LVC policies is likely to expand and intensify around the world in the near future. To reduce the shortcomings deriving from the complexity of such instruments and consequently ease adoption process of such policies, a series of suggestions and preconditions are identified:

- Public authorities should hire, among the ranks of their employees, well-trained professionals in the field of urban planning or real estate, that would be able to negotiate with the developers, to develop models of impact assessment and to assess the limits of what may be exacted from the developer and property owners without generating undesired negative effects.
- At the local level, public authorities should monitor land prices fluctuations in order to be able to challenge potential complaints that the LVC policies in fact raise the cost of housing or other real estate products. This added care in turn would favour political consensus and foster social acceptability.
- In areas where corruption levels are high, public authorities should refrain from adopting discretion-based value capture instrument (such as Negotiated Exactions), since for these kind of policies a precondition for their successful application is a good level of trust in government.
- Consequently, and in a more general way, discretion-based value capture instrument should be accompanied by sufficient levels of transparency to help withstand legal challenges and maintain the whole system well lubricated (although full transparency on the other hand may clash with the developer's economic interest to protect its private affairs).
- In the case of the application of LVC policies on property owners, a "worsement" compensation fund should also be made available and would be paid where the value of land prior from an infrastructure project resulted higher than that of the actual condition. This kind of compensation recognises the possibility of potential losers following governments decisions regarding urban development and management (with the awareness that, if planning increases efficiency as a whole, "betterment" will always be greater than "worsement"). This solution would preserve the integrity and equity of the system.

6.3 Conclusion and future directions

Despite going a long way if thinking about where it originated from, this work leaves some relevant open questions unanswered. Furthermore, as it was getting closer to a conclusion, it opened up new research lines that will need to be independently investigated in order to provide a more comprehensive understanding of the Milanese case.

First, a more comprehensive approach should incorporate the study of land values for commercial properties transactions, and, potentially more important, residential properties for rent. It is often the case, in fact, that the former properties are those more closely interested in capturing transit users flows, while the residential properties for rent are usually occupied by a younger population of students and workers, highly mobile and increasingly without a private vehicle in possession. These properties are supposed to emerge with even higher accessibility coefficients when analysed through an HPM model.

Secondly, a further line of research would be that of investigating how land value related to infrastructure accessibility is capitalized in different areas of the city, assuming that a more central location results in more transportation choice and shorter distances to cover. This triggers a whole set of ideas and thoughts that would need a more detailed origin-destination matrix that would somehow rank each of the stations by the accessibility to the system it provides, with a stronger differentiation. On the same reasoning line, the lack of information on working destinations, leisure habits of the population and their geographical description further contributes to limiting the overall accuracy of the HPM model of this research.

Lastly, from the policy side, a further line of investigation is represented by the testing of different LVC policy combinations and their revenue collection capacity for the Milanese metro network, with a special focus on the upcoming M4 Blue line. Ideally, this would have been the desired conclusion of this work but, acknowledging the complexity of the issue, the decision was to leave this interesting topic for a future research.

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Appendix

1. General layout: t = 1
2. Specific announcement: t = 2
3. Basic engineering project: t = 3
4. Start of construction: t = 4
5. Opening: t = 5
6. Completion: t = 6

Addition of new stations: + *n*

Year	House data	M1 Red	M2 Green	M3 Yellow	M5 Lilac	M4 Blue
1952		t = 1	t=1			
1953						
1954						
1955		t = 2	t = 2			
1956		t = 3	t = 3			
1957		t = 4	t = 4			
1958						
1959						
1960						
1961						
1962						
1963						
1964		t = 5				
1965						
1966		+ 4				
1967						
1968						
1969			t = 5			
1970			+ 1			
1971			+ 2			
1972			+ 8			
1973						
1974						
1975		+ 4				
1976						
1977				t = 1 / t = 2		
1978			+ 3			
1979						
1980		+ 4				
1981			+ 3	t = 3 / t = 4		
1982						
1983			+ 3			
1984						
1985			+ 3			
1986		+ 3				
1987						
1988						
1989						
1990				t = 5		
1991				+ 7		
1992		+ 1				
1993						
1994			+ 1			
1995				+ 1		
1996						
1997						
1998						
1999					t = 1	
2000						
2001						
2002						
2003				+ 1	t = 2	
2004						
2005		t =6	+ 1			t = 1
2006	•				t = 3	
2007	•				t = 4	
2008	•					
2009	•					
2010	•					t = 2
2011	•		t = 6	t = 6		t = 3
2012	•					t = 4
2013	•				t = 5	
2014	•					
2015	•				t = 6	
2016	•					
2017	•					
2018						
2019						
2020						
2021						t = 5
2022						
2023						t = 6

Table 7. Timeline of the Metropolitana di Milano. Produced by the author