Master's Thesis

Impact of new subway line on nearby housing price : Moderating effect of network centrality

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Abstract

In both academic and policy domains, how public transportation improvement affects property values within adjacent regions has been continously debated and has attracted attention. Multifarious studies have been conducted which tend to support significant relationship between transit development and surrounding property values. However, the most common way of arguing the effect of transit development on property value is addressing the transit accessibility by including just 'proximity' to transit station in the analysis. In addition to just 'proximity', it is necessary to consider the varying importance of each transportation node in a transit network for a wider understanding and arguing of relationship between transit development and property value. Based on the concept of 'network centrality', each subway station is considered as a transit node in an entire subway network in a city. How the varying importance of each subway station in a subway network and substantial variation in accessibility throughout the network have significant effect to housing price are argued in this study.

This study analyzes the impact of line 9 in Seoul on nearby housing price and how the network centrality of each station can have significant influence. Specifically, in cross-sectional analysis, how the network centrality can have an important role in determining nearby housing price after the first opening and the second extension of line 9 is analyzed. On the other hand, in inter-temporal analysis, how the network centrality can have moderating effect on the direct marginal price impact of the first opening and the second extension of line 9 is analyzed.

The result of the study showed that the network centrality value is an influential determinant of nearby housing price both after the first opening and after the second extension of line 9. Also, the network centrality value has the moderating effect for the marginal price impact of the first opening and the second extension of line 9. Among the four types of network centrality, the closeness centrality and the betweenness centrality have great importance compared to the degree centrality and the eigenvector centrality. Effectiveness of a certain station in order to using both line 9 stations and also other stations in the network is an important factor for determining housing price. In addition, in terms of the betweenness, each station's role as an important 'mediator' in the network so the user can easily use other lines or stations also is another important factor for determining housing price.

This study suggests that consideration about the relative importance of each subway station in the entire subway network needs to be included in assessment of a certain transport policy implementation with proper measurement of development profit. In addition, consideration about the network centrality can bring more benefit to design better transportation policy with effective linkage to various housing supply policy.

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Ⅰ. Introduction

1.1 Research background

Continuous debate about how public transportation improvement affects values of properties within adjacent regions has attracted attention in both academic and policy domains. On the academic aspect, this issue is closely related with the substantiation of conventional urban economic theories. Central point of classic bid-rent theory from Alonso(1964) is that land users show high demand for accessible land to central business district in order to maximize their profitability. Integration of Alonso's model with Muth(1969) and Mills(1967, 1972) models more explains about the urban economic agent's competition for location choice. All agent has budget constraint and transport cost to commute, so that they compete and are willing to pay more for more accessible land to the central business district. If a transportation improvement reduces the transport cost for commuting, additional time carries more personal utility benefits(Klovers and Pereira, 2016). Since the transportation can be seen as utilities which reduce the transport cost, it holds that nearby properties in surrounding this 'transportation amenity' should see high demand. Finally, this high demand will bid up prices and generate 'transportation premium'.

In terms of policy aspect, assessment of a certain transport policy implementation can be done with measurement of development profit. By analyzing land value or property value uplift, whether the distribution of development profit due to transport development is well distributed or concentrated at a certain area can be grasped. Conversely, if there is development loss due to the adverse impact of transport development such as pollution or noise, drops of property and land value are usually observed after the development. In addition, it is necessary to understand the response of housing demand for different transport characteristics of each transport development policy. For instance, each subway line and even each station has different characteristics. Understanding which transport-related factors causes positive or negative responses in terms of housing demand will help to design better transportation policies and will also be a great help in effective linkage between housing supply policy and transport policy.

Due to the aforementioned importance of the issue in both academic and policy aspect, multifarious studies have been conducted which tend to support significant relationship between transit development and surrounding property values(Voith, 1993; Gatzlaff and Smith, 1993; Landis et al, 1994; Baum-Snow and Kahn, 2000; Bowes and Ihlanfeldt, 2001; Cervero, 2003; and many others). Results show the mix of amenity and dis-amenity effect of the transit. Some cases show minimal impact in a certain area. It is because analyses vary considerably in terms of variable operationalization, model specification, spatial context and time frame. However, the most common way of arguing the effect of transit development on property value is addressing the transit accessibility by including just 'proximity' factor in the analysis. Continuous measures of transit access such as straight-line distance to subway station, railway station or bus stops have been used. Even more traditional binary variable which indicates whether a property is inside or outside a given distance ring-buffer has also been used(Bowes and Ihlanfeldt, 2001). On the other hand, the actual walking distance along the street network has also been included and compared for finding more significant proximity variable, rather than using just 'perceived' proximity such as line-distance or distance-buffer(Hess and Almeida, 2007). Either way, 'proximity' is considered in almost studies, even though other types of concepts about the transit accessibility have been suggested recently. Batty(2009) suggested alternative type of accessibility which can be interpreted as 'centrality' and it focuses about physical network of a transportation mode. Varying importance of each transportation node, such as a subway station or bus stop, and quite substantial variation in accessibility between nodes or node clusters according to the structure of the physical network are made. Moniruzzaman and Antonio(2012) also suggested similar concept which is interpreted as 'by-transit' accessibility. They criticized that current studies mostly consider 'to-transit' accessibility which is same as 'proximity' as it is mentioned above. On the other hand, 'by-transit' accessibility means the difference in travel cost or opportunity depending on the importance of adjacent transit node in a transportation network. Therefore, in addition to just 'proximity', it is necessary to consider the varying importance of each transportation node in a transit network for a wider understanding and arguing of relationship between transit development and property value.

1.2 Research Purpose

Beyond just 'proximity' to transit node which has been addressed frequently, this study tries to consider an alternative type of transit accessibility as a key variable for arguing relationship between transit development and housing price. Among the above-mentioned alternative types of transit accessibility, 'network centrality' is considered in this study. Each subway station is considered as a transit node in an entire subway network in a city. How the varying importance of each subway station in a subway network and substantial variation in accessibility throughout the network have significant effect to housing price are argued in this study.

Specifically, this study analyzes how each subway station's network centrality has moderating effect on the association between new subway line opening(and the additional extension of line) and adjacent housing prices. First of all, by doing the cross-sectional comparison which is focusing on the time after the subway line opening(and the extension), this study examines whether the difference in network centrality of each subway station operates as an important factor for determining the housing price in station catchment area. Second, by using difference-in-difference(DID) method, this study identifies effect of post time and treatment based on the inter-temporal housing price variation before and after the subway line opening. In this process, how each subway station's network centrality has moderating effect on housing price variation before and after the subway line opening(and additional extension) by including interaction variable between treatment dummy, post-time dummy and network centrality value. In short, this study aims to find proper answers for these two research questions as follows. 1) Does the network centrality of each subway station work as an important determinant of housing prices in each station catchment area after the new subway line opening(and additional extension)? 2) Does the network centrality have significant moderating effect in the relationship between new subway line opening(and additional extension) and inter-temporal housing price variation?

For the purpose of the study, the paper is composed as follows. First, research background and purpose of this study are introduced. Second, relevant literatures are reviewed and lessons learned from previous researches are used as frameworks for the analysis about the relationship between new subway line opening(and additional extension) and nearby housing price considering subway station's network centrality. Third, operationalization of variables and examination of the empirical model by undertaking cross-sectional comparison model and difference-in-difference model based on hedonic regression are addressed. Fourth, network centrality variation change before and after the new subway line opening(and additional extension) and the results of each model are addressed. Finally, concluding observations, implications and limitations of this study are suggested.

Ⅱ. Literature Review

2.1 Theoretical framework of property location choice

Most of theories about land value or property value have rooted in Von Thünen(1863)'s explanation of variations in farmland values even if they have similar fertility. According to Von Thünen, the key factor which makes value difference of farmlands is the accessibility to the central market place. In terms of studies hereafter, bid-rent model integration from several urban economists such as Alonso(1964), Muth(1969), and Mills(1967, 1972). Base idea of bid-rent model is that every agent has budget constraint and transport cost to commute, so that they compete and are willing to pay more for more accessible property to the central business district. Finally, this leads to a rent-gradient line according to the distance from the central business district. Therefore, in lots of past studies, prominent factor for accounting the difference between property values is the accessibility to the central business district. Closeness to CBD is mostly considered as an attractive factor which increases property prices.

However, Fejarang(1993) suggested that the investment in transport infrastructure can reduce the demand concentration around the CBD because transit stations can attract agents to live near and make them enjoy benefits from transport cost saving. Hence, each price curve around each transit station will be created because there is also high demand for nearness to transit station. Eventually, these multiple price curves of transit stations over the city can reduce the degree of demand concentration around the CBD. Motivated by this suggestion, multifarious studies try to include transit accessibility factor in conventional hedonic pricing methodology which is introduced by Rosen(1974) with integration of physical and environmental characteristics of properties.

2.2 Relationship between transit accessibility and housing price

Due to the importance of transit accessibility for property location choice mentioned in theories, a vast body of literature has estimated the impact of proximity on property values. Proximity is usually measured as the continuous travel distance. In other word, straight-line distance from each property to transit station is usually considered as the transit accessibility. Even more traditional binary variable which indicates whether the property is inside or outside a given distance-ring buffer is also used(Bowes and Ihlanfeldt, 2001). One of popular research methods is using a radial distance buffer up to one-, half-, quarter- mile around transit station. Hess and Almeida(2007) shows greater significance of the actual walking distance depending on the street network, rather than using conventional proximity measures.

However, a bunch of literature review articles about the impact of a transit proximity on nearby property value has noted that inconsistent results(knapp, 1998; Ryan, 1999; Cervero et al, 2002; Smith and Gihring, 2004; Klovers and Pereira, 2016). Results show the mix of amenity and dis-amenity effect of the mass transit. Some case shows minimal impact in a certain area. It is because analyses vary considerably in terms of variables and model specifications, spatial context and time frame. In addition, the uniqueness of local transport system and its relationship with land use environments may be also other important reason of inconsistent results.

Various modes of public transportation including bus rapid transit(Cervero and Kang, 2011), bus, light and heavy rail, and subway. There are some agreements amongst researchers about the impact of various transit modes. Several studies have shown that nearby property values near the bus stops shows moderate or modest benefit for better transit proximity, because most bus stops lack the locational permanency. In other word, bus stops is not fixed and its location can easily be moved(Goodwin and Lewis, 1997; Barker, 1998). On the other hand, studies about the impact of rail transit, especially commuter rail or subway which operates with faster speed and frequent interval, shows higher premium(Parsons Brinckerhoff, 2001; Cervero and Duncan, 2002).

2.3 Expectation effect of the transportation improvement on housing price

Rather than focusing on only single point of time after the completion of transit development, Yiu and Wong(2005) emphasized the need to consider the expectation effect before the completion of transit improvement. Assumption that investors' consideration of expected improvements when pricing and trading neighborhood properties is quite conceivable. This study empirically analyzed the positive price effect even before the completion of tunnel construction and suggested the need of intertemporal analysis on the effect of transit improvement on nearby housing price.

Theoretically, this empirical result is also reasonable. Cagan(1956)'s adaptive expectation model assumes people form their expectations with the backward-looking position. In other word, people form their future expectations based on the past empirical information. In this case, past empirical information is about further development in surrounding area of new transit development. Muth(1961) also proposed similar explanation with the rational expectation model. This model argued that people would forecast based on all of the information available including past experiences. However, the evidence for these theories had been made mainly in the macroeconomic side. Recently, researches on the impact of transit development on housing price considering both before and after the development has been carried out.

For instance, Dubé, Jean, et al.(2014) presents a spatial difference-in-difference model in order to account for spatiotemporal dimensions of each property. This analysis captures the effects of exogenous changes in effect of transit amenity, specifically new commuter rail service, on nearby housing prices. The estimation results for the commuter rail in Montreal suggest subtle gain comparing before the completion of the rail. Similarly, Im and Hong(2017) investigates the intertemporal impact of newly built subway line on nearby housing price. Two subway lines are already built in this area. Analysis results based on the hedonic models in difference-in-difference framework suggests that properties near the new line can earn premium, but properties which are also located near to existing lines cannot earn such benefits. Besides, a wide array of analyses(Dubé, Jean, et al. 2018; Ransom, 2018) estimates the intertemporal impacts of various transit developments on housing prices recently.

2.4 Beyond just 'proximity' as a transit accessibility

Though the transit accessibility has become a central concept and widely considered in both cross-sectional and intertemporal studies that have been carried out, studies have mainly dealt with just 'proximity' to transit stations so far. Recently, in addition to the various theorization about the accessibility, analyses using alternative accessibility variables instead of conventional 'proximity' variable have been carried out.

Moniruzzaman and Antonio(2012) suggested 'by-transit' accessibility concept. They criticized that current studies mostly considered 'to-transit' accessibility which is same as 'proximity' as it is mentioned above. On the other hand, 'by-transit' accessibility means the difference in travel cost or opportunity depending on the importance of adjacent transit node in a transportation network. In other word, there would be the heterogenous impact of each transit station due to varying accessibility even in a same network.

Batty(2009) also emphasized the 'Centrality' concept of transit accessibility. It focuses about physical network that each transit station is included. In other word, it is related with the graph-theoretical nodal accessibility concept which is applied widely in various transportation network assessment(Garrison, 1960; Nystuen and Dacey, 1961; Muraco, 1972; Murayama, 1994). Each transit station is considered as node in a network. There would be varying importance of each transportation node and quite substantial variation in accessibility between nodes or node clusters according to the structure of a network. Currently, 'centrality' variable which is interpreted as graph-theoretical nodal accessibility has been widely operationalized by the network analysis. Xiao et al.(2016) examine the dynamic relationship between street configuration and housing prices. Space-syntax analysis is employed to track changes in street accessibility within the urban street network. The results provide that urban street configuration significantly related with housing price changes. Social network analysis is also applied for transportation network efficiency assessment(Derrible and Kennedy, 2010; Stoilova and Stoev, 2015; Andor et al., 2015; Xiaolei et al., 2016). Even though the network analysis of street is widely used in arguing relationship between street accessibility and housing prices, transit network centrality has not been considered in the study about the relationship between transit accessibility and housing prices.

As many authors mentioned about the possibility of heterogenous price premium due to station-specific characteristics(Hess and Almeida, 2007; Aziz et al, 2017), the varying importance of each station in a transit network can also be an important factor of heterogenous price impact on housing price. This study hypothesizes that not only the proximity to transit station but also the network centrality of 'that' transit station has influence on the relationship between transit development and housing price. Specifically, this study examines whether the network centrality of each transit station has moderating effect on the relationship between transit development and housing price in both cross-sectional analysis model and intertemporal analysis model.

Ⅲ. Research Design

3.1 Research Scope

Spatial Scope

Among the developments of various transportation modes, this study analyzes the impact of new subway line on nearby housing prices. Since 2008, Seoul has tried to establish a less car-dependent transportation system based on 'Seoul Urban Railway Network Construction Plan'. Seoul is a representative case area where public transportation centered system organization, mainly with the urban railway, has been established continuously. Figure 1 shows that the red lines are already planned in 2008 plan and green lines are newly planned in 2015 plan. Various urban railway lines are planned to be placed in areas where the public transportation connections have not been effective.

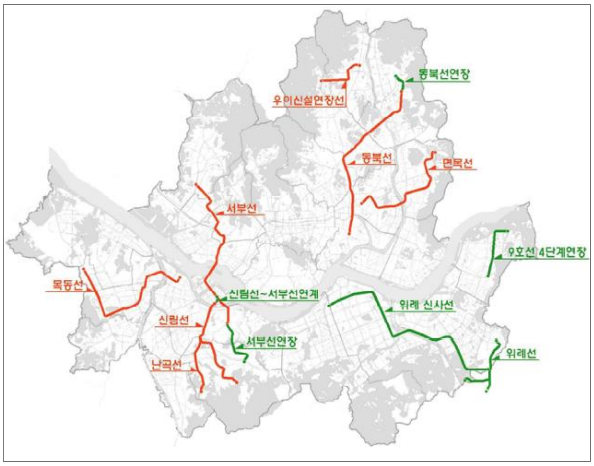

Figure 1. Seoul Urban Railway Network Construction Plan [1]

In July 2009, new subway line which is called as 'Seoul Metro Line 9' was opened. In the southern regions of the Han river of Seoul, there was no subway line which directly connects between the east and the west so the dependency of car and bus was quite high. With the opening of subway line 9, the east-west movement in the southern region of the Han river gained high efficiency. In particular, Gangseo-gu area, where the connection on subway lines is low compared to other areas in Seoul, is a typical beneficiary. Following the second extension of the line 9 in March 2015, there are also plans for the third and fourth extensions in near future.

This study analyzes cross-sectional and inter-temporal influences of both the first opening and the second extension of subway line 9. Black and yellow mixed line is the subway line 9 as it is shown in

[1] Seoul 10-year Urban Rail Network Construction Plan, 2015

figure 2. Figure 3 is the map of subway line 9. Figure 3 also shows that the first opening section was from '개화' to '신논현' station and second extension connects from '신논현' to '종합운동장'. Spatial range for this study is the first opening section from '개화' to '신논현'. '개화' is excluded because it is used as a vehicle base and the number of samples within station catchment area is extremely small. '마곡나루' is also excluded in this study because construction is completed recently.

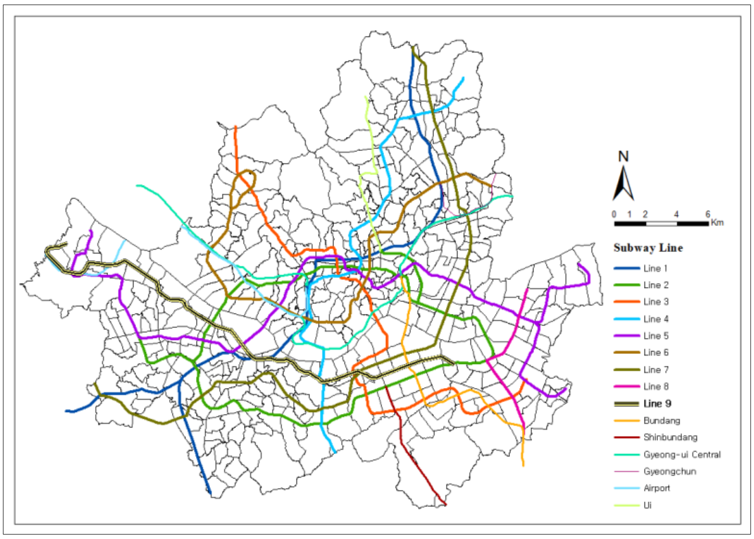

Figure 2. Entire subway network in Seoul

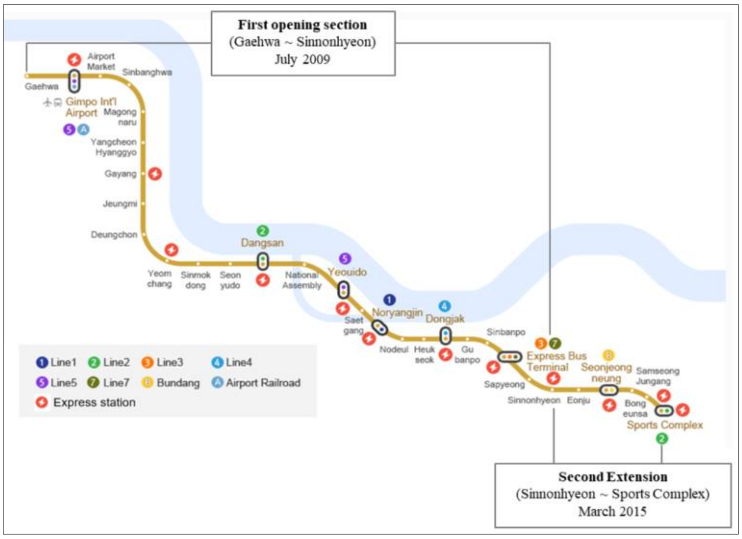

Figure 3. Map of subway line 9 [2]

Temporal Scope

Report about starting work of line 9 was lodged in June 2006. The first section from '개화' to '신논현'

[2] Seoul Metro Line 9

was opened in July 2009 and the second extension from '신논현' to '종합운동장'. As it is mentioned earlier, this study analyzes with both cross-sectional model and inter-temporal model. In terms of cross-sectional analysis, this study analyzes whether the network centrality plays an important role in determining housing price in the period after the first opening and the second extension of subway line 9. Specifically, the first cross-sectional model considers housing prices after two years from first opening of line 9 and the second cross-sectional model considers housing prices after two years from second extension of line 9. On the other hand, inter-temporal analysis considers both before and after periods of each opening. Respectively, two years before and after the first opening and two years before and after the second opening are considered. Figure 4 summarizes above explanations about the temporal scope of this study.

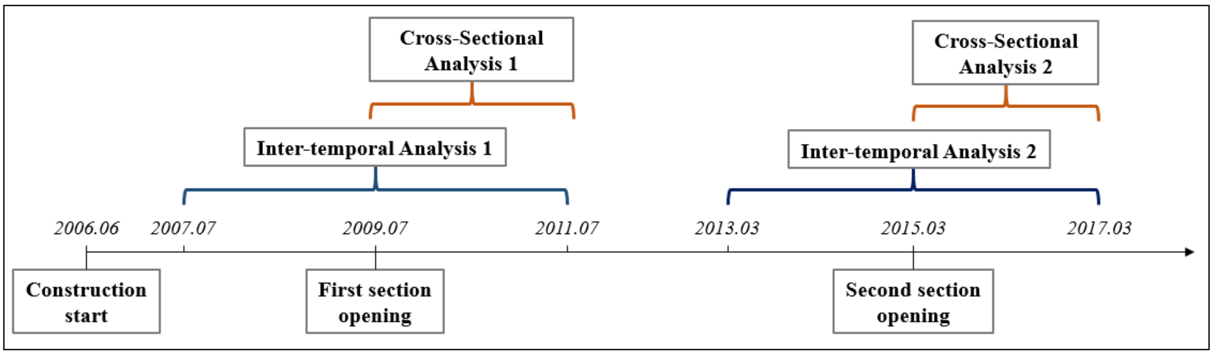

Figure 4. Temporal scope of the study

Unit of analysis

In both cross-sectional analysis and inter-temporal analysis, a key research object is housing price and the main purpose of the study is to measure the influences of various variables including the network centrality of each station on housing price. This study uses real transaction price of each individual apartment unit within 1000m buffer area from each station. In cross-sectional analysis, how the network centrality of each station affects housing price is analyzed. Also, interaction variable between network centrality and straight-line distance from each station is included to analyze distance-varying influence of the network centrality. On the other hand, in inter-temporal analysis, the opening or extension effect of the subway line between station-catchment area and non-station-catchment area is compared primarily. And then, how the network centrality can have moderating effect in the opening ore extension effect of new subway line on housing price is measured. Therefore, in inter-temporal analysis, price of properties located from 600m to 1000m from each station is also included as a 'control' group.

3.2 Data and Variable operationalization

Dependent variable

As it is mentioned above, the analytical model in this study is basically oriented to the hedonic price model. Therefore, the dependent variable of this study is real transaction price of each individual apartment unit within 1000m buffer area of each station in the first section of subway line 9. Real transaction price data which can be gathered from the real transaction price disclosure system of the ministry of land, infrastructure and transportation includes not only transaction price but also other information such as address, transaction date, name of apartment complex, area of exclusive use, transaction date, floor and built year. Real transaction price data from July 2007 to July 2011 which is two years before and after the first opening of subway line 9 and data from March 2013 to March 2017 which is two years before and after the second opening of subway line 9 are included in the analysis of this study. Price is log-transformed to ensure the normality of the dependent variable as much as possible. Also, price is adjusted with monthly price index to control price fluctuation by the housing market condition and other macroeconomic condition.

Independent variable

a. Physical and locational characteristics of property

In addition to available information about the physical characteristics of each individual housing unit in real transaction price data, other physical characteristics which can be obtained from the building register are also included such as the number of households and the number of total floor. To consider the demand about reconstruction of the old apartment unit, squared value of building age is also included. In terms of locational characteristics, straight-line distance to Han river, the nearest elementary school and the nearest subway station of line 9 are included. Walking is an important means of accessing to elementary school, various studies consider whether the elementary school belongs to the walking accessible zone as a key locational variable. Also, this study considers the accessibility to the Han river as a neighborhood amenity variable.

b. Subway network centrality of each station

Recently, social network analysis has been applied as a network analysis method based on graph theory. It has attracted attention as a method for effectively evaluating the connectivity and centrality of the transit nodes constituting the network. Also, it has been recognized for its effectiveness in network efficiency analysis of various transportation modes(Derrible and Kennedy, 2010; Stoilova and Stoev, 2015; Andor et al., 2015; Xiaolei et al., 2016). In a transit network, each transit station is a node and linkage between node and node is a link.

This study considers four representative centrality variables : degree, closeness, betweenness, and eigenvector. Concepts of degree centrality, closeness centrality and betweenness centrality are suggested by Freeman(1979). Firstly, the degree centrality is closely related with the number of links directly connected to each node. As shown in Equation 1.1 below, the matrix elements of the incidence matrix having values of 0 or 1 according to whether the node n and the node s are directly connected to each other are added. In a subway network, each link represents a subway line so high degree centrality means the opportunity of using various subway lines in a certain node. A node which has high degree centrality value can be considered as a transfer station having many transfer routes.

$$C_d(n) = \sum_{s \in N} A_{ns} \tag{1.1}$$

In terms of the closeness centrality, it represents geographical centrality of the node in the network. As shown in Equation 1.2, closeness centrality is estimated as a reciprocal of the sum of the shortest distance to all nodes in the network. The nodes with high closeness centrality value are usually stations in the city center area so the location is the most effective to utilize subway stations all over the city.

$$C_c(n) = \frac{1}{\sum_{s \in N} d(n,s)} \tag{1.2}$$

On the other hand, the betweenness centrality represents the ratio of whether the shortest path connecting any two nodes in a transit network passes the target node or not. In other word, the node with high betweenness centrality means that the node is a pinch point, an important traffic intermediary point, and an important bridge in the network.

$$C_b(n) = \sum_{s \neq t \neq n \in N} \frac{\sigma_{st}(n)}{\sigma_{st}} \tag{1.3}$$

Finally, the concept of the eigenvector centrality is suggested by Bonacich(1972). The eigenvector centrality extends the concept of the degree centrality and is based on the concept that nodes which are connected to important nodes are more important. In other word, it focuses more on the relative importance of the nodes in the network. The node with high eigenvector centrality usually have friends who have a wide circle of acquaintance. Hence, the node with high eigenvector centrality are usually linked to the nodes with high degree centrality. Eigenvalue for the equation 1.4 and 1.5 is estimated for each node.

$$C_e(n) = \frac{1}{\lambda} \sum_{s \in N} A_{ns} C_e(s) \tag{1.4}$$

$$\lambda C_e = A C_e \tag{1.5}$$

Many studies are based on the concept that the centrality of node is determined by the attributes of the link between nodes(Park and Gang, 2010; Mishra et al., 2012; Mishra et al., 2015; Kim et al., 2014). In the subway network, links represent subway lines which have different operational characteristics such as capacity, operational headway, vehicle speed, the number of service a day or etc. Operational characteristics can be considered the weight of the link in the network analysis. This study considers the operational headway in both rush hour and normal hour of weekdays. The average daily number of service in weekday is also considered as a link weight. Information for the operational headway and the average daily number of service in weekday can be gathered from KORAIL, Seoul Metro and Korea Transport Institute. Each link has a value of 1 without considering any link weight, but normalized values of the operational headway and the number of service are multiplied for considering link weights.

For the measurement of network centrality, 'igraph' package in R which is introduced by Csardi and Nepusz(2006) is implemented. This package covers both complex network analysis and social network analysis with easy code and visualizes effectively. Network value of every subway station in two different subway networks in two different point of time is measured. The first is the network immediately after the first opening of the subway line 9 and the second is the network immediately after the second extension of the subway line 9. All centrality value is also normalized.

3.3 Analytical Methods

a. Cross-sectional analysis

The purpose of cross-sectional analysis is to examine whether the network centrality which is different for each station is an important determinant of nearby housing price. It examines the influence of station-specific network centrality on the price samples within 1000m buffer area from each station. In addition, interaction variable between the network centrality and straight-line distance from each station is included to analyzed distance-varying influence of network centrality. Cross-sectional analysis is based on the hedonic price method including physical and locational characteristics of properties within station catchment area. In addition, monthly dummy variable is included to control the monthly price fluctuations that the adjustment with monthly price index can not fully control. Also, dummy variable for each 'Gu' which means autonomous district in Korea is also considered to control the difference between each housing submarket.

In terms of the analysis model, a basic regression model using Ordinary Least Squares(OLS) cannot fully control the influences of unobserved variables for each apartment complex that each individual housing unit is included. Therefore, a multi-level linear model is applied to control the influences of unobserved variables and to minimize the effect of spatial heterogeneity. Prices of housing units which are located in the same apartment complex share the characteristics of the apartment complex. It can trigger strong correlation. Simple OLS linear regression analysis without considering this can invoke overestimation of regression coefficients. Hence, in the analysis, multi-level linear model sets each apartment complex as an upper level group that each individual housing unit consists. In addition, random intercept model which assigns the random effect to the intercept value of each apartment complex is applied. Model formula is as shown as equation 2.1 in below.

$$\begin{aligned} \text{L1}: \ & Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + r_{ij} \\ \text{L2}: \ & \beta_{0j} = \gamma_{00} + u_{0j} \\ & \beta_{ij} = \gamma_{10} \\ \therefore \ & Y_{ij} = \gamma_{00} + \gamma_{10}X_{ij} + u_{0j} + r_{ij} \end{aligned} \quad (2.1)$$

In equation 2.1, Y_{ij} is the log-transformed and price index adjusted price of i-th housing unit which is located in j-th apartment complex. β_{0j} means the intercept at level 1 and β_{1j} means regression coefficient at level 1. X_{ij} is the characteristics of housing unit which can be measured at level 1. In this study, physical and locational characteristics, the network centrality of the nearest station of line 9, monthly dummy variable, and dummy variable for each 'Gu' are included in X_{ij}. r_{ij} is the random effect at level 1 and means the residual of the price of individual housing unit. As the fixed effect in level 2, γ_{00} and γ_{10} are intercept and regression coefficient respectively. u_{0j} is the random effect in level 2 and means the intercept of j-th apartment complex. Consideration of the random effect in level 2 also controls the unobserved characteristics due to the spatial heterogeneity of each apartment complex.

b. Inter-temporal analysis

Inter-temporal analysis is also based on the multi-level hedonic price model which is implemented in the cross-sectional analysis. However, using difference-in-differences(DID) estimator, inter-temporal analysis directly estimates the marginal price impact of new subway line opening(or extension of line). Baseline model using difference-in-differences(DID) estimator is shown in below equation 2.2.

$$Y_{it} = \beta_0 + \beta_1 Treat_i + \beta_2 Post_t + \beta_3 (Treat * Post)_{it} + \beta_4 X_i + \sum \gamma_k month_k + \varepsilon_{it} \quad (2.2)$$

Y_{it} represents the log-transformed and price index adjusted price of i housing unit for the month t. $Treat_i$ is a dummy variable indicates the treatment group affected by the first opening(or the second extension) of subway line 9, which are the housing units within the station catchment area of subway line 9. $Post_t$ is a dummy variable denotes the period after the first opening(or the second extension) of subway line 9. $(Treat * Post)_{it}$ indicates the interaction term between time dummy and dummy for the treatment group and this variable is the DID estimator in the model. Therefore, the willingness to pay for the profits of accessibility improvement which is brought by the first opening(or the second extension) of subway line 9 is estimated by β_3.

In addition, this study tries to estimate the moderating effect of the network centrality of subway station. By including the double-interaction term between time dummy, dummy variable for the treatment group and the network centrality of the nearest station of line 9, how can the network centrality of each station have moderating effect to direct marginal price impact after the subway line opening (or extension of line). In other word, how the difference in network centrality value of each station can make difference in marginal price impact of each station even in the same subway line is analyzed. Applying this strategy, the equation 2.2 can be revised as shown in below equation 2.3. *C* is the network centrality of the nearest station in line 9.

$$Y_{it} = \beta_0 + \beta_1 Treat_i + \beta_2 Post_t + \beta_3 (Treat * Post * C)_{it} + \beta_4 X_i + \sum \gamma_k month_k + \varepsilon_{it} \quad (2.3)$$

Both in DID baseline model in equation 2.2 and the strategic model in equation 2.3, the concept of the random intercept multi-level model is included in the analysis.

Ⅳ. Results

4.1 Network centrality measurement

Top ranking station group in entire network for each period

Table 1 and Table 2 show the top 20 stations with the highest value of each network centrality in the Seoul subway network after the first opening of the subway line 9 and after the second extension respectively. Stations which belong to the line 9, especially transfer station in the line 9, have high relative importance in the network after the first opening of line 9. However, after the second extension of line 9, the great relative importance of major transfer stations in line 9 has declined. Through the second extension of line 9, the relative importance of other stations rather than just the transfer stations also increase. Due to increased connectivity of line 9 after the second extension, it can be understood that the relative importance, which is highly concentrated mainly to the transfer stations, is also distributed to other stations. In other word, relative importance of other stations in line 9 also increase after the second extension.

Table 1. Top rank group stations in the network after the first opening

Ranking	Network Centrality			
	Degree	Closeness	Betweenness	Eigenvector
1	종로3가	시청	**노량진**	종로3가
2	**고속터미널**	종로3가	종로3가	을지로4가
3	동대문역사문화공원	종각	시청	동대문역사문화공원
4	**노량진**	서울역	종각	종로5가
5	신길	남영	서울역	동대문
6	신도림	**노량진**	남영	종각
7	가산디지털단지	용산	용산	을지로3가
8	시청	을지로4가	동대문	시청
9	여의도	동대문역사문화공원	**동작**	동묘앞
10	서울역	종로5가	**고속터미널**	충무로
11	창동	대방	군자	신당
12	동대문	**노들**	신길	청구
13	**김포공항**	동대문	동묘앞	광화문

14	**당산**	을지로3가	**노들**	서울역
15	구로	을지로입구	대방	을지로입구
16	동작	**샛강**	**흑석**	안국
17	군자	**흑석**	종로5가	충정로
18	영등포구청	광화문	동대문역사문화공원	신설동
19	을지로4가	충정로	왕십리	혜화
20	왕십리	신길	신설동	서대문

**** Stations in bold belong to the subway line 9***

Table 2. Top rank group stations in the network after the second extension

Ranking	Network Centrality			
	Degree	Closeness	Betweenness	Eigenvector
1	동대문역사문화공원	동대문역사문화공원	동대문역사문화공원	동대문역사문화공원
2	**고속터미널**	시청	동대문	을지로4가
3	종로3가	종로3가	서울역	을지로3가
4	공덕	을지로4가	공덕	종로3가
5	**김포공항**	종각	왕십리	동대문
6	**당산**	을지로3가	**노량진**	신당
7	**동작**	을지로입구	신당	충무로
8	**노량진**	서울역	상왕십리	청구
9	사당	충무로	시청	종로5가
10	신도림	공덕	군자	을지로입구
11	시청	신당	**동작**	동묘앞
12	여의도	회현	**당산**	종각
13	서울역	명동	**고속터미널**	시청
14	왕십리	남영	종로3가	상왕십리
15	영등포구청	충정로	충무로	혜화
16	을지로4가	동대문	충정로	명동
17	충정로	**노량진**	회현	광화문

18	창동	종로5가	명동	신금호
19	동대문	용산	합정	충정로
20	건대입구	숙대입구	천호	서울역

**** Stations in bold belong to the subway line 9***

Table 3. Network centrality value in the network after the first opening

Station	Network Centrality Value			
	Degree	Closeness	Betweenness	Eigenvector
김포공항	0.70097	0.31150	0.05454	0.04626
공항시장	0.34838	0.34169	0.06954	0.00734
신방화	0.34838	0.37413	0.08684	0.00900
양천향교	0.34838	0.40906	0.10413	0.00732
가양	0.37851	0.44696	0.12150	0.06482
증미	0.34838	0.48823	0.13886	0.01145
등촌	0.34838	0.53352	0.15623	0.02922
염창	0.37851	0.58304	0.17367	0.07961
신목동	0.34838	0.63738	0.19111	0.14056
선유도	0.34838	0.69728	0.20855	0.35847
당산	0.68477	0.76364	0.32931	0.87669
국회의사당	0.34838	0.81051	0.25420	0.13804
여의도	0.71604	0.87081	0.29967	0.33255
샛강	0.34838	0.91102	0.27238	0.34373
노량진	0.85098	0.97906	1.00000	0.73877
노들	0.34838	0.92839	0.49111	0.27290
흑석	0.34838	0.90167	0.48444	0.11179
동작	0.64691	0.88050	0.51597	0.75501
구반포	0.34838	0.84762	0.37282	0.28353
신반포	0.34838	0.81714	0.36622	0.12867
고속터미널	0.91230	0.80104	0.51442	0.74916

사평	0.34838	0.72443	0.01936	0.04310
신논현	0.17434	0.65572	0.00017	0.01683

Table 4. Network centrality value in the network after the second extension

Station	Network Centrality Value			
	Degree	Closeness	Betweenness	Eigenvector
김포공항	0.68238	0.40046	0.12312	0.04907
공항시장	0.35766	0.42672	0.13042	0.00750
신방화	0.35766	0.45489	0.15064	0.01245
양천향교	0.35766	0.48554	0.17114	0.00743
가양	0.38552	0.51892	0.19219	0.09613
증미	0.35766	0.55686	0.21371	0.01056
등촌	0.35766	0.59831	0.23584	0.02664
염창	0.38552	0.64565	0.25833	0.07173
신목동	0.35766	0.69777	0.28083	0.19493
선유도	0.35766	0.75544	0.30332	0.38197
당산	0.76759	0.81960	0.58187	0.88411
국회의사당	0.35766	0.81310	0.20339	0.17535
여의도	0.67908	0.86204	0.24950	0.34287
샛강	0.35766	0.89752	0.22022	0.37809
노량진	0.71830	0.94709	0.67228	0.74571
노들	0.35766	0.90633	0.31671	0.28222
흑석	0.35766	0.88147	0.30899	0.18294
동작	0.73147	0.89221	0.61027	0.71677
구반포	0.35766	0.86164	0.42315	0.37127
신반포	0.35766	0.83647	0.41469	0.16740
고속터미널	0.85444	0.82189	0.54780	0.77222
사평	0.35766	0.75950	0.07399	0.05515
신논현	0.38552	0.71275	0.05661	0.02462

Network centrality variation

Following four graphs present how the variation of the network centrality value of stations in the line 9 changes through the first opening and the second extension of the line 9. These graphs give more clearer understandings about how the relative importance of line 9 stations in the entire subway network of Seoul changes.

Firstly, in terms of the degree centrality, change in the centrality of the stations from '김포공항' to '선유도' is not remarkable. However, the gap between the peak value and the minimum value decreases slightly, and the difference of centrality values between the major transfer stations also gradually becomes similar. Since the degree centrality is closely related with the number of directly connected links, it is necessary to grasp patterns through other centrality variation changes as well.

Second, the closeness centrality values of the stations, which are located in the center of line 9 and also connected well with other lines in the network, are slightly reduced while the centrality values of the other stations even far from the center of line increase. Closeness centrality value variation change shows the improved accessibility through the second extension of line 9 is distributed to other stations as well.

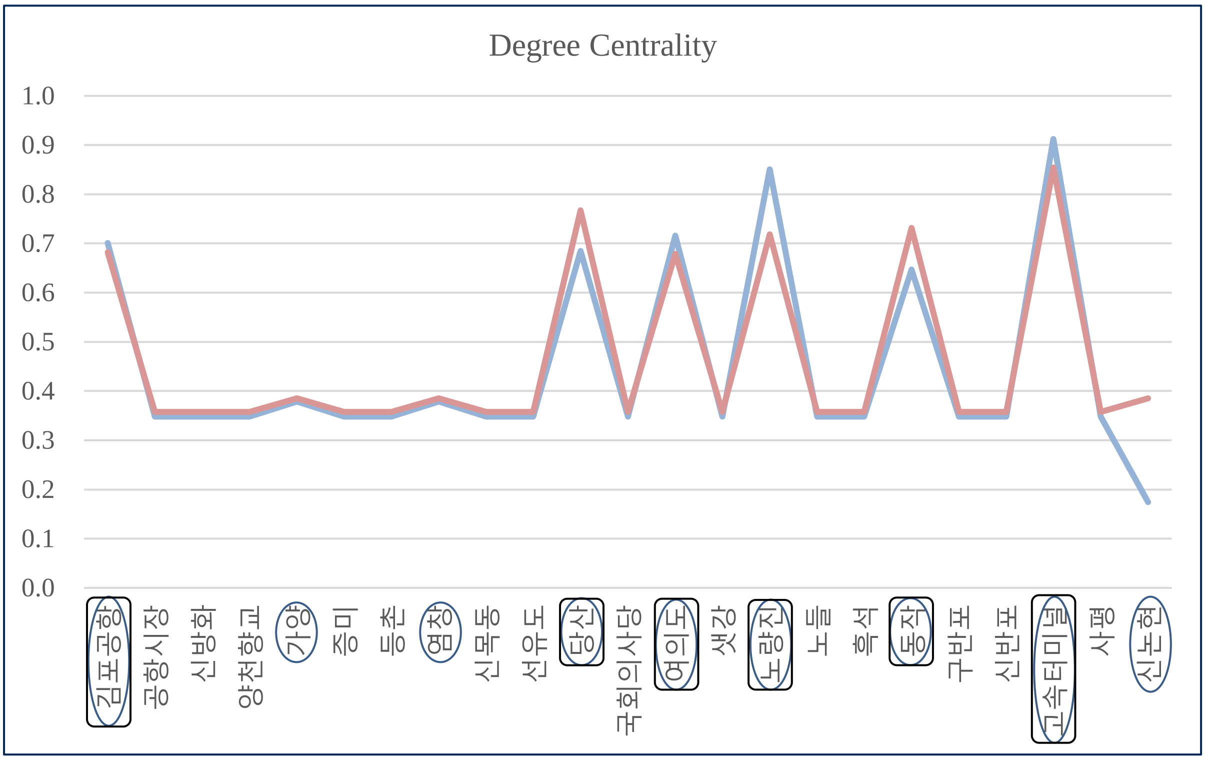

Figure 5. Degree centrality variation change
** Blue(Red) line : After the first opening(second extension) of line 9*
** Transfer station : Boxed / Express station : Circled*

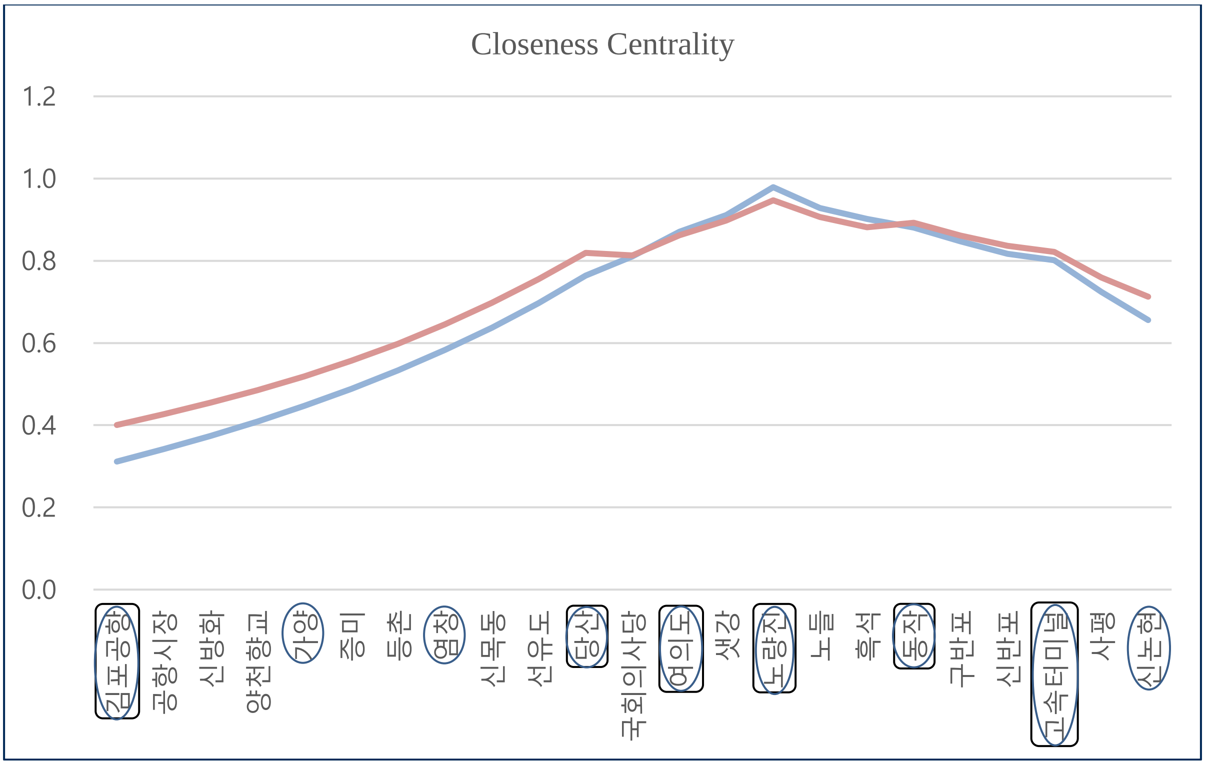

Figure 6. Closeness centrality variation change

** Blue(Red) line : After the first opening(second extension) of line 9*

** Transfer station : Boxed / Express station : Circled*

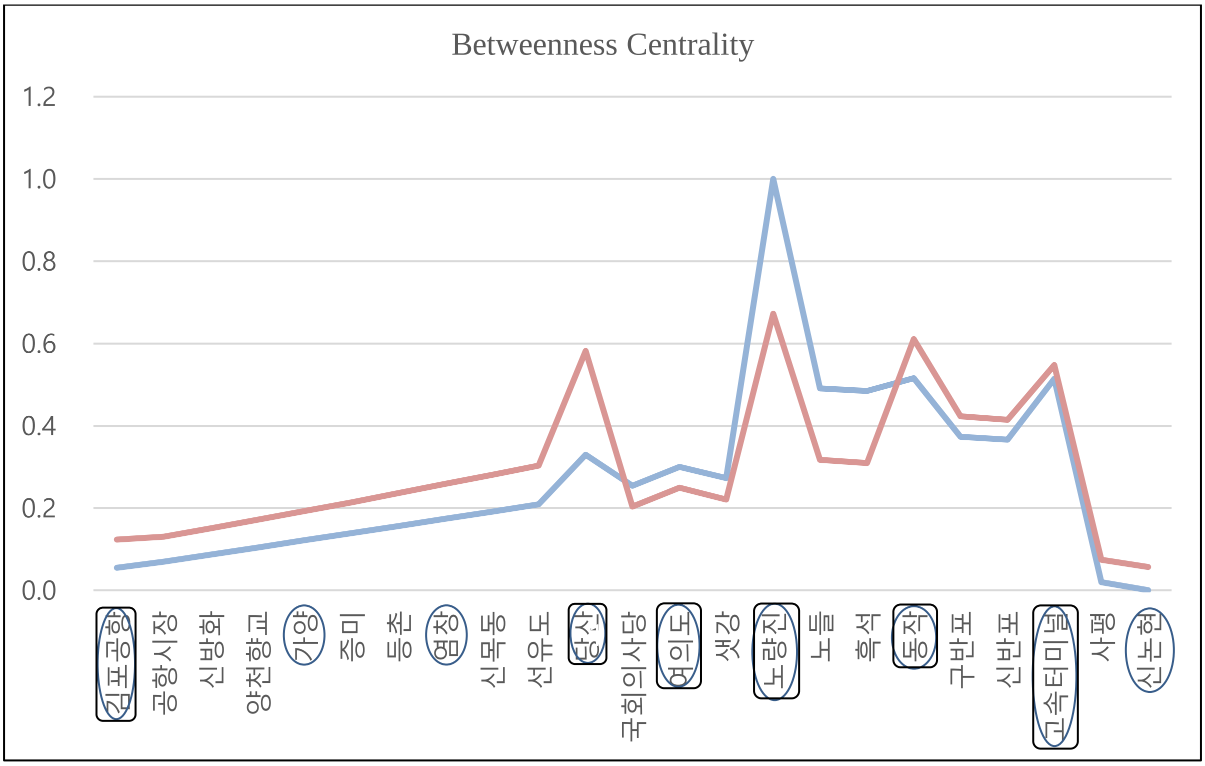

Figure 7. Betweenness centrality variation change

** Blue(Red) line : After the first opening(second extension) of line 9*

** Transfer station : Boxed / Express station : Circled*

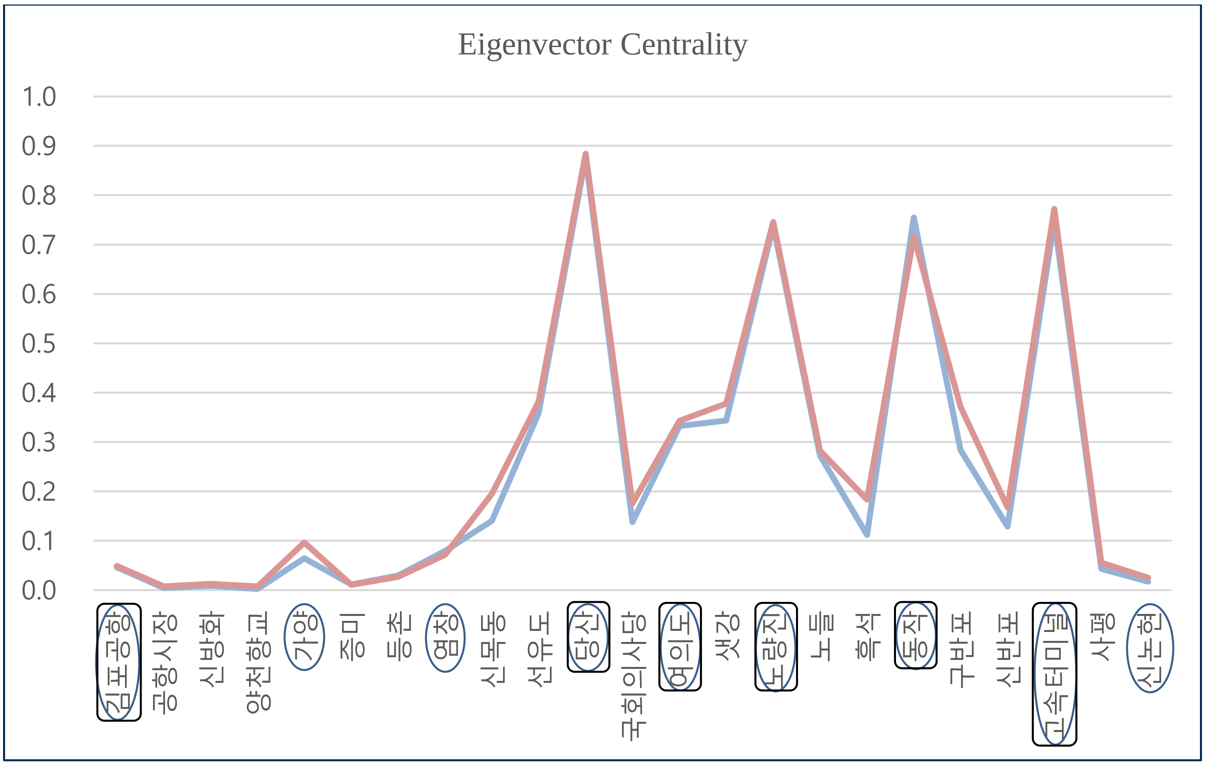

Figure 8. Eigenvector centrality variation change

** Blue(Red) line : After the first opening(second extension) of line 9*

** Transfer station : Boxed / Express station : Circled*

In the change of the betweenness centrality variation, the relative importance of '당산' station and stations on the left of '당산' have increased due to the second extension of line 9 and also indirect linkage between the Airport line and Gyeong-ui central line. High values near '여의도' and '노량진' seem to be slightly reduced after the second extension. Stations on the right of '동작' are closely linked to the section of the second extension so their betweenness centrality values increases.

Conceptually, the eigenvector centrality is an extension of and is based on the degree centrality. Since there is not much big change in variation of the degree centrality, there isn't also significant change in variation of the eigenvector centrality. However, the eigenvector centrality can capture the difference of relative importance between stations more because it also considers the importance of directly connected stations rather than just the number of direct link. Overall, the eigenvector centrality values of other stations rather than transfer stations slightly increase.

To summarize the overall pattern, high centrality values were concentrated near the major transfer stations. However, due to the increased accessibility through the second extension of line 9, more distributed patterns of the centrality values to other stations can be observed. Difference between the peak and the minimum is also reduced.

4.2 Cross-sectional analysis

Descriptive Statistics of samples for each analysis period

Cross-sectional analysis includes the samples in each station catchment area and are transacted after the first opening or the second extension of line 9. 10,931 and 21,731 samples are dealt with for each period.

Table 5. Descriptive statistics of samples after the first opening (N = 10,931)

		Mean	Std.dev	Min	Max
Dependent Variable					
ln(index adjusted price)		10.9668	0.6374	8.6148	12.8365
Independent Variable					
Physical Characteristics	Area	85.4225	35.6881	16.78	273.54
	Floor	8.5881	5.6188	1	39
	Building age	15.0336	10.0425	0	40
	$(\text{Building age})^2$	326.8517	375.4783	0	1600
	# of Households	99.5411	72.7980	16	757
	Total floor	15.5010	6.6518	5	41
Locational Characteristics	Elementary school within 600m	0.9356	0.2455	0	1
	Han river within 600m	0.6623	0.4729	0	1
‘Gu’ dummy variable	Gangnam-gu	0.0170	0.1293	0	1
	Gangseo-gu	0.3193	0.4662	0	1
	Dongjak-gu	0.0755	0.2642	0	1
	Seocho-gu	0.3142	0.4642	0	1
	Yangcheon-gu	0.0864	0.2809	0	1
	Yeongdeungpo-gu	0.1877	0.3905	0	1
Station distance	Distance	548.6156	208.996	30.4795	990.6264
Network Centrality	Degree	0.1547	0.2228	0.0311	0.8225
	Closeness	0.7492	0.1369	0.5376	0.9921
	Betweenness	0.1212	0.2045	0.0021	0.7546
	Eigenvector	0.2669	0.2697	0.0041	0.9742

Overall, the average value and the distribution from the mean of almost variables are similar in both two periods. However, especially in terms of the network centrality value, the mean values are increased. In addition, the standard deviation of almost centrality is reduced. This shows that the pattern about the change in variation of the centrality value is also shown on the analysis samples.

Table 6. Descriptive statistics of samples after the second extension (N = 21,731)

		Mean	Std.dev	Min	Max
Dependent Variable					
ln(index adjusted price)		10.9765	0.5762	9.1754	12.8882
Independent Variable					
Physical Characteristics	Area	84.6458	34.5703	12.16	273.54
	Floor	8.8239	5.8597	1	39
	Building age	18.4951	9.6987	0	46
	$(\text{Building age})^2$	436.1277	434.4474	0	2116
	# of Households	102.0307	75.6337	16	757
	Total floor	16.0415	6.5259	5	41
Locational Characteristics	Elementary school within 600m	0.9405	0.2365	0	1
	Han river within 600m	0.6164	0.4863	0	1
'Gu' dummy variable	Gangnam-gu	0.0069	0.0825	0	1
	Gangseo-gu	0.4295	0.4950	0	1
	Dongjak-gu	0.1010	0.3013	0	1
	Seocho-gu	0.2033	0.4024	0	1
	Yangcheon-gu	0.0794	0.2704	0	1
	Yeongdeungpo-gu	0.1800	0.3841	0	1
Station distance	Distance	542.4338	217.3428	30.4795	990.6624
Network Centrality	Degree	0.2748	0.1743	0.1946	0.7742
	Closeness	0.8214	0.0630	0.7378	0.9684
	Betweenness	0.1426	0.1880	0.0211	0.7422
	Eigenvector	0.2731	0.2741	0.0016	0.8047

Influencing factors of housing price after the first opening

Table 7 represents distance-varying influences of the network centrality in determining nearby housing price located withn 1000m buffer area of each station after the first opening of line 9. In terms of explanatory power of models, the adjusted R^2 value of each sub-model is bigger than 0.82, so each sub-model can explain over 82% of variance. Also, ICC values are over 0.83, so each sub-model can explain over 83% of upper-groups' variance. The direction of the relationship between the physical characteristics and housing price is similar to previous researches. However, the influences of locational characteristics such as walking accessibility to the elementary school or Han river is not significant in the model. Also, the price difference between housing submarkets is properly controlled at the normally accepted level. Among the four centrality, the closeness and the betweenness are significant. When the closeness centrality value increases by 0.1, housing price increases by 1.5%. When the betweenness centrality value increases by 0.1, housing price increases by 1.2%. In terms of distance-varying influence of centrality, closer distance from the station can get more influence of the network centrality.

Table 7. Cross-sectional analysis for the period after the first opening

		Target network centrality variable			
		Degree Centrality	Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
Physical Characteristics	Area	0.00897***	0.00897***	0.00897***	0.00897***
	Floor	0.00472***	0.00472***	0.00472***	0.00472***
	Building age	-0.00543**	-0.00543**	-0.00567**	-0.00560**
	(Building age)^2	0.00020**	0.00019**	0.00019**	0.00019**
	# of households	0.00014	0.00015	0.00016	0.00015
	Total floor	0.01658***	0.01654***	0.01672***	0.01664***
Locational Characteristics	Elementary school within 600m	0.06771*	0.06632*	0.07021*	0.06612*
	Han river within 600m	0.00664	0.00398	0.00441	0.00062
Monthly dummy variable		(Omitted)			
'Gu' dummy variable	Gangnam-gu	(Reference)			
	Gangseo-gu	-0.28172***	-0.26978***	-0.27989***	-0.28877***
	Dongjak-gu	-0.09236	-0.08128	-0.08932	-0.10374

Seocho-gu	0.26037***	0.26628***	0.26700***	0.26412***
Yangcheon-gu	-0.10718*	-0.10312*	-0.10301*	-0.12236*
Yeongdeungpo-gu	-0.14649**	-0.12757**	-0.11856*	-0.14973*
Distance	-0.00013**	-0.00006**	-0.00013**	-0.00015**
Network Centrality	0.19244	0.15303**	0.12367**	0.05837
Distance * Network Centrality	-0.00022**	-0.00014**	-0.00024**	-0.00015*
Constant	9.54178***	9.59691***	9.69119***	9.70670***
The number of samples	10,931			
Adj. R^2	0.82862	0.82869	0.82811	0.82781
ICC	0.83461	0.83516	0.83518	0.83517

Influencing factors of housing price after the second extension

After the second extension of line 9, similar pattern in the influences of the network centrality are observed in terms of not only the averaged influences but also the distance-varying influences. Influences of the closeness centrality and the betweenness centrality are still significant. Closer distance from the station still can get more influence of the network centrality.

Table 8. Cross-sectional analysis for the period after the second extension

		Target network centrality variable			
		Degree Centrality	Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
Physical Characteristics	Area	0.00653***	0.00653***	0.00653***	0.00653***
	Floor	0.00349***	0.00349***	0.00349***	0.00349***
	Building age	-0.03031***	-0.03027***	-0.03035***	-0.03022***
	(Building age)^2	0.00096***	0.00096***	0.00096***	0.00096***
	# of households	0.00048**	0.00047**	0.00044**	0.00048**
	Total floor	0.02403***	0.02425***	0.02416***	0.02420***
Locational Characteristics	Elementary school within 600m	0.01983	0.01896	0.02192	0.01786
	Han river within 600m	0.04501**	0.03938*	0.04370*	0.03612

Monthly dummy variable		(Omitted)			
'Gu' dummy variable	Gangnam-gu	(Reference)			
	Gangseo-gu	-0.46087***	-0.46237***	-0.46626***	-0.46723***
	Dongjak-gu	-0.35827***	-0.35629***	-0.35720***	-0.35726***
	Seocho-gu	0.16215**	0.16958**	0.16443**	0.16658**
	Yangcheon-gu	-0.33784***	-0.33724***	-0.34251***	-0.34095***
	Yeongdeungpo-gu	-0.51640***	-0.49467***	-0.51573***	-0.49368***
Distance		-0.00018*	-0.00017*	-0.00008*	-0.00010*
Network Centrality		0.14427	0.16463**	0.13971**	0.04063
Distance * Network Centrality		-0.00016**	-0.00011**	-0.00018**	-0.00024
Constant		10.43015***	10.00878***	10.00878***	10.00878***
The number of samples		21,731			
Adj. R^2		0.8474	0.8462	0.8462	0.8460
ICC		0.8910	0.8917	0.8910	0.8917

4.3 Inter-temporal analysis

Descriptive Statistics of samples for each analysis period

Inter-temporal analysis includes the samples before and after the first opening or the second extension of line 9. Not only the samples within the station catchment area but also the samples within the buffer area from 600m to 1000m are dealt with. Almost half of samples is included in the post-time group and in the treatment group.

Table 9. Descriptive statistics of samples before and after the first opening (N = 21,797)

		Mean	Std.dev	Min	Max
Dependent Variable					
ln(index adjusted price)		10.8960	0.6438	8.6148	12.8869
Independent Variable					
Physical Characteristics	Area	82.9887	34.9537	16.78	273.54
	Floor	8.4515	5.5323	-1	40
	Building age	14.6015	9.8964	0	40

	(Building age)^2	311.1381	365.7779	0	1600
	# of Households	99.705	70.4865	16	757
	Total floor	15.2754	6.5389	5	41
Locational Characteristics	Elementary school within 600m	0.9328	0.2503	0	1
	Han river within 600m	0.6655	0.4718	0	1
'Gu' dummy variable	Gangnam-gu	0.0163	0.1266	0	1
	Gangseo-gu	0.3390	0.4734	0	1
	Dongjak-gu	0.0787	0.2692	0	1
	Seocho-gu	0.2856	0.4517	0	1
	Yangcheon-gu	0.0815	0.2736	0	1
	Yeongdeungpo-gu	0.1989	0.3992	0	1
Station distance buffer(Treatment)	(0 ~ 200m)	0.0349	0.1836	0	1
	(200 ~ 400m)	0.2261	0.4183	0	1
	(400 ~ 600m)	0.3244	0.4682	0	1
Post time dummy	Post	0.5015	0.5000	0	1

Table 10. Descriptive statistics of samples before and after the second extension (N = 37,689)

		Mean	Std.dev	Min	Max
Dependent Variable					
ln(index adjusted price)		10.9537	0.5939	9.0712	12.8882
Independent Variable					
Physical Characteristics	Area	84.3292	34.8476	12.16	273.54
	Floor	8.8524	5.8622	-1	39
	Building age	17.7668	9.8620	0	46
	(Building age)^2	412.9169	425.4185	0	2116
	# of Households	102.1023	75.8365	16	757
	Total floor	16.0876	6.5439	5	41
Locational Characteristics	Elementary school within 600m	0.9357	0.2453	0	1
	Han river within 600m	0.6319	0.4823	0	1
'Gu'	Gangnam-gu	0.0088	0.0932	0	1

dummy variable	Gangseo-gu	0.4136	0.4925	0	1
	Dongjak-gu	0.0990	0.2986	0	1
	Seocho-gu	0.2227	0.4161	0	1
	Yangcheon-gu	0.0780	0.2682	0	1
	Yeongdeungpo-gu	0.1779	0.3825	0	1
Station distance buffer(Treatment)	(0 ~ 200m)	0.0623	0.2417	0	1
	(200 ~ 400m)	0.2206	0.4147	0	1
	(400 ~ 600m)	0.2994	0.4580	0	1
Post time dummy	Post	0.5766	0.4941	0	1

Impact of the first opening on nearby housing price

The direct marginal price impacts of the first opening to nearby housing prices are 1.9% price increase in 0 to 200m buffer area, 0.9% increase in 200m to 400m buffer area and 0.5% increase in 400m to 600m buffer area.

In terms of the strategic DID model with the interaction variable between treatment dummy, post-time dummy and the network centrality value, positive moderating effect of the network centrality value is observed. After the first opening of line 9, in 0 to 200m buffer area, housing price increases by 2.4% when the closeness centrality value increases by 0.1. In 200m to 400m buffer area, housing price increases by 1.8% when the closeness centrality value increases by 0.1. Also in the inter-temporal analysis, the great influences of the closeness centrality and the betweenness centrality are observed.

Table 11. Baseline DID model

		Coefficient
Physical Characteristics	Area	0.00937^{***}
	Floor	0.00463^{***}
	Building age	-0.01055^{***}
	$(\text{Building age})^2$	0.00072^{***}
	# of households	0.00007
	Total floor	0.02063^{***}
Locational Characteristics	Elementary school within 600m	0.05225
	Han river within 600m	0.01678

Post time dummy variable		0.27901
Monthly trend variable		-0.01330
Monthly dummy variable		(Omitted)
'Gu' dummy variable	Gangnam-gu	(Reference)
	Gangseo-gu	-0.23163***
	Dongjak-gu	-0.10218**
	Seocho-gu	0.21113***
	Yangcheon-gu	-0.16511***
	Yeongdeungpo-gu	-0.18217***
Treatment group	0~200m	0.12316***
	200~400m	0.06259**
	400~600m	0.05330**
DID estimator	**(0~200m) * *Post***	0.01957***
	(200~400m) * *Post*	0.00907**
	(400~600m) * *Post*	0.00541**
Constant		9.97654***
N = 21,797	Adj. R^2 = 0.83444	ICC = 0.78544

Table 12. Strategic DID model

		Target network centrality variable			
		Degree Centrality	Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
Physical Characteristics	Area	0.00937***	0.00937***	0.00937***	0.00937***
	Floor	0.00462***	0.00464***	0.00462***	0.00462***
	Building age	-0.01035**	-0.01080**	-0.00996**	-0.00954**
	(Building age)^2	0.00071***	0.00073***	0.00070***	0.00068***
	# of households	0.00007	0.00007	0.00007	0.00007
	Total floor	0.02065***	0.02068***	0.02062***	0.02056***
Locational Characteristics	Elementary school within 600m	0.05207	0.05194	0.05200	0.05207
	Han river within 600m	0.01780	0.01744	0.01784	0.01604
Post time dummy variable		0.27316	0.26612	0.27182	0.26930

Monthly trend variable		-0.01304	-0.01278	-0.01299	-0.01289
Monthly dummy variable		(Omitted)			
'Gu' dummy variable	Gangnam-gu	(Reference)			
	Gangseo-gu	-0.28834***	-0.29162***	-0.28761***	-0.28747***
	Dongjak-gu	-0.10132*	-0.10355*	-0.10135*	-0.09964*
	Seocho-gu	0.21259***	0.21179***	0.21262***	0.21149***
	Yangcheon-gu	-0.16503**	-0.16564**	-0.16391**	-0.16225**
	Yeongdeungpo-gu	-0.17730**	-0.17964**	-0.17499**	-0.17382**
Treatment group	0~200m	0.13279***	0.12350***	0.12322***	0.12299***
	200~400m	0.06237**	0.06181**	0.06234**	0.06226**
	400~600m	0.05281**	0.05372**	0.05251**	0.05249**
Interaction Variable 1	**(0~200m) * *Post***	0.02198	0.02538	0.02145	0.02287
	(200~400m) * *Post*	0.01726***	0.01410***	0.01846***	0.02007***
	(400~600m) * *Post*	0.01228**	0.01423**	0.01313**	0.01784**
Interaction Variable 2	**(0~200m) * *Post * C***	0.19625	0.24242**	0.20485*	0.05096
	(200~400m) * *Post * C*	0.06051	0.17981***	0.17914***	0.05776**
	(400~600m) * *Post * C*	0.04543	0.14984***	0.10503***	0.03921**
Constant		9.96880***	9.96510***	9.96586***	9.96586***
The number of samples		21,797			
Adj. R^2		0.83393	0.83385	0.83354	0.83356
ICC		0.78640	0.78609	0.78686	0.78691

Impact of the second extension on nearby housing price

However, in terms of the second extension of line 9, the direct marginal price impacts to nearby housing prices decrease in every distance buffer area. 1.1% price increase in 0 to 200m buffer area, 0.9% increase in 200m to 400m buffer area and 0.2% increase in 400m to 600m buffer area. Overall, the marginal price impact of the second extension of line 9 is lower than the impact of the first opening.

In terms of the influence of network centrality, similar pattern about the moderating effect of the network centrality value is observed in the strategic DID model. After the second extension of line 9, in 0 to 200m buffer area, housing price increases by 2.6% when the closeness centrality value increases by 0.1. In 200m to 400m buffer area, housing price increases by 2.1% when the closeness centrality value increases by 0.1. In 400m to 600m buffer area, housing price increases by 2.0% when the closeness centrality value increases by 0.1. Overall, influences of the all network centrality are similar even after the second extension of line 9.

Table 13. Baseline DID model

		Coefficient
Physical Characteristics	Area	0.00681***
	Floor	0.00355***
	Building age	-0.02337***
	$(\text{Building age})^2$	0.00080***
	# of households	0.00045**
	Total floor	0.02376***
Locational Characteristics	Elementary school within 600m	0.03279
	Han river within 600m	0.03770*
Post time dummy variable		-0.13665
Monthly trend variable		-0.00594
Monthly dummy variable		(Omitted)
'Gu' dummy variable	Gangnam-gu	(Reference)
	Gangseo-gu	-0.48346***
	Dongjak-gu	-0.35138***
	Seocho-gu	0.15285**
	Yangcheon-gu	-0.33376***
	Yeongdeungpo-gu	-0.49097***
Treatment group	0~200m	0.08658***
	200~400m	0.05729**
	400~600m	0.01881
DID estimator	**(0~200m) * *Post***	0.01170***
	(200~400m) * *Post*	0.00929***
	(400~600m) * *Post*	0.00155**
Constant		10.18360***
N = 37,689	Adj. R^2 = 0.85342	ICC = 0.86774

Table 14. Strategic DID model

		Target network centrality variable			
		Degree Centrality	Closeness Centrality	Betweenness Centrality	Eigenvector Centrality
Physical Characteristics	Area	0.00681***	0.00681***	0.00681***	0.00681***
	Floor	0.00335***	0.00334***	0.00335***	0.00334***
	Building age	-0.02395***	-0.02494***	-0.02438***	-0.02448***
	(Building age)^2	0.00082***	0.00084***	0.00083***	0.00083***
	# of households	0.00044***	0.00045**	0.00045**	0.00045**
	Total floor	0.02380***	0.02413***	0.02391***	0.02393***
Locational Characteristics	Elementary school within 600m	0.03261	0.03575	0.03225	0.03261
	Han river within 600m	0.03732*	0.04016*	0.03938*	0.03761*
Post time dummy variable		-0.14776	-0.10960	-0.12937	-0.13578
Monthly trend variable		0.00619	0.00542	0.00580	0.00594
Monthly dummy variable		(Omitted)			
'Gu' dummy variable	Gangnam-gu	(Reference)			
	Gangseo-gu	-0.48510***	-0.50273***	-0.48503***	-0.48813***
	Dongjak-gu	-0.35228***	-0.34640***	-0.35002***	-0.34879***
	Seocho-gu	0.15287**	0.15208**	0.15386**	0.15368**
	Yangcheon-gu	-0.33475***	-0.34122***	-0.33218***	-0.33539***
	Yeongdeungpo-gu	-0.48867***	-0.49348***	-0.48875***	-0.48567***
Treatment group	0~200m	0.08481***	0.08228***	0.08054***	0.08455***
	200~400m	0.05733**	0.06010**	0.05789**	0.05730**
	400~600m	0.01878	0.02109	0.01855	0.01846
Interaction Variable 1	**(0~200m) * *Post***	0.01071***	0.01088***	0.01057***	0.01018***
	(200~400m) * *Post*	0.01001***	0.01085***	0.01031***	0.01003***
	(400~600m) * *Post*	0.00133***	0.00141***	0.00136***	0.00127***
Interaction Variable 2	**(0~200m) * *Post* * *C***	0.19867	0.25893***	0.17611***	0.11015***
	(200~400m) * *Post* * *C*	0.07414	0.21026***	0.10329***	0.06607**
	(400~600m) * *Post* * *C*	0.04937	0.19662**	0.08829***	0.06200

Constant	10.18646***	10.19012***	10.18804***	10.18852***
The number of samples	37,689			
Adj. R^2	0.85304	0.85234	0.85285	0.85265
ICC	0.86838	0.87092	0.86889	0.86918

Ⅴ. Discussion

This study analyzes how each subway station's network centrality has moderating effect on the association between new subway line opening and adjacent housing prices. Focusing on the 'network centrality' beyond just 'proximity' to the station, how the relative importance of each subway station can bring the heterogeneous price determining influence in a certain period and how it can bring the heterogenous marginal price impact after the subway line opening or extension are analyzed in this study. The main results were as follows.

First, in terms of the change in the variation of the network centrality, the tendency that high centrality values were concentrated near the major transfer station is slightly reduced after the second extension of line 9. Due to the increased accessibility through the additional extension of line 9, centrality values seem to be distributed to other stations in line 9. Difference between the peak and the minimum is also reduced.

Second, the network centrality value is also an influential determinant of nearby housing price both after the first opening of line 9 and after the second extension of line 9. In addition to the proximity to the subway station, the network centrality value of each stations is also important factor of determining nearby housing price. Among the four types of network centrality, the closeness centrality and the betweenness centrality have great importance compared to the degree centrality and the eigenvector centrality. Effectiveness of a certain station in order to using both line 9 stations and also other stations in the network is measured by the closeness. This effectiveness is an important factor for determining housing price. In addition, in terms of the betweenness, each station's role as an important 'mediator' in the network so the user can easily use other lines or stations also is another important factor for determining housing price.

Third, the network centrality value has also the moderating effect for the marginal price impact of the first opening and the second extension of line 9. After the first opening and the second extension of line 9, housing price increases when the network centrality value increases. The magnitude of the moderating effect of the network centrality value is similar in both periods.

Overall, it is expected that most of the effect due to improved accessibility is already capitalized in housing price after the first opening of line 9. Even after the second extension, influences of the network centrality are still significant. The relative importance of each station is still important factor of housing price, especially in the perspective of the closeness centrality and the betweenness centrality.

Several limitations also exist in this study. First, consideration about the difference of network centrality value between the network before the opening (or extension) and the network after the opening (or extension) is also needed. Before the network establishment, there is a difficulty that how the network centrality value of planned station catchment area where the station is not built yet is determined. 'Zero' value is not also reasonable. It is necessary to devise a method which can take into account the indirect network connectivity from the surrounding stations that are not located in walking zone but users are willing to access with bus or walking. In addition, this study uses the simple way to consider the weight of each link between nodes by applying public information which can be gathered easily. Not just using the operational headway and the number of services in a day, other service and operational characteristics of each subway line should be considered further. Lastly, other various concepts of network centrality rather than four types of centrality in this study can be also used further study for wider understanding about the influences of the network centrality in the relationship between transit improvement and housing price. For more clearer presentation of validity in the network centrality measurement, useful validation methods also need to be considered in further study.

Ⅵ. Conclusion

Previous literatures about the relationship between the transit improvement and housing price mostly consider only the proximity to transit station as the accessibility variable. Since the alternative and new concepts of the transit accessibility have recently been introduced widely, this study considers the network centrality as an alternative accessibility variable for more wider understanding about the relationship between the transit improvement and housing price. How the influences of four types of network centrality such as the degree centrality, the closeness centrality, the betweenness centrality, and the eigenvector centrality have significance in the relationship with housing price is analyzed by both cross-sectional analysis and inter-temporal analysis with the case of the subway line 9 in Seoul. The result of the study has significance in both theoretical and policy perspective.

In terms of theoretical implication, this study can demonstrate that the relative importance of each station, especially in the perspective of the network centrality, makes heterogenous effect of the improved accessibility to housing price. In addition to the recent tendency of considering the station-specific characteristics such as landscape, physical, service characteristics of each station in various studies, relative importance of each station in the entire subway network also needs to be considered.

In terms of policy aspect, consideration about the relative importance of each subway station in the entire subway network needs to be included in assessment of a certain transport policy implementation with the measurement of development profit. How the distribution of development profit is well distributed or concentrated at a certain area will be more effectively assessed with the network centrality consideration. In addition, in terms of housing demand, relative importance of the nearest station is also an important demand factor of housing. Therefore, consideration about the network centrality can bring more benefit to design better transportation policy with effective linkage to various housing supply policy.

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