경제학석사 학위논문

The Impact of Road and Urban Railway Network Accessibility on Housing Prices

도로와 도시철도 접근성이 주택가격에 미치는 영향

2021년 8월

서울대학교 대학원

농경제사회학부 지역정보학전공

이 호 준

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이호준의 석사 학위논문을 인준함
2021년 8월

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Abstract

The Impact of Road and Urban Railway Network Accessibility on a Housing Price

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This study analyzed the effect of employment centers' accessibility level on housing prices, focusing specifically on the road and urban railroad network layout in Seoul. Using 2019 housing transaction data from the city of Seoul and the city's transportation networks to measure gravity-based accessibility, I estimated the housing price functions for three general categories of housing lot size. The analysis reveals that greater transportation network accessibility to multiple business districts positively affects housing prices, and the road and railway accessibility elasticities were 4.0146 and 0.8385, respectively. Moreover, we found that the impact of road accessibility on housing prices was larger than that of railway accessibility, regardless of housing lot size. However, the impact of railway accessibility was relatively higher for small- and medium-sized houses than for large houses, and road accessibility was a more prominent price-determining factor for large houses, which may be due to the relationship between residents′ commuting preferences and the size of their residences. In addition, we found a complementary relationship between accessibility to the business district by road and railway, implying that demand for different means of commuting exists. Meanwhile, despite controlling for accessibility to the workplace, it was determined that the relationship between distance to the Gangnam business district in Seoul and housing price was significantly negative, suggesting that the Gangnam business district plays an important role in providing urban amenities. Lastly, it was predicted that house prices would change if urban railway accessibility was improved and found housing price disparities between and within five areas in Seoul based on the scenarios of different railway lines’ development. Therefore, policymakers and urban planners must also consider these impacts on the housing market when developing transportation networks. Additionally, they must address different household characteristics and how they are related to different transportation mode preferences when implementing housing market policies in order to improve accessibility when developing transportation networks.

주요어 : **Housing price, Proximity to the urban center,
Gravity-based accessibility, Transportation network**

학 번 : 2019-20252

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Chapter 1. Introduction

The accessibility to multiple workplaces from one's residence has become an important factor for price calculation in Seoul's housing market. According to the 2019 Korean Housing Survey conducted by the Ministry of Land, Infrastructure, and Transport (MLIT), 29% of the respondents in the Seoul Metropolitan Area stated that they moved to new residences due to a change in employment, and therefore wanted to be closer to their workplaces—the second-highest reason for relocation. In 2008, 42% of employees in Seoul resided in the same locations as their workplaces, a figure that rose to 51% in 2018. Accessibility to the workplace has become an important factor to consider for home purchasers, as more severe traffic congestion in recent years has increased commute times. Moreover, life near a business district, where living infrastructure is well-established, provides residents with more convenient access to urban amenities. Therefore, housing prices have continued to rise in regions with better workplace accessibility, as preference for residence close to the workplace becomes more prevalent.

Furthermore, the importance of accessibility has been highlighted by Seoul's planning authorities. The Seoul Metropolitan Government's Seoul 2030 Urban Master Plan establishes the goal of reorganizing the city's overall urban structure from consisting of 1 major center, 5 subcenters, and 11 regional centers, to transforming into 3 major centers, 7 subcenters, and 12 regional centers. This urban plan recognizes the urban structure of Seoul as a polycentric city, and emphasizes the decentralization of urban functions to various regions. Consequently, the accessibility to multiple regions is likely to become a key factor for people seeking to enjoy a variety of urban services, including jobs. Heikkila et al. (1989) developed several explanations for the phenomenon by which residential property values may be affected by accessibility to each business district, including: an increase in turnover, an increase in multiple-worker households, and the discordance between former and successive residents' workplace locations. The fact that the turnover rate is greater than 30% and that the multiple-worker household rate is over 40% in Seoul highlights the importance of multi-regional accessibility when choosing housing location.

This study focused on analyzing the relationship between the accessibility to multiple workplaces and housing prices in Seoul, which has become a polycentric city with decentralized employment, and where the preference for accessibility to business districts is increasing. The house price function was estimated using variables that include transport network accessibility indicators, which were measured by the weighted sum of residence-to-work travel times by road and railway networks.

The remainder of this thesis is organized as follows: Chapter 2 introduces the theoretical background and reviews previous literature discussing the relationship between housing prices and accessibility and methods for measuring accessibility; Chapter 3 presents the analysis, methodology, data, variables, and estimation results for the housing price function; and finally, Chapter 4 summarizes the results, explains their policy implications, and discusses future possible research directions.

Chapter 2. Literature Review

This chapter explains the theoretical background of the trade-off model between house price and accessibility to employment, and reviews the empirical studies discussing the impact of accessibility on housing prices and different methods of accessibility measurement.

2.1. Theoretical Background

The theoretical framework for examining the trade-off between house price and spatial employment accessibility is based in classical urban land-use microeconomic theory. The basic urban trade-off model is derived from the work of Alonso (1960), and was further elaborated by Brueckner (1987). The key concept of this model is that a change in commuting cost must be balanced by corresponding changes in housing price and consumption in order to maintain household utility and guarantee that households fully maximize their utility.

This trade-off model is largely based on four assumptions (Brueckner, 2011); 1) All jobs in the city are in the central business district (CBD), 2) the city has a dense radial road network, 3) the households residing in the city are homogeneous, meaning that all households have identical preferences, and 4) the city's residents consume only two types of goods: a composite non-housing good and housing. Among these assumptions, the second assumption could be eased to focus on a general transportation network rather than a radial road network by using the network distance of transportation networks. Under this model's four assumptions, the common strictly quasi-concave utility function of households is written as Equation 3-(1)

$$u = u(c, q) \qquad 3\text{-}(1)$$

where c is the consumption of a composite non-housing good and q is the consumption of housing in square feet. Commuting cost per unit of distance is denoted as t, thus the commuting cost for residents living x network distance from the CBD is calculated as tx. Let household income be denoted by y, with the disposable income for households living at network distance x from CBD represented by $y-tx$. If the unit price of composite goods c is 1 and the housing price per square feet is denoted as p, the household's budget constraint is set as Equation 3-(2).

$$c+pq=y-tx \qquad 3\text{-}(2)$$

It is assumed that the price of composite goods is the same at any given location of the city, and therefore spatial variation in p is the important factor which represents the existence of equal utility everywhere in the city. Replacing c in the utility function by the budget constraint Equaition 3-(2), the household's utility maximizing problem is written as Equation 3-(3).

$$\max_{q} u(y-tx-pq, q) \qquad 3\text{-}(3)$$

Solving the household's utility maximizing problem with the budget constraint Equation 3-(3), with the first order conditions, the marginal rate of substitution between consumption of the composite goods and consumption of housing is calculated as

$$MRS=\frac{u_2}{u_1}=p \qquad 3\text{-}(4)$$

where u_1 and u_2 are the partial derivatives of utility for each type of good.

Supposing that there was an additional requirement where the maximized utility level is u_0 as shown in Equation 3-(5), then the solutions of q and p rely on the value of parameters x, y, t, u_0.

$$u(y-tx-pq,q)=u_0 \quad 3\text{-}(5)$$

$$q=q(x,y,t,u_0) \quad 3\text{-}(6)$$

$$p=p(x,y,t,u_0) \quad 3\text{-}(7)$$

To identify the trade-off relationship between the distance from CBD and housing price, Equation 3-(5) is completely differentiated with respect to x.

$$-u_1\cdot\left(t+p\frac{\partial q}{\partial x}+q\frac{\partial p}{\partial x}\right)+u_2\cdot\frac{\partial q}{\partial x}=0 \quad 3\text{-}(8)$$

Using Equation 3-(4), Equation 3-(8) shows that p is a decreasing function of x as follows.

$$\frac{\partial p}{\partial x}=-\frac{t}{q}<0 \quad 3\text{-}(9)$$

This inverse relationship between p and x can be seen in Figure 1 through an indifference curve illustration. The key concept represented by this figure is that residents must enjoy equal utility at all locations regardless of where they reside in the city, when all of the households maximize their utility. As distance from the CBD x increases from x_0 to x_1, the household's disposable income decreases from $y-tx_0$ to $y-tx_1$. In order to ensure that the utility of residents living in different locations is equal to u_0, the budget line should be rotated counter-clockwise. In other words, the absolute value of the budget line's slope should be reduced, indicating a decline of p. It thereby follows that p decreases as x increases.

Based on this trade-off model between the distance to business districts and housing prices, there were many empirical studies which analyzed the impact of accessibility on residential property values. Along with the expansion of urban territory, several studies have looked at the effect of having multiple business districts, instead of only considering the CBD. In addition, with the increased emphasis on the movement to multiple regions, the accessibility variables were calculated to replace distance variables x. In Section 2.2. these empirical studies are further discussed.

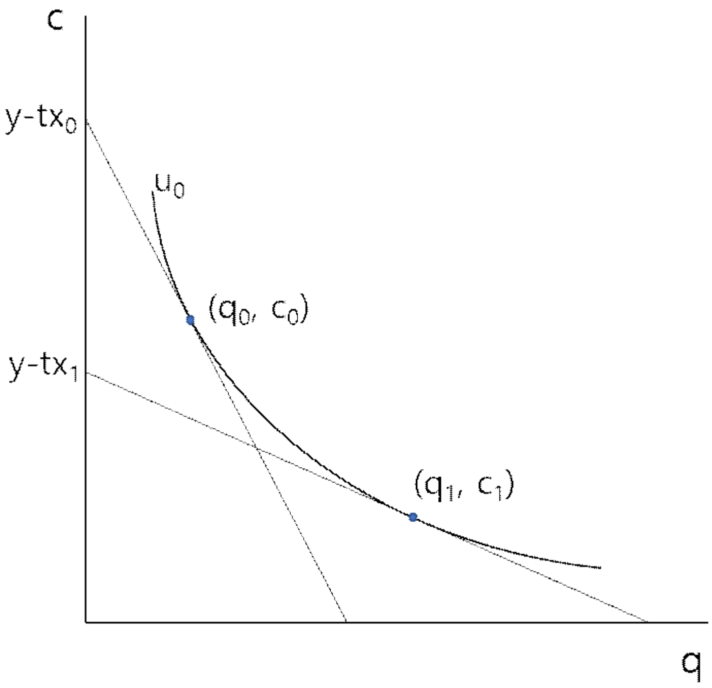


Figure 1. Household's decision-making

2.2. Empirical studies

2.2.1. Relationship between housing price and accessibility to business districts

Alonso (1960) proposed the trade-off model between the bid - rent and the distance to the city center. Several empirical studies analyzing the determinants of housing prices have investigated the inverse relationship between housing price and the distance to the central business district (CBD), where the commercial and business districts of the city are concentrated in a monocentric city. Multiple studies focused on Korea in particular have shown that housing prices fell as the straight distance between apartments and the CBD increased (Oh and Lee, 1997; Choi and Yun, 2004). Tse and Chan (2003) insisted that the physical distance from the CBD was an inadequate measure to test the urban economic location model in Hong Kong, mainly due to geographical features. They therefore suggested economic distance, including commuting cost and commuting time, as an alternative to physical distance, and detected the negative impact of economic distance on property values. By comparing the value of the gradient of economic distance with the actual cost of commuting, the results showed that the economic distance value was accurately reflected in property prices. Chen and Hao (2008) raised a question of the identical price effect of distance from the city center in any direction, and examined asymmetric price gradients, which varied depending on direction. The findings revealed that the distance between houses and the CBD had a less negative impact on housing prices located in a more economically-thriving region. Meanwhile, McMillen (2003) observed the differential effects of the CBD on housing prices over time. Using repeat sales models, McMillen discussed the decreasing influence of the CBD in the 1980s, whereas the enhanced importance of CBD indicating the return of centralization was identified in the 1990s.

Meanwhile, many studies have challenged the monocentric assumption that all employment is concentrated in the CBD, and have instead used employment subcenters to estimate housing price. Several studies controlled the distance to the CBD when analyzing housing price, but they found an insignificant effect on housing value (Kain and Quigley, 1970; Heikkila et al., 1989; Waddell et al. 1993). For instance, Heikkila et al. (1989) examined land values in Los Angeles by taking into consideration multiple employment centers, and found that distance to the CBD was insignificant and had an unexpected sign. Moreover, Waddell et al. (1993) explored nonlinear housing price gradients in a multi-nodal urban area and emphasized the influence of non-CBD employment centers on housing prices. These two studies implied that distance to the CBD was no longer a significant factor of property values. In addition, they noted the increasing impact of emerging employment centers′ accessibility on housing price.

Some studies identified the inter-temporal changes of accessibility to the CBD and subcenters′ effects on property values over time (McDonald and McMillen, 1990; Richardson et al., 1990; Bae et al., 2003; Kim and Lee, 2005). McDonald and McMillen (2003) concluded that Chicago was still a dominant center or economic activity, regardless of the growth and decline of subcenters from 1960 to 1980. Richardson et al. (1990) revealed that the distance to the CBD had a weak effect on housing prices in the 1970s, and had no influence at all in 1980. Moreover, Bae et al. (2003) showed that although the influence of the Gangnam subcenter, the subcenter located in the south-eastern part of Seoul, is larger than that of the CBD on house prices, the importance of distance to the CBD was strengthened. By contrast, the impacts of the distance to the Gangnam subcenter declined from 1989 to 2000, due to the opening of the subway's Line 5 in Seoul. Using a modified repeat sales model, Kim and Lee (2005) analyzed the dynamic changes of amenity effects on housing prices in Seoul. The impact of the CBD decreased gradually, whereas the influence of the Gangnam subcenter increased over time from 1993 to 2004.

To reflect incomplete substitutes and complements between multiple subcenters, studies have constructed and used a variable to represent multicenter accessibility as one indicator, rather than the distance to each center individually. This integrated accessibility indicator, which replaces the distance from each center, was calculated in various ways, such as using the average weight distance to each center (Ottensmann et al., 2008), or calculating gravity-based accessibility, as proposed by Hansen (1959) (Burnell, 1985; Osland and Thorsen, 2008; He, 2020). These indicators demonstrated the urban economic theory which shows that a trade-off relationship between accessibility to employment center and housing value can work properly within the polycentric city. Moreover, studies using these indicators provide evidence that integrated accessibility indicators performed better than distance (time) to the CBD.

2.2.2. Impacts of Transportation accessibility on housing price

The impact of transportation accessibility on real estate values has remained a controversial issue. In general, a positive relationship between transportation infrastructure location and house price account for a capitalization effect. However, this capitalization effect varies with the attributes of the transportation facility, the phase of the infrastructure's construction, and the economic status of residents.

Moreover, transportation accessibility and property value have a positive relationship, but transportation infrastructure can at times also adversely affect housing prices, mainly due to negative traffic externalities (e.g., noise and high congestion). Levkovich et al. (2016) separated the impact of highway development on housing prices into changes in accessibility and the negative externalities. Changes in accessibility level due to highway development were a significant factor in rising house prices, but increased noise pollution and traffic intensity caused a decline in housing prices. Sung (2011) examined the potential impacts of transit-oriented development on housing prices around subway stations in Seoul. The presence of express stations and the number of arterial roads and bus stops adjacent to the house were factors which increased the premium of apartment prices. However, the presence of an express transfer station decreased house prices due to increased congestion, regardless of the distance from the residence to the station. Lee and Kim (2014) discovered that apartment prices near on-ground multi-functional stations rose from 3.6% to 9.4%, which is lower than the price percentage changes of residences near other types of stations, mainly due to railway noise and overcrowding. This negative effect was maximized when the residences were 200 meters from the stations. Kang and Seo (2016) found that on-ground stations lowered housing prices by 7.3% when compared to the effect from underground stations, whereas express stations increased surrounding housing prices. This study also identified that the subway lines that run through commercial and business districts played an important role in increasing property values. Wang (2015) showed similar results in Beijing, where subway lines passing the CBD had a higher capitalization effect on real estate value than that of suburban lines.

Studies investigating the impact of various infrastructure accessibilities on residential property prices at different construction stages have mostly focused on new railway lines. For instance, Choi and Yun (2004) compared a coefficient of distance from the residence to the nearest station on housing prices before and after the Seoul subway's Line 7 opened. The effect of distance to the subway station was more sensitive before the opening of the line, as opposed to after the opening. Meanwhile, the catchment area of the subway station affecting housing prices broadened by 20 meters after the operation of the new line. Choi and Sung (2011) also detected that the subway accessibility was capitalized through increased property prices before the construction of the new line, and the area of the station’s influence gradually expanded as the construction stage progressed. Although house prices rose substantially due to the newly opened line, several studies reported a decreasing trend in the effect of the new line on property values after its opening (Bae et al., 2003; McMillen and McDonald, 2004; Kang and Sung, 2019). Kang and Sung (2019) attributed this result to the fact that the expectations of metro accessibility that were excessively reflected in housing prices before the new line opened, but then stabilized once the subway demand was more accurately measured.

Some studies have demonstrated that groups in different economic positions had different trade-off preferences for transportation accessibility. For instance, Seo and Nam (2019) categorized apartments into three categories according to size, and assumed that the size of apartments represented economic status. Households living in large-sized apartments were not significantly affected by subway accessibility, but those residing in small-sized apartments were more sensitive to transportation accessibility. Moreover, several studies have used quantile regression to determine the differential effects of transportation accessibility at each housing price level (Kim and Park, 2013; Bae and Choi, 2018). These studies obtained results showing that subway accessibility positively affected apartments with lower prices, but its effect was less positive or insignificant on apartments with higher prices in South Korea. Using interaction variables between transportation proximity and the administration fee, Ma et al. (2014) found that the impacts of rail station accessibility were greater for low- and medium-income neighborhoods.

2.2.3. Measuring accessibility

Accessibility is defined as a place's inherent advantage with respect to the ease of being able to participate in activities; and it is spatially distributed by overcoming spatial frictions (Hansen, 1959; Ingram, 1971). Accessibility has been calculated in various ways for several reasons: the possibility of obtaining data to measure accessibility, using a specific methodology for the analysis, and the for the purposes of research. Researchers have used three main approaches to compute accessibility: (1) Proximity dummy variables or the number of amenities in the buffer area, (2) minimum distance or time to infrastructure; and (3) gravity potential opportunities. In particular, proximity dummy variables and minimum distance or time have been used to examine the local impacts of transportation facilities, whereas gravity-based accessibility has been used to determine regional impacts.

Dummy variables and the number of facilities based on distance or travel time cut-off values generated by a concentric buffer around the house have served as a typical accessibility measure. This accessibility method was used to determine the catchment area of transportation services (Choi and Yun, 2004), to compare the price of the house with a new transportation facility (Dubé et al., 2013; Bae and Choi, 2018) and assess the capitalization effects of amenities (Sung, 2011; Yang et al., 2011; Ma et al., 2014). Dubé et al. (2013) and Bae and Choi (2018) estimated the housing price function through a difference in difference (DID) method to examine the impact of new rail lines. These studies adopted different distance ring buffers organized by a variety of cut-off criteria. They explained the effect of rail stations on house values, which depended on the different catchment areas. Sung (2011), Li et al. (2019), and Yang et al. (2019) selected the number of bus stops within a certain distance range from the house as the proximity of bus accessibility, due to the limitations of taking all bus routes into consideration. Meanwhile, Ma et al. (2014) simultaneously considered BRT station and metro station proximity dummy variables made of ring buffers.

Another common approach to measure accessibility is the minimum distance or travel time. The straight line distance from the origin to the destination is often chosen as the minimum distance. In a housing price study, the origin was the house, but the destinations varied depending on the study's analysis subject: including, the nearest rail station (McMillen and McDonald, 2004; Andersson et al., 2010; Choi and Sung, 2011; Wang, 2015; Kang and Seo, 2016; Kang and Sung, 2019), the entry of highway intersections (Oh and Kim, 2009; Andersson et al., 2010), and the number of BRT stations (Yang et al., 2019). To investigate the temporal variation of accessibility before and after the operation, some studies controlled for the interaction term between the distance from the nearest station and transaction year (McMillen and McDonald, 2004; Kang and Sung, 2019). Wang (2015) placed subway lines into three groups according to where subway lines passed, and included the shortest distance to a subway station according to each group as a variable to examine heterogeneous capitalization effects. The straight line distance, as the minimum distance, does not reflect the actual distance; therefore, shortest network distance and the travel time to transportation facilities gained popularity as indicators of accessibility (Des Rosiers et al., 2000; Tse and Chan, 2003; Bae et al. 2003; Rodríguez and Targa, 2007; Dorantes et al., 2011; Bae et al. 2018).

There have also been housing price studies which have shown that gravity-based accessibility is well-suited for measuring different-sized populations' accessibility to decentralized opportunities (Mitra and Saphores, 2016). Additionally, this accessibility had the advantage of measuring the regional impact of transportation infrastructure. In order to fully capture both transportation's local and regional impacts in the long-term, the traffic flow of the region should also be taken into consideration (He, 2020). Hansen (1959) formulated the basic idea of gravity-based accessibility, which is a function of the difficulty of arriving at any given destination, which is essentially a decreasing function of the distance weighted by the opportunities available in each destination. The form of the decreasing function has continued to vary with different studies. Burnell (1985) defined accessibility as the sum of manufacturing employment divided by simple travel cost. Meanwhile, Levkovich et al. (2016) calculated potential economic accessibility with a weighted negative power function. Instead of dividing opportunities into a power function of distance or travel time, many studies adopted the negative exponential function as a decreasing function (He, 2020; Adair et al., 2000; Ahlfeldt, 2011; Osland and Thorsen, 2008; Giuliano et al., 2012). He (2020) computed accessibility as an assumption that all employment zones had the same weight. However, the number of trips (Adair et al. 2020) and the number of jobs (Osland and Thorsen, 2008; Ahlfeldt, 2011; Giuliano, 2012) are weighted in each destination to reflect the different opportunities at each zone when computing accessibility.

2.3. Summary

In summary, analyses of the impact of workplace accessibility from residential areas on housing prices must take several issues into consideration. First, to reflect the polycentric structures of cities, we should use spatial accessibility trade-off models that reflect multi-regional accessibility in order to best estimate housing price functions. As cities expand their urban territories expand, they begin to develop polycentric urban structures. Several studies have obtained unexpected results by estimating housing price functions for monocentric cities that are actually polycentric. The emergence of new business districts has necessitated the modification of the traditional spatial accessibility trade-off model, which only had one business district, to now take into consideration the accessibility to multiple centers. Second, the impact of transportation accessibility on housing price is determined by the characteristics of the transportation infrastructure and the economic level of the people living near the facilities. This implies that the qualitative characteristics of transportation facilities—for example, whether nearby metro lines can be used for convenient transportation to major office districts and whether negative factors (e.g., noise and overcrowding) are present—are also important determinants of housing price. Finally, different accessibility measurements have been used to determine the local and regional impacts of transportation. Therefore, an appropriate accessibility measurement must be selected, depending on the scope and purposes of the study, and the available data.

Taking these issues into consideration, this study analyzed the impact of accessibility to multiple business districts on housing prices using transportation networks in Seoul. Additionally, while previous studies have measured accessibility using only one of the dominant transportation networks in the city (either road or rail networks), the present study examined the impact of both the road and urban railway networks within the city's broader transportation network, as they are both important methods of commuting in Seoul. These points comprise the main contributions of this study.

Chapter 3. Analysis

3.1. Methodology

3.1.1. Measuring network accessibility

Gravity potential accessibility is adopted to measure the accessibility of each house to other districts in Seoul, assuming a polycentric urban structure of Seoul. In general, A_i, the gravity-based accessibility of house i considering decentralized opportunities, is computed as Equation 3-(10).

$$A_i = \sum_j B_j f(t_{ij}) \tag{3-(10)}$$

where B_j represents the opportunities at district j and t_{ij} is the network distance from house i to the center of district j. f is the distance decay function in which the accessibility decreases as t_{ij} increases. The gravity-based accessibility indicators are the weighted sum of the difficulties of reaching each district′s center for each district’s respective opportunities.

I verified the hypothesis that residents prefer houses located a suitable distance from employment opportunities using the number of places of employment in each district denoted as B_j. The functional form of the distance decay function is selected as a negative exponential function, as expressed by Equation 3-(11).

$$f(t_{ij}) = e^{-\beta t_{ij}} \tag{3-(11)}$$

β is the impedance parameter of the distance decay function which is typically determined using observed travel distance or time. Yi and Kim (2016) estimated the value of β for railways and roads in South Korea. Referring to Yi and Kim (2016), the present study determined the values of β for road and railway as 0.017 and 0.009, respectively.

A road network distance and a railway network distance are measured in different ways. The road network distance is the shortest travel time taken from the residential zone i to the center of each district j while using the road network. The shortest travel time is calculated by assuming that if the speed limit is more than 60 km per hour, residents move to 60 km per hour; otherwise, residents move at the maximum speed limit of the road. The railway network distance is composed of three parts: (1) The travel time using the metro from the nearest station of house i to the nearest station of the center of district j; (2) the walking time from house i to its nearest station; and (3) the walking time from the center of district j to its nearest station. When calculating the travel time by metro, I constructed the origin-destination time matrix of railways between all stations in Seoul, and considered the different transfer times for each station. For the walking time measurement, I assumed the average walking speed to be 4 km per hour. These accessibility indicators measured in two transportation modes using gravity-potential methods were selected as the proxy variables of proximity to the multiple business districts.

3.1.2. Hedonic price model

Since Rosen (1974) elaborated the theory of hedonic prices based on the spatial equilibrium of consumers and producers' locational decisions, the hedonic price model has been the most widely used model to investigate the determinants of residential property values. In hedonic theory, each housing is addressed as a component of different products, in that the observed price of housing relies on a vector of each house's characteristics. Revealed housing price is composed as a set of the implicit prices for the attributes of each house.

Various factors determine housing price, and the model divides these factors into three categories: 1) Housing structure (floor area, age of dwelling, and the number of rooms, bathrooms, and parking); 2) accessibility (distance to CBD or other region); and 3) locational attributes (distance to school, shopping center, park, and transportation facilities). Taking these into account, the housing price is expressed as Equation 3-(12)

$$P_i = g(H_i, A_i, L_i) \tag{3-(12)}$$

where P_i is the observed housing price and H_i, A_i, L_i are the hedonic characteristic vectors of the housing structure, accessibility, and locational attributes, respectively.

This study adopted the double-log hedonic price function by transforming both the independent and dependent variables into log values, in order to allow for the interpretation of the independent variable's coefficients as a series of elasticities (Heikkila et al., 1989). These elasticities explain the relative implicit prices of housing characteristics, not the absolute effects of housing attributes. Therefore, the double-log hedonic price function (rather than distance or traveling time) is suitable in this study because it is difficult to use the absolute gravity-based accessibility value itself to intuitively explain the impacts on housing price. Equation 3-(13) presents the hedonic price function.

$$\log P_i = \alpha_i + \sum_h \beta_h \log(H_{ih}) + \sum_a \beta_a \log(A_{ia}) + \sum_l \beta_l \log(L_{il}) + \varepsilon_i \tag{3-(13)}$$

3.2. Data

This study focuses on housing prices in Seoul, where the apartment is the most common housing type. Therefore, for the purpose of this study, the housing price is defined as the sale price of apartments. The sample period is the year 2019, when housing prices were relatively more stable due to less government intervention in the housing market as compared to other years. In addition, the available road network and the urban railway network data is taken from annually-gathered data. Similarly, the transportation network data is also taken from annually-gathered data; thus, changes in the network in the middle of the year are not easily reflected. In particular, new urban rail lines and stations were opened and added in the middle of years other than 2019, making it difficult to control for them properly.

Table 1 describes the data sources of the variables. A total of 74,815 apartment transactions across 5,992 apartment complexes in Seoul in 2019 published by MLIT and “Naver real estate” are used to analyze housing prices and characteristics. Housing data are constructed by combining data from these two sources. Data with missing information from either source are excluded from the dataset.

To measure accessibility indicator, I must obtain the following: transportation network GIS data, urban railway operations information, and the level of employment by districts. The Korean Transport Database provides Railway network and road network GIS data, and the road network data were used without additional processing for our network analysis. However, for urban railway network data, each line’s operation timetables and station operation information, published by Korail and Seoul Metro, were incorporated into the urban railway network GIS data in order to take transfer times and the travel times between stations into consideration. The data on the number of workers in 424 districts of Seoul were obtained from the, "Statistics on the number of businesses and employees in Seoul" dataset, compiled by the Seoul Metropolitan Government.

In analyzing housing prices, I need to control for urban amenity services, facility data, and the location attributes of houses, such as parks, shopping centers, and schools. Urban amenity services and facility information come from the Seoul Metropolitan Government and the Ministry of the Interiors and Safety. These data contain the address and coordinates of parks, stores, and schools, which can be used for network analysis.

Table 1 Data source of variables

Variable	Data	Source
Housing characteristics	The real housing transaction price data	Ministry of Land, Infrastructure and Transport (MLIT)
	Naver real estate	Naver portal site
Accessibility indicators	Railway network GIS data	Korean Transport Database
	Road network GIS data	Korean Transport Database
	Metro time table	Korail, Seoul metro
	The number of employees by districts	Seoul government
Location attributes	Information of park	Seoul government
	Licensing information of shopping center	Seoul government
	Information of school and university	Ministry of the Interiors and Safety (MIS)

3.3. Variables

Table 2 presents the description of variables used to estimate the hedonic price of housing. The dependent variable is the average transaction sale price of apartments per square meter in the same area in the same apartment complex. Despite controlling for house attributes within housing that shares common facilities and the same area, housing prices vary depending on inaccessible information of housing conditions, such as the direction of the window of each apartment and the views of the apartments (Tse and Chan, 2003). Using the mean sale price of all housings instead of individual transaction price can help minimize the influence of variables that are difficult to observe.

The hedonic model in Section 3.1.2 posits that variables affecting housing prices are classified into three categories. Among the three categories, the main explanatory variables in this study consist of accessibility variables. Meanwhile, road and railway accessibility indicators measured by gravity-based accessibility are used as accessibility variables. These variables indicate the convenience of moving to another area, which means that the larger the value, the easier it is to move to other regions. Traveling times from each residence to the three major business districts, namely, the CBD, the Yeouido business district (YBD), and the Gangnam business district (GBD), are used to examine whether accessibility indicators could substitute the distance to the city center within a polycentric city structure framework of analysis.

Variables in housing attribute category include heating type, entry type, area, age, number of rooms, bathrooms, apartment parking lots, and the total number of households in apartment complexes, which were drawn from previous studies which analyzed characteristics of the Seoul housing market environment. The number of rooms, bathrooms, and parking lots are adopted as explanatory variables when estimating the hedonic price of the house. Meanwhile, a linear relationship does not exist between the apartment price and the apartment age due to the issue of reconstruction in Seoul; thus, the apartment age is considered the square term. The total number of households and heating type are used to control the resident's response to housing costs, as apartment complexes with more households tend to have low maintenance fees, and heating costs vary depending on the heating type. Moreover, the entrance type is classified into a stair type and corridor type: corridor-type apartments could cause privacy violations and noise pollution as all households on the same floor share a single corridor, whereas stair-type apartments have a structure in which only two households share stairs with elevators. Therefore, the entrance type is controlled in terms of privacy protection and noise pollution.

Meanwhile, location characteristics are used to control the local impact of amenities around the house. I used the network distance to the nearest urban railway station to identify advantages of improving accessibility or disadvantages due to noise and overcrowding at the local level because of its location near the subway. Characteristics of the nearest station, such as transfer, ground, and rapid stations, are also used to supplement the network distance to the nearest station variable. Many previous studies reported that educational factors affect housing prices resulting from the high demand for educational services in South Korea. Educational factors are controlled for by the distance of middle schools because middle school districts play a vital role in college entrance examination. Moreover, the number of private educational institutions by district was adopted as a variable, because people prefer houses located in districts where educational institutions are concentrated, due to the aforementioned high demand for education. Meanwhile, distance to university is used to control for the negative externality of the entertainment district around the university. Lastly, distance to park and shopping centers is used because the presence of amenity facilities near the house can have a positive impact on housing prices.

Table 2 Variables Description

	Variable	Definition	Unit
Dependent variable	Price	Sale price of apartments per square meter	10,000won/m^2
House Attributes	Size	Exclusive area for apartments	m^2
	Age	Apartment Age	Year
	Room	Number of rooms	Number
	Bathroom	Number of bathrooms	Number
	Parking	Number of parking lot per household	Number
	Household	Number of apartment household	Number
	Heat	Heating type (1=individual, 0=others)	Dummy
	Entry	Entrance type (1=stair, 0=others)	Dummy
Accessibility	Railway	Weighted sum of accessibility to each business district using urban railway network	Indicator
	Road	Weighted sum of accessibility to each business district using urban road network	Indicator
	CBD	Network distance to CBD	Meter
	YBD	Network distance to YBD	Meter
	GBD	Network distance to GBD	Meter
Location Attributes	Station	Network distance to nearest urban railway station	Meter
	Transfer	Nearest station (1=transfer, 0=non-transfer)	Dummy
	Ground	Nearest station (1=ground, 0=underground)	Dummy
	Rapid	Nearest station (1=rapid, 0=non-rapid)	Dummy
	Mart	Network distance to nearest shopping center	Meter
	Middle	Network distance to nearest middle school	Meter
	University	Network distance to nearest university	Meter
	Park	Network distance to nearest park	Meter
	Education	Number of private educational institution by district	Number

3.4. Results

Table 3 presents the descriptive statistics for the variables. The basic prices statistics indicate that the distribution of housing price per square meter is skewed to the left, implying that transforming the price variable to log values is appropriate when estimating price function.

Table 3 Descriptive Statistics

Variable	Min	Max	Mean	Standard Deviation	Unit
Price	225.92	4,104.62	943.49	485.60	10,000won/m^2
Size	10.78	272.74	85.27	36.99	m^2
Age	1	52	17.65	9.29	Year
Room	1	8	3	0.83	Number
Bathroom	1	5	1.70	0.50	Number
Parking	0.02	15.35	1.23	0.75	Number
Household	1	12,456	560.62	875.97	Number
Heat	0	1	0.76	0.42	Dummy
Entry	0	1	0.76	0.43	Dummy
Railway	176.32	358.04	292.31	28.32	Indicator
Road	370.84	452.92	422.91	18.52	Indicator
CBD	423.24	28,060.95	13,490.28	4917.60	Meter
YBD	299.26	34,796.76	15,120.07	7730.35	Meter
GBD	396.27	32,932.79	15,382.42	6923.80	Meter
Station	1.07	4,468.99	845.37	532.20	Meter
Transfer	0	1	0.24	0.42	Dummy
Ground	0	1	0.20	0.40	Dummy
Rapid	0	1	0.04	0.19	Dummy
Mart	4.01	7,410.57	1,995.65	1,223.51	Meter
Middle	1.72	4,347.75	916.29	629.47	Meter
University	13.99	10,584.01	2,691.13	1,644.12	Meter
Park	6.20	7,510.55	1,857.98	1,073.81	Meter
Education	56	1779	631.73	440.06	Number

Figure 2 presents the value of the railway accessibility indicator, and Figure 3 shows the road accessibility indicator on a map of Seoul. Road and railway accessibility are high for dwellings in the center of Seoul, but they tend to decrease for housing in the city's suburban regions. More specifically, there is a further difference between the two measures, as the value of road accessibility decreases radially from the center, whereas the value of railway accessibility reduces irregularly depending on the location of the urban railway line. Figure 4 presents a map of housing prices per square meter in Seoul. It shows that the highest housing price per square meter is near the GBD, which has the largest number of workers in Seoul, followed by the central part of Seoul. Meanwhile, the north-eastern part of Seoul has lower housing prices than those of other regions. Based on the pattern shown in the three figures, I can infer that the accessibility to multiple workplaces accessibility through transportation networks is a key determinant of housing price.

Figure 2. Railway accessibility indicators in Seoul

Figure 3. Road accessibility indicators in Seoul

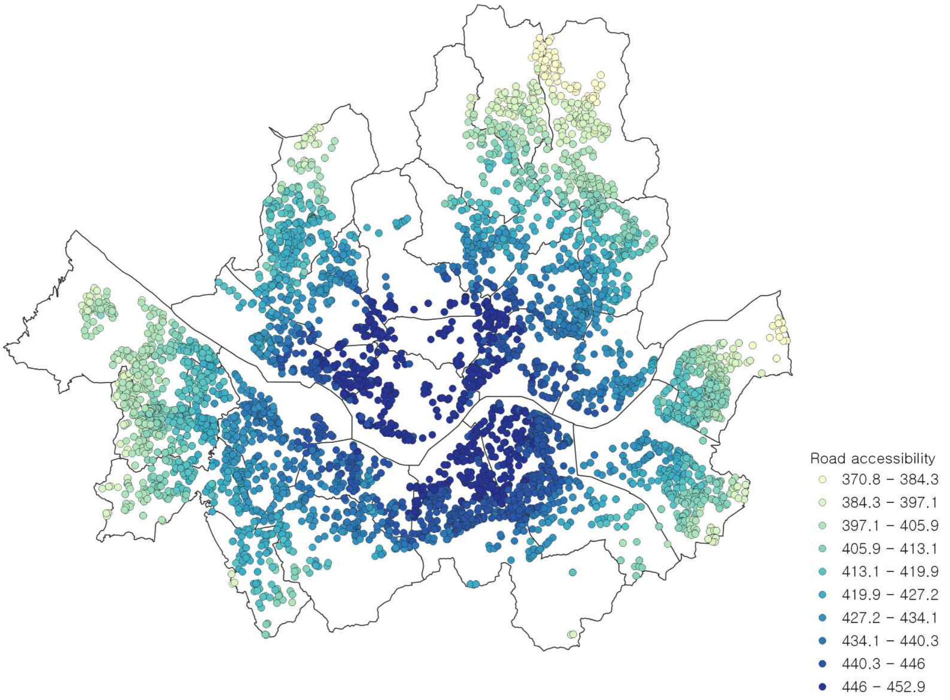
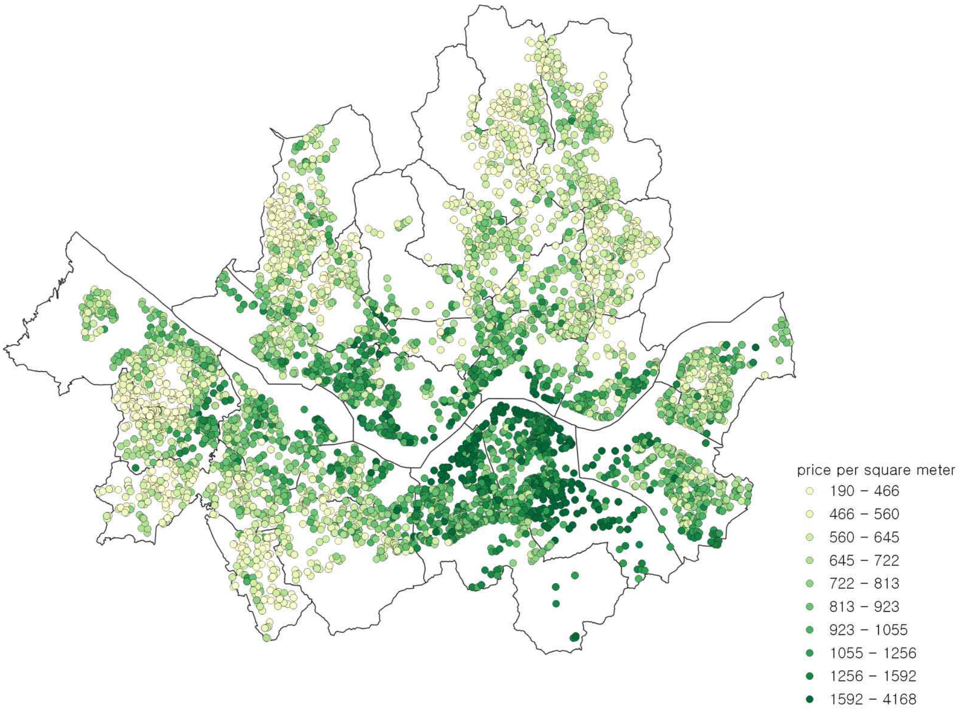


Figure 4. Housing Price per square meter in Seoul



A hedonic housing price function is estimated by dividing housing into three categories: small, medium, and large houses. The small house group included houses with exclusive areas of less than 60 m^{2}, the medium house group included houses with exclusive areas of more than 60 m^{2} and less than 85 m^{2,} and the large house group included houses with exclusive areas of more than 85 m^{2}. The preference for accessibility varies depending on the residential areas, which could be a proxy variable for the number of household members and the economic status of the households in Korea. In addition, the interaction term for road accessibility and railway accessibility is also included in the estimation, in order to identify the substitute and complementary relationships between roads and railways. Table 4 presents the estimated housing price function results.

Table 4 Results of housing price function

	Variable	All	Small	Medium	Large
House Attributes	log(Size)	−0.2615*** (0.0116)	−0.1995*** (0.0204)	−0.0704* (0.0424)	−0.0230 (0.0300)
	log(Age)	−0.2117*** (0.0124)	−0.1122*** (0.0176)	−0.1271*** (0.0222)	−0.5951*** (0.0400)
	log(Age)^{2}	0.0198*** (0.0030)	−0.0062 (0.0048)	−0.0015 (0.0052)	0.0971*** (0.0084)
	log(Room)	0.1516*** (0.0133)	0.1470*** (0.0183)	0.0616* (0.0355)	−0.1310*** (0.0352)
	log(Bathroom)	0.0024 (0.0107)	0.0687*** (0.0199)	−0.0225 (0.0163)	−0.0457 (0.0307)
	log(Parking)	0.1064*** (0.0064)	0.1109*** (0.0107)	0.0834*** (0.0102)	0.0898*** (0.0138)
	log(Household)	0.1331*** (0.0018)	0.1312*** (0.0038)	0.1441*** (0.0025)	0.1200*** (0.0037)
	Heat	−0.1935*** (0.0067)	−0.2111*** (0.0133)	−0.1796*** (0.0098)	−0.1702*** (0.0128)
	Entry	0.0189*** (0.0061)	0.0287*** (0.0096)	0.0149* (0.0091)	−0.0197 (0.0142)

Table 4 Results of housing price function (continued)

Accessibility	log(Railway)	-38.4672^{***} (3.4174)	-26.3704^{***} (6.4064)	-43.5436^{***} (4.5801)	-59.4865^{***} (7.4201)
	log(Road)	-32.8903^{***} (3.1683)	-21.9025^{***} (5.9411)	-38.3056^{***} (4.2407)	-50.9900^{***} (6.8865)
	log(Railway) *log(Road)	6.4999^{***} (0.5663)	4.5260^{***} (1.0619)	7.3767^{***} (0.7598)	9.8834^{***} (1.2278)
	log(CBD)	0.0201^{**} (0.0079)	0.0405^{***} (0.0157)	0.0723^{***} (0.0113)	-0.0333^{**} (0.0145)
	log(YBD)	0.0180^{**} (0.0050)	0.0135 (0.0097)	0.0103 (0.0074)	0.0185^{**} (0.0093)
	log(GBD)	-0.1144^{***} (0.0070)	-0.0736^{***} (0.0136)	-0.1614^{***} (0.0106)	-0.0931^{***} (0.0123)
Location Attributes	log(Station)	0.0398^{***} (0.0043)	0.0347^{***} (0.0073)	0.0442^{***} (0.0061)	0.0277^{***} (0.0093)
	Transfer	-0.0212^{***} (0.0057)	0.0042 (0.0103)	-0.0179^{**} (0.0079)	-0.0490^{***} (0.0117)
	Ground	-0.0288^{***} (0.0064)	-0.0262^{**} (0.0114)	-0.0350^{***} (0.0087)	-0.0426^{***} (0.0139)
	Rapid	0.1303^{***} (0.0122)	0.1266^{***} (0.0237)	0.1209^{***} (0.0172)	0.1511^{***} (0.0227)
	log(Mart)	-0.0267^{***} (0.0031)	-0.0294^{***} (0.0057)	-0.0264^{***} (0.0043)	-0.0204^{***} (0.0065)
	log(Middle)	-0.0051^{*} (0.0028)	-0.0059 (0.0052)	-0.0100^{***} (0.0038)	-0.0018 (0.0061)
	log(University)	0.0679^{***} (0.0036)	0.0718^{***} (0.0069)	0.0504^{***} (0.0049)	0.0789^{***} (0.0072)
	log(Park)	-0.0005 (0.0032)	-0.0061 (0.0059)	-0.0021 (0.0044)	0.0035 (0.0065)
	Education	0.1417^{***} (0.0048)	0.1204^{***} (0.0093)	0.1323^{***} (0.0069)	0.1746^{***} (0.0089)
	Constant	200.9552^{***} (19.0612)	132.9795^{***} (35.7246)	231.7897^{***} (25.4785)	313.3136^{***} (41.5210)
Observation		12,401	3,585	5,342	3,474
Adjusted R^2		0.7186	0.6695	0.7692	0.7210
*p<0.1, **p<0.05, ***p<0.01					

Using the coefficients of the two accessibility indicators, I identified the impact of a residential area's accessibility to multiple business districts on housing prices based on the transportation network. However, the coefficients of the accessibility indicators should be calculated by also taking the interaction term into account, as the two accessibility indicators' interaction term is included in the estimation equation. Table 5 presents the calculated results. In the total sample model, the coefficients on road and railway accessibility indicators are significantly positive at the 25%, 50%, and 75% average levels of accessibility, which means that close proximity to multiple workplace raises housing prices, regardless of the means of transportation that residents use. The railway accessibility elasticity is 0.8385, and the road accessibility elasticity is 4.0146 for the average level of alternative network accessibility. This result supports the trade-off theory that posits that there is an inverse relationship between the distance from the residence to the workplace and the housing price. Furthermore, Table 5 shows that better network accessibility increases housing prices, even when estimating only for small, medium, and large house samples, and also for the entire sample. In other words, most respondents preferred residences with better accessibility to various regions when purchasing a house, regardless of the size of the dwelling.

In addition, the coefficient on road accessibility is larger than that of urban railway accessibility, regardless of the housing sizes. This means that road network has a greater impact on housing prices than an urban railway network on a house of any size. For small-sized houses, a 1% increase of railway and road accessibility increases the housing prices by 0.9992% and 3.7954%, respectively, at the average level of alternative network accessibility. For medium-sized houses, a 1% increase in railway and road accessibility raises housing prices by 1.0455% and 3.5161%, respectively. Meanwhile, a 1% increase in rail accessibility increases housing prices by 0.4459% and a 1% increase in road accessibility lifts housing prices by 5.3374% in large-sized houses.

Table 5 Accessibility elasticity to housing price

Alternative transportation accessibility quantile	All		Small		Medium		Large	
	Rail	Road	Rail	Road	Rail	Road	Rail	Road
25%	0.6496	3.6342	0.8480	3.5067	0.8195	3.0544	0.1573	4.8412
50%	0.8962	4.1117	1.0173	3.8324	1.0471	3.5863	0.5537	5.4614
75%	1.1113	4.4745	1.1679	4.1137	1.2989	4.0075	0.7665	5.9616
Mean	0.8385	4.0146	0.9992	3.7954	1.0455	3.5161	0.4459	5.3374

However, because changes in accessibility values are not intuitive compared to changes in time or distance, for a more intuitive interpretation, the variation rate in housing prices was calculated for when road network time and railway network time increase by 1%. This calculated variation rate is based on the same criteria of a 1% increase in network time, making it easier to determine which transportation network more greatly impacts housing prices. Table 6 reports the statistics of the variation rate in housing prices when transportation network time increases by 1%. Figures 5 and 6 present the variation rate in housing in the case of an increase in road network time and railway network time, respectively.

Table 6 Variation rate in housing prices when increasing network time

Quantile	All		Small		Medium		Large	
	Rail	Road	Rail	Road	Rail	Road	Rail	Road
25%	-0.0056	-0.0087	-0.0061	-0.0084	-0.0069	-0.0079	-0.0038	-0.0107
50%	-0.0048	-0.0077	-0.0056	-0.0075	-0.0059	-0.0070	-0.0029	-0.0096
75%	-0.0039	-0.0070	-0.0049	-0.0066	-0.0049	-0.0062	-0.0009	-0.0087
Mean	-0.0047	-0.0079	-0.0055	-0.0076	-0.0058	-0.0070	-0.0021	-0.0097

Figure 5. Variation rate when increasing road network time

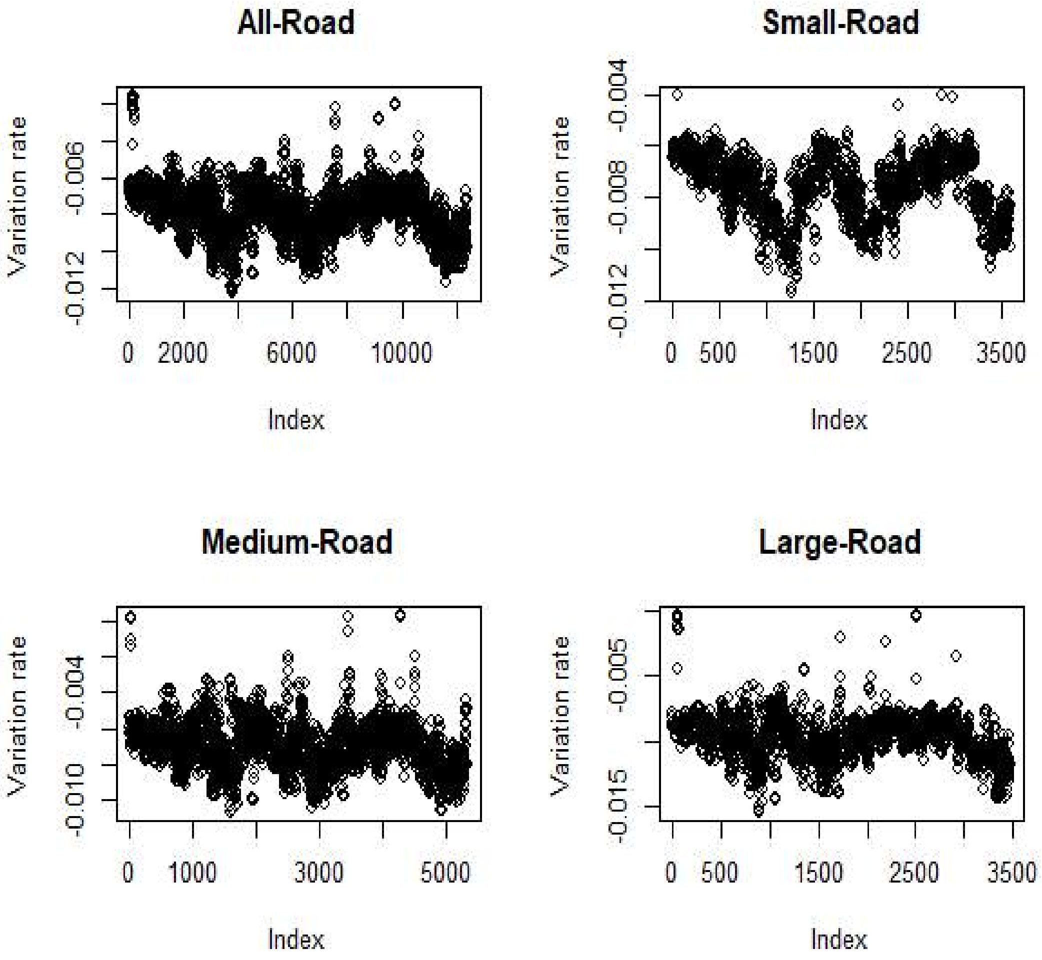
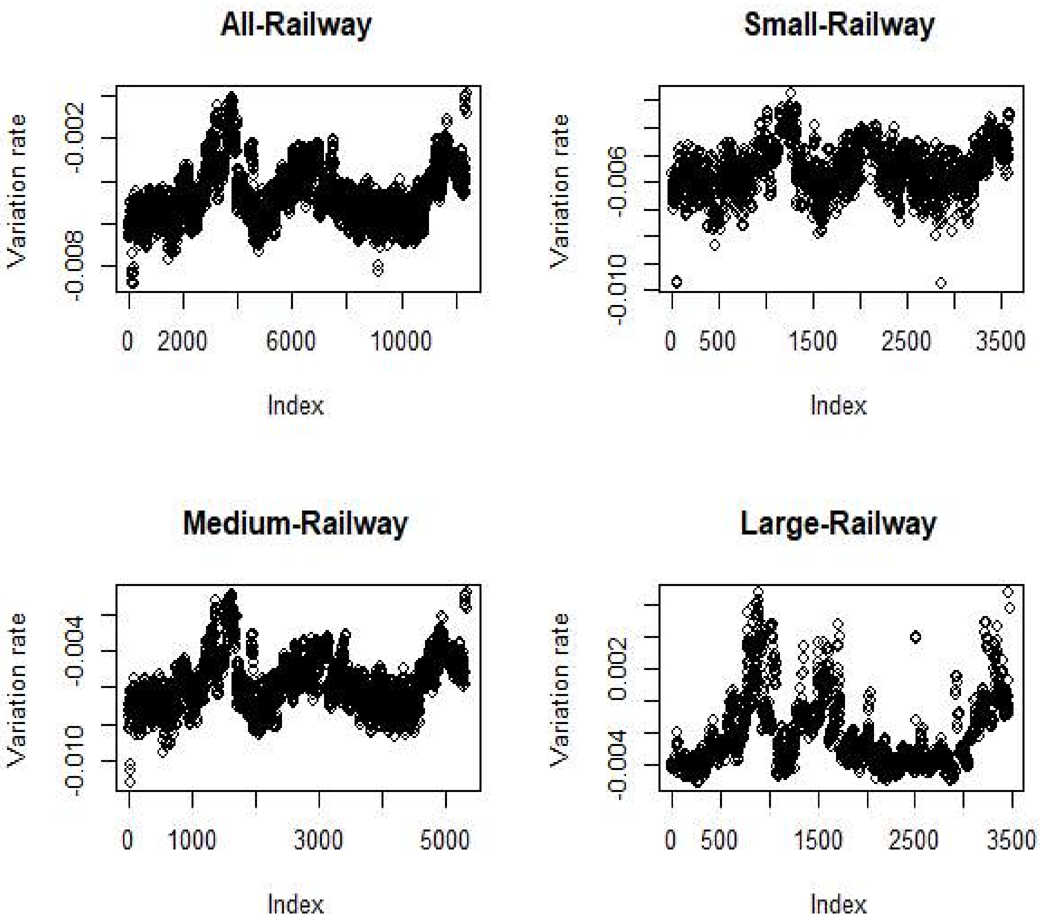


Figure 6. Variation rate when increasing railway network time



When the railway network time increases by 1%, the reduction rate in housing prices is 0.0047% on average for all samples. In the case of increased road network time, the housing price is discounted by 0.0079%. Thus, when choosing a house, the results implied that homeowners prefer road accessibility to railway accessibility within the overall housing market. The dominant transportation network is the same regardless of the housing size with regards to the variation rate in housing prices. In small-sized houses, the decreasing rate of housing prices for the railway network is 0.0055%, and the decreasing rate for the road network is 0.0076%. Meanwhile, the medium-sized housing price falls by 0.0058% for the railway network and 0.0070% for the road network. The price of large-sized houses decreases by 0.0021% and 0.0097% in the case of the railway network and road network, respectively. In small and medium-sized houses, the rates of decrease in housing prices for both transportation networks do not exhibit significant difference. The decreasing rate of housing prices for the railway network in small- and medium-sized houses is higher than that for large-sized houses. By contrast, in large-sized houses, the decreasing rate of housing prices for the road network is remarkably high. Overall, small and medium-sized houses are generally inhabited by younger individuals in their 20s and 30s (Ministry of Land, Infrastructure and Transport, 2014; 2019). Individuals who newly entering into society as adults are more likely to use the urban railway to commute rather than cars, as they have not yet built up the capital to purchase a car, and therefore, railway accessibility would rank relatively higher in importance. In contrast, residents living in large-sized houses tend to come from the relatively economically stable class. As a result, they are more likely to use cars as a means of commuting instead of public transportation, in order to minimize inconvenience. This differential preference in commuting method, according to income level and house size, may therefore explain why road accessibility would have a more significant impact on large-sized house prices than railway accessibility.

The interaction-term coefficient is positive and statistically significant, indicating the presence of a complementary relationship between road accessibility and urban railway accessibility. Moreover, the larger the house size, the larger the coefficient on the interaction terms. In the large-sized house sample, the coefficient of the interaction terms between railway accessibility and road accessibility is the largest. Thus, residents in large-sized houses consider road and railway accessibility to be more complementary than residents of small- and medium-sized houses. Within the dataset, the average number of households in large houses is higher than the average number of households in small- and medium-sized houses (MLIT, 2014; 2019). If the number of household members is large, members of various age groups are more likely to live together, making it more likely that the demand for different commuting means is high. Due to this high demand for various commuting means, residents in large houses have the most significant complementary relationship between railway and road.

For the coefficients of distance to the CBD, YBD has a positive sign, except for the coefficient for distance to the CBD for large-sized houses. Meanwhile, the coefficient of GBD is significantly negative, despite controlling for accessibility to the business districts. This implies that a close distance to the CBD or the YBD results in a housing price discount, but proximity to the GBD carries a price premium. This result is similar to that of Bae et al. (2003). The CBD is an old and traditional business district in Seoul, and so its competitiveness has declined, resulting from the relocation of urban amenities and urban attraction services to other emerging areas, thereby only having the role of providing jobs. Although the YBD, where the financial industry concentrates, has multiple urban attractions, such as large commercial establishments, the area's ability to provide jobs to financial workers has a greater impact than the appeal of urban leisure activities. In contrast, the negative elasticity of distance to the GBD implies the advantages of urban attractions in Seoul. The GBD offers several urban attractions for enjoyment; and therefore, the distance to the GBD could be regarded as a proxy variable for urban attraction (Osland and Thorsen, 2008).

Among the house attributes, the effect of the number of parking lots per household and the total number of households in an apartment complex had a significantly positive impact on housing prices. In terms of residence age, the square term of the age variable was only significant within the large-sized house sample. Therefore, a U-shaped relationship exists between age and house price, implying that the price increase resulting from the reconstruction of apartments is limited to large houses. When considering heating type, housing prices are lower for individual heating-type residences. The presence of a stair entrance is a factor which raises the price of small and medium-sized apartments, but not for large apartments. The coefficient of the exclusive area is negatively significant in small-sized and medium-sized houses. Residents in small-sized and medium-sized houses are less able to pay for housing costs; thus, they reduce the cost burden by reducing the area, and their preference for a relatively large area house is low.

The increase in distance to the nearest station positively affects housing prices. Controlling the regional impact of the urban railway network and the nearest station's characteristics, I determined that the local impact of the station on housing price is negative. This implies that the negative externalities (e.g., noise and overcrowding caused by the station's location) are greater than the benefits (e.g., commercial and convenience facilities near the station). This result is also concretely illustrated by the coefficient on the characteristics of stations. A factor causing a decline in housing prices is a ground station or transfer station being the nearest station, as the noise and overcrowding could be severe in regions adjacent to stations with these attributes.

On the contrary, the presence of a rapid station positively impacts housing prices, mainly due to its convenience and ability to transport residents quickly to other areas. The proximity of shopping centers and marts to the residence are also determinants which increase housing prices. Moreover, the effects of distance from school and university are different. In the case of universities, housing prices increase as the distance increases, whereas in middle schools, housing prices increase as the distance decreases. The price of houses located in districts where there are more private educational institutions is higher than that of houses located in other areas. This result shows that there is high preference for housing located in districts with a stronger possibility for quality education, due to the strong demand for educational services in Korea.

3.5. Simulations

The development of transportation networks which improves urban railway accessibility through the operation of express lines and new line construction will inevitably affect housing prices. Therefore, this study predicts how the improvement of urban railway accessibility would change the housing prices in Seoul, with respect to the disparities in housing prices both between and within regions. Twenty five counties in Seoul were classified into five areas according to their regional classification in the Seoul 2030 plan, consisting of the central, northeast, northwest, southeast, and southwest areas. The scenarios modeling increased urban railway accessibility assume that the operation time between the stations on railway lines is reduced by half. To determine whether the disparities in housing prices in Seoul are reduced when improving the accessibility of houses with a lower price, I selected four urban railway lines, which pass through where housing prices are relatively low, for this study's scenarios: Line 2 (circulating line), Line 3 (southeast - northwest line), Line 4 (south - northeast line), and Line 6 (north line). Housing prices in Seoul are mainly low in the northern area, and these four selected lines pass through the northern area. Line 2 was chosen to identify the overall improvement effect of accessibility on housing prices in Seoul. Lines 3 and 4 were selected because these lines connect areas with high and low housing prices through relatively short distances, when compared with other railway lines in Seoul. Line 6, which passes around areas where housing prices are low, is selected to analyze the effect of improved accessibility on housing prices in areas with low housing prices. Figure 5 presents the map of showing the regional classification of Seoul and the four urban railway lines subject to scenarios.

Regional house price disparities are measured by a Theil index, which has the advantage of being able to decompose total disparities into subgroup disparities and within subgroup disparities (OECD, 2016). The Theil index is defined as Equation 3-(14):

$$Theil = \frac{1}{N}\sum_{i=1}^{N}\frac{p_i}{\overline{p}}\ln\left(\frac{p_i}{\overline{p}}\right) \qquad 3\text{-}(14)$$

where N is the number of housing price data, p_i is the price of house i, and $\overline{p}$ is the mean of the housing prices across all samples. When M subgroups exist, the Theil index is decomposed into two components (Equation 3-(15)):

$$Theil = \sum_{j=1}^{M} s_j Theil_j + \sum_{j=1}^{M} s_j \ln\left(\frac{\overline{p_j}}{\overline{p}}\right) \ \text{for} \ s_j = \frac{N_j}{N}\frac{\overline{p_j}}{\overline{p}} \qquad 3\text{-}(15)$$

where $Theil_j$ is the Theil index for subgroup j, $\overline{p}_j$ is the average of the housing prices across subgroup j, and N_j is the number of housing price data in subgroup j. The first term of Equation 3-(15) is the disparities within subgroups, and the second term is the disparities between subgroups. The zero value of the Theil index represents complete equality, and the higher values of Theil index imply a higher level of disparity.

Figure 7. Four railway lines for scenarios

Table 7 shows the Theil index of four scenarios by housing sizes. The value of the Theil index for each scenario that is smaller than that of the base case is represented by a shaded gray cell in Table 7, indicating a narrowing gap in the house prices. The analysis of the four scenarios yields the following results. First, the values of the Theil index between the subgroups in the large-sized houses increase for all scenarios, whereas those for the small-sized and medium-sized houses decline, except for in the Line 3 scenario. This implies that the disparities in housing prices between the five areas reduce for the small-sized and medium-sized houses, rather than for the large-sized houses, when urban railway accessibility increases. Second, the Theil indices within the subgroups have larger values in all scenarios than in the base case, regardless of the housing sizes. The main reason for the subgroups' larger Theil index values in the four scenarios stems from the widening gap of housing prices in the southeast area, where the average housing price level remains the highest in Seoul. Lastly, the four scenarios have different impacts on the housing price disparities in each area. In general, the housing price disparities tend to decrease in areas where the urban railway line corresponding to the scenario passes. In particular, the Line 2 scenario contributes to the decreasing of housing price disparities in the central area for small-sized and medium-sized housing, and closes the housing price gap of small-sized houses in the southwest area. The inequality of the housing prices is widened in the Line 3 scenario, except for the small-sized houses in the northwest area. The Line 4 scenario effectively reduces the disparities of small-sized housing prices located in the central and northeast areas in Seoul. The variation of the housing prices in the northwest area is eased in the Line 6 scenario case.

In summary, urban railway development located in areas where housing prices are relatively low could help stabilize housing prices by narrowing the overall housing price gaps in Seoul. However, it is important to note that the housing price disparities within the southeast area, where housing prices are highest in Seoul, could widen as urban railway accessibility increases, despite the development of other lines that do not pass through the southeast area (e.g., Lines 4 and 6). Therefore, the government should continue to focus on developing transportation networks which reduce the housing price inequality both between and within regions, in order to both ease excessive price gaps between regions and stabilize the overall housing prices in Seoul.

Table 7 Theil index of four scenarios

Size	Scenario	Total	Within	Between	Central	Northeast	Northwest	Southeast	Southwest
Small	Base	0.1007	0.0786	0.0220	0.0828	0.0770	0.0405	0.1031	0.0652
	Line2	0.1024	0.0806	0.0219	0.0808	0.0827	0.0414	0.1052	0.0649
	Line3	0.1049	0.0813	0.0236	0.0850	0.0810	0.0401	0.1060	0.0673
	Line4	0.0994	0.0794	0.0200	0.0813	0.0727	0.0411	0.1058	0.0694
	Line6	0.1004	0.0797	0.0208	0.0829	0.0777	0.0365	0.1047	0.0678
Medium	Base	0.1183	0.0889	0.0294	0.0505	0.0805	0.0544	0.1169	0.0774
	Line2	0.1228	0.0940	0.0289	0.0493	0.0909	0.0547	0.1236	0.0789
	Line3	0.1274	0.0958	0.0316	0.0519	0.0879	0.0553	0.1275	0.0817
	Line4	0.1218	0.0936	0.0282	0.0519	0.0795	0.0548	0.1251	0.0845
	Line6	0.1212	0.0929	0.0283	0.0500	0.0841	0.0496	0.1232	0.0822
Large	Base	0.1197	0.0834	0.0363	0.0744	0.0868	0.0442	0.0883	0.0800
	Line2	0.1290	0.0896	0.0394	0.0746	0.1020	0.0453	0.0942	0.0848
	Line3	0.1306	0.0903	0.0403	0.0752	0.1004	0.0452	0.0959	0.0843
	Line4	0.1247	0.0866	0.0381	0.0778	0.0921	0.0443	0.0913	0.0830
	Line6	0.1242	0.0869	0.0372	0.0763	0.0932	0.0421	0.0919	0.0833

Chapter 4. Conclusion

This study identifies the effect of accessibility to multiple employment centers on housing prices using the layout of road and railway networks in Seoul. For the purposes of this study, the housing price was defined as an apartment complex's average selling price in 2019 in Seoul. Using road and railway network data, I calculated the origin–destination time matrix of all railways in Seoul in 2019. Moreover, in order to more accurately model the commuting experience, the walking time to the nearest railway station from the apartments and town workplaces were also calculated in the accessibility measurement. Based on the time distances from the apartments to the workplaces, accessibility using transportation networks is measured using gravity-based accessibility, reflecting the number of jobs by districts. The housing price function is estimated for each size by dividing the three apartment sizes.

The major finding of this study is that greater accessibility to multiple workplaces via transportation networks affects the prices of all dwelling sizes, regardless of the type of transportation mode. However, the degree to which accessibility via railway and road networks impacts housing prices varies according to house size. Railway accessibility is a relatively significant factor for small- and medium-sized houses, but road accessibility is more important for those purchasing large houses. The typical age and economic status of residents varies depending on house size, meaning that typical commuting methods may vary according to house size, and so different-sized houses would experience differential impacts from increased transportation or road accessibility. Moreover, the accessibility to the business district via road and railway is shown to be a complementary relationship, and this complementary relationship strengthened as housing size increased. Third, the network accessibility indicators did not completely replace accessibility to GBD, which is regarded as one of the largest employment centers in Seoul. Accessibility to the largest business districts remains a major determinant of housing prices, as these districts provide both the attraction of urban leisure activities and jobs. Drawing from these results, policies seeking to stabilize housing prices by improving remote regions' accessibility should consider household characteristics that depend on dwelling size and their respective transportation mode preferences.

Furthermore, when predicting changes in house prices due to improvements in urban railway accessibility, the housing price disparity between and within the five areas in Seoul is different, depending on the specific urban railway line developed. In addition to the railway lines analyzed in this study, the government has been in the process of developing the Great Train Express (GTX) line within the Seoul metropolitan area in order to strengthen the city′s overall transportation network. However, when the construction of the GTX first began, there were concerns that the gap in housing prices was widening, as only houses in regions where the GTX line passes through would experience increases in their values. Therefore, when the government intervenes in the housing price market through the development of a transportation network, it must pay attention to the changes in the housing price gaps both between and within regions in order to most equitably lay out the transportation network.

This study only focused on analyzing the pricing of apartments, which is the dominant residence type in Seoul, as finding accurate house attribute data for other residence types remains difficult. Non-apartment residences account for 30% of all housing in Seoul;

therefore, more meaningful results could be obtained in future studies by taking into consideration other housing types. Additionally, although buses are an important part of the city’s public transportation system, this study did not take bus accessibility into consideration due to a lack of consistent GIS data on the bus routes running through Seoul. Therefore, future studies including the impact of bus accessibility would be worthwhile. Finally, when calculating railway network accessibility, the operational properties of urban railways, such as the intervals between trains and numbers of stops, were not taken into consideration, though they greatly affect the usability level of different stations. Future research should aim to take these properties into consideration, and thereby build a more robust model of analysis.

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국문초록

도로와 도시철도 접근성이 주택가격에 미치는 영향

본 연구의 목적은 서울의 도로망과 도시철도망을 이용하여 다지역 고용지에 대한 접근성이 주택가격에 미치는 영향을 분석하는 것이다. 서울의 2019년 '부동산 실거래가 데이터'와 도로망과 철도망 지리정보데이터를 활용하여 중력기반 접근성을 측정하고, 주택규모를 소형, 중형, 대형 3개로 나누어 주택규모별 주택가격함수를 추정하였다. 본 연구의 주요 결과는 다음과 같다. 첫째, 주택가격에 대한 도로 접근성 탄력성은 4.0146, 철도 접근성 탄력성은 0.8385로, 다지역 고용지에 대한 도시와 도시철도 접근성이 주택가격에 긍정적으로 영향을 미쳤다. 주택규모에 관계없이 도로 접근성이 도시철도 접근성보다 주택가격에 미치는 영향력이 더 컸다. 그러나 소형주택과 중형주택에서는 도시철도 접근성이 주택가격에 미치는 영향이 대형 주택에 비해 상대적으로 큰 반면에 대형 주택에서는 도로 접근성이 주택가격에 미치는 영향이 두드러졌다. 이는 주택규모에 따라 거주자의 경제적 특성이 상이하여 교통수단 선호도가 달라지고, 교통수단에 대한 다른 선호가 주택가격에 다르게 반영됨을 보여준다. 또한, 도로와 도시철도 접근성은 상호대체적 관계가 아닌 상호보완적인 관계를 가지고 있는 것으로 나타났다. 서울의 3개 도심 중 강남 도심권 변수는 접근성 변수를 통제하였음에도 불구하고 음의 값으로 유의하게 나타났는데, 이는 강남 도심권이 일자리 제공뿐만 아니라 도시의 편의시설 제공에 중요한 역할을 하고 있음을 시사한다. 마지막으로, 도시철도망 접근성을 개선하였을 때 집값을 예측한 결과, 서울의 5개 권역간 및 권역내의 주택가격 격차는 개발되는 철도 노선에 따라서 다르게

나타났다. 결과를 종합한 본 연구의 정책적 함의는 다음과 같다. 공공부문과 도시계획자는 교통망을 개발할 때, 해당 교통망 개발이 주택가격 격차 및 안정화와 관련하여 주택시장에 미치는 상이한 영향을 고려해야 한다. 더욱이, 교통망 개발에 의한 접근성 향상을 바탕으로 특정 계층의 사람들을 위한 주택시장 정책을 추진할 때, 주택규모에 따라 달리질 수 있는 교통수단 선호와 관련된 가구별 특성을 고려할 필요가 있다.

주요어 : 주택가격, 도심까지의 접근성, 중력기반 접근성, 교통망
학　번 : 2019-20252