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Analysing Determinants of Property Development Activities in Seoul's Gwangjin District: A Parcel-Level Approach

Yeonjae LEE[1] *and* ***Seongwon LEE***[2]*

Authors' affiliations and addresses:
[1] College of Real Estate, Konkuk University, 05029, Gwangjin, Seoul, Korea
e-mail: 22petales@gmail.com

[2] College of Real Estate, Konkuk University, 05029, Gwangjin, Seoul, Korea
e-mail: won.cool.lee@gmail.com

***Correspondence:**
Seongwon Lee, College of Real Estate, Konkuk University, 05029, Gwangjin, Seoul, Korea
tel.: +82 2 450 3553
e-mail: won.cool.lee@gmail.com

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Abstract
This study investigates the factors influencing property development activities in Seoul's Gwangjin district over an eight-year period from 2011 to 2018. We constructed two comprehensive models (econometric and machine learning) encompassing location, zoning, neighbourhoods, building characteristics, and market conditions to analyse property development behaviour at the individual-parcel level. We utilize three data samples (completed building plot sample, near-subway station completed building plot sub-sample, and vacant-plot sample). We used either the Hausman–Taylor or a random-effect model. The nonlinearity of building age and age squared is confirmed. Therefore, the economic life of existing buildings is a key driver of (re)development in urban settings. Land assembly and the nonlinearity of area size require land assembly-friendly policy interventions. This comprehensive analysis provides valuable insights for urban planners, underscoring the need for a spatially targeted, strategic approach to property development, particularly with developer incentives.

Keywords
property development, land assembly, vacant land, Hausman–Tayler model, Korea

Introduction

Whitehand (2001) cited parcel boundaries as one of the most immutable elements of urban form. Moreover, Conzen (2009) noted that even wars and natural disasters are unlikely to change land boundaries. However, without land delineation changes in cities, cities will fail to generate sufficient economic growth and innovation (Brooks and Lutz, 2016). Amid this growing demand for private initiatives and the trend of deregulation, density bonuses and land assembly are considered important means to improve urban functions through greater property development (PD). Many theoretical papers have described the importance of land assembly and its difficulties (e.g., holdup) in a property (re)development context in urban settings (Tsai, Wang, 2022). Brooks and Lutz (2016) considered land assembly premiums, whereas others investigated vacant land and soon-to-be-demolished structure sale prices in a cross-sectional manner. Few studies have investigated property development activities systematically (Lai et al., 2021). Therefore, structural explanations of urban property (re)development decision-making — from land acquisition to eventual property development — in very dense, industrialized urban settings are lacking.

Our study aims to analyse the factors affecting property development activities in Gwangjin and provide implications for urban planning policy formulation. We examine the factors influencing PD in Seoul's Gwangjin district over an eight-year period, from 2011 to 2018, using whole-parcel data (total population). We construct two comprehensive models (econometric and machine learning) encompassing location, land use, amenities, zoning regulations, neighbourhoods, building characteristics, and financial market conditions to analyse the determinants of property development behaviour on a parcel-by-parcel basis. We utilize three data samples (completed building plot sample, completed building plot near subway station subsample, and vacant-plot sample), and we assume that there was a systemic difference between vacant parcels and completed building plots even when the residual value of the structure is zero.

We found that land assembly, building age, area size, and vacant land status positively and significantly impact property development. These results suggest that land assembly-friendly policy interventions are needed to promote development activities aimed at urban renewal. We also illustrate the necessity of a density bonus policy at the individual parcel level, aiming to have the developer, as the beneficiary, further stimulate it. The remainder of this paper is organized as follows. Section 1 describes the background, purpose, scope, and methodology of the study. Section 2 discusses the hypotheses and originality of this paper by reviewing previous research on urban land (UL) and efficient real estate development. Section 3 describes the research design, and Section 4 presents the empirical analysis. Section 5 concludes the study by outlining its limitations.

Literature Review

1.1 Theoretical Background

The theories related to urban PD include those of DiPasquale and Wheaton (1996) and Capozza and Helsley (1990). DiPasquale and Wheaton (1996) explained market equilibrium by linking spatial markets with asset and real estate development markets. Essentially, they showed that higher demand for spatial services increases the price of assets, which in turn stimulates real estate development. Capozza and Helsley (1990) examined the relationships among urban growth, land prices, and rent. They investigated the effect of uncertainty on equilibrium land rents and prices in growing urban areas. They found that, even for risk-neutral investors, uncertainty affects land rents and prices, potentially delaying the conversion of agricultural land to UL. Furthermore, it could add an option value to the value of agricultural land, so that the price of land at the urban periphery exceeds its opportunity cost. The results also showed that uncertainty affects the timing of land development, increasing the option value and delaying development.

Real estate (re)development also exhibits a certain cyclicality related to the physical deterioration or functional obsolescence of real estate structure over time (i.e., depreciation; Geltner et al., 2020). By focusing on changes in the land market (rent gap) and transportation, real estate developers and investors generally seek to capitalize on new development, redevelopment, and other investment opportunities. Amin and Capozza (1993) analysed several continuous redevelopment processes, which eventually led to continuous high-density (re)development. They found that the variables that influence redevelopment decisions are zoning, reserve rents, land prices, and financing costs. However, the rent gap alone is not sufficient, and transaction costs and institutional factors should also be considered (Lai et al., 2021)

1.2 Land Assembly and Property Development

A typical line of research regarding the highest and best use of fragmented UL concerns incentives such as density bonuses, incentive zoning programmes, deregulations, and conversion incentives (Ahlfeldt and McMillen, 2015; Amin and Capozza, 1993; Lum et al., 2004; Shoup, 2008; Wang et al., 2022). Other classical land economic analyses focused on plottage and plattage. These concepts concern whether the shape of the land price function is concave or convex with respect to the land area. In terms of the empirical analyses, this line of research considers the price of the land parcel as the dependent variable and the area of the lot as the primary independent variable. These studies recommend either a land split or an assembly of UL to achieve the optimal land size (Isakson, 2013). In general, there is an optimal area size that is suitable for each type of space. The left-side region of the optimal size is advantageous when assembled because the land area is narrower than the optimal area, whereas the right-side region has a wider area than necessary; therefore, a split is advantageous (Colwell and Munneke, 1999; Colwell and Sirmans, 1978).

In the United States, the cost of a split (i.e., subdivision) is relatively higher due to infrastructure and utility installation costs; it is believed that large land areas are less expensive. This is related to the notion of plattage (Colwell and Sirmans, 1978). However, Lin and Evans (2000) argued in favour of plottage. In cities that are already quite fragmented (e.g., Tokyo and Taipei), assembly costs are higher, and consequently, assembled land should be more expensive (Lin, 2005; Tabuchi, 1996).

Several studies have examined the characteristics of developers who assemble land parcels (Gabbe, 2018; Neutze, 1987). Neutze (1987) emphasized that individual parcel owners who are not members of specialized PD companies cannot develop property individually and do not have the financial resources to assemble nearby land parcels. Gabbe (2018) identified various property developers in urban renewal scenarios. Lee and Shin (2021) recommended a specific matching incentive design for local developers. Studies have also recommended developer-friendly property development incentive systems (Li et al., 2019; Tang, Tang, 1999).

There is limited literature on parcel-level-specific development behaviour (Zöllig and Axhausen, 2012). In alignment with our study on property (re)development in urban settings, Kang (2010) used land registration books, but owing to difficulties in obtaining detailed parcel-level information, he mainly used district-level macro variables in Seoul and used changes in the data for 2001 and 2007. Our study augments parcel-level data by using building registration books and adds a spatial measurement methodology, as shown in Baltagi et al. (2015). Although development activities based on rent gaps exhibit clustering, not all parcels in a gentrifying neighbourhood are developed simultaneously, even when they are adjacent to each other (Weber et al., 2006). Therefore, a parcel-level model must be developed (Chakir and Callo, 2013).

Zöllig and Axhausen (2012) conducted a multinomial logit analysis of new construction activities in Zürich, Switzerland, defining the vicinity or neighbourhood as a radius of 105–334 m. However, the spatial scope of development activity was modelled at 150 m (number of buildings built before 1995) and 300 m (number of residents relocated in the past 5 years). There are many neighbourhood measurement methods in the literature: 1600 metres (Carrión-Flores et al., 2009) or a half-mile radius (Tepe and Guldmann, 2017). In Gwangjin, neighbourhoods are much smaller, within a radius of 50 m (Lee, Shin, 2023). Baltagi et al. (2015) considered spatial econometric models to be particularly important. Considering that the spatial weighting matrix is too large to be computationally tractable (Carrión-Flores et al., 2009), they introduced a reduced-form spatial econometric measure that considers only the most recent 140 property transactions in the vicinity. Otherwise, it is necessary to use a supercomputer with a parallel processing technique (Tepe and Guldmann, 2017).

1.3 Density Incentives and Development Activities

There is a large body of research on high-density development (Turk et al., 2020; Zhu, 2012). The following empirical studies examined whether density bonuses through urban planning positively affect denser PD through developers' land assembly activities. Gallagher et al. (2019) in Australia and Fredrickson et al. (2016) in New Zealand argued that developers' land assembly is autonomous and driven by market supply and demand, independent of zoning. McFarlane et al. (2023) conducted a logit analysis using Australian data. They contended that the cheaper the land, the greater the potential for land assembly, and that development with land assembly is more likely to occur on the outskirts of cities than in more expensive urban centres. Furthermore, actual housing development was not driven by land assembly but rather concentrated on existing large lots, and density bonuses had a limited effect on promoting land assembly. Fredrickson et al. (2016) reported that land assembly did not result in high-density development in New Zealand. This was attributed to New Zealanders preferring single-family homes, suggesting land expropriation and joint venture-type development between private landowners and public corporations (e.g., Kāinga Ora-Housing New Zealand) for high-density development.

Conversely, Dong (2021) demonstrated a positive effect over a 15-year time horizon, with the magnitude of the effect varying by neighbourhood. High-density neighbourhoods with capacity constraints to provide an additional floor area ratio demonstrated a limited scope for further development. Balzarini and Boyd (2024) studied Philadelphia's tax incentives for affordable housing. They showed that an unintended problem is that small landowners lack the capacity and finances to undertake sufficiently large developments to capitalize on tax incentives. To recapture these tax incentives fairly, the city reassessed property values, increasing the property tax burden, which was subsequently passed on to tenants, leaving small landlords unhappy. In a similar vein, few studies have examined who should be the target of density bonus policies — landlords or developers. However, it is difficult to distinguish between them simply because, generally, developers eventually become landlords. Tang and Tang (1999) and Li et al. (2019) recommended much more sophisticated policy interventions aimed at developers as policy targets, since developers essentially develop property.

Several papers have investigated cities as case studies. Wong (2004) proposed the concept of a vertical city to address land scarcity and examined residents' willingness to accept it through a case study of a high-rise public housing development in Singapore. The vertical city in this study included three elements: maximizing ground-level public space, introducing an efficient interfloor movement system, and integrating diverse spatial uses within the structure. Recently, Huang et al. (2023) studied vertical urban development in Brisbane, Australia, from the perspective of urban consolidation and recommended a parcel-level land assembly-friendly policy intervention.

1.4 Urban Vacant Land

Definitions of vacant land (VL) vary to the extent that consensus seems impossible. Davidson and Dolnick (2004), citing the American Planning Association, defined it as land without any structure. Moreover, Pagano and Bowman (2000), pioneers in the field of VL survey research, included both structure-free land and underutilized land, as well as abandoned structures. Song et al. (2020) included idle land to reflect Chinese legislation, but distinguished between parks and natural green spaces where human activity is not observed. Newman et al. (2016) studied vacant addresses, defined as buildings where the U.S. Postal Service has not collected mail for more than 90 days. The VL in our study is land without buildings (713 parcels), similar to that in Huang et al. (2023), excluding 266 parcels attached to the main building and auxiliary areas that function as car parks. We also excluded 77 publicly owned parcels (Jaeger, 2013). Both categories were available for independent development, leaving 370 parcels for the final analysis.

Studies have pointed to the failure of UL growth to keep pace with population growth as a cause of VL (Newman et al., 2018; Seto et al., 2011). Pagano and Bowman (2000) emphasized small lot size, irregular shape, and poor location as characteristics of vacant properties and reported that 26% of vacant properties have been long abandoned. Therefore, a distinction can be made between vacant and demolished sites (Glaeser and Gyourko, 2003). There are systematic differences between vacant and demolished sites, including where they occur and how long they last (Gedal and Ellen, 2018). The effects of density incentives have been examined by distinguishing between VL, completed building sites, and infill land (Dong, 2021).

Research Design

Research Area

Gwangjin is one of the 25 districts in northeastern Seoul (Figure 1), with an area of 17 km^2, approximately 33,307 land lots, and a population of 366,939 (21,585 people/km^2) as of 2015.

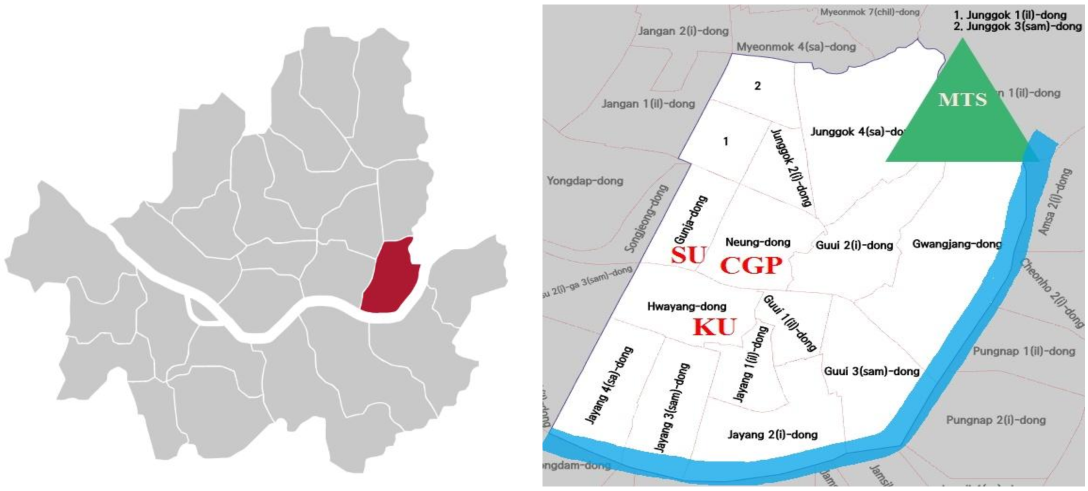

Fig. 1. Gwangjin District, Seoul, Korea: (left) Kurykh and Anwoosuk; (right) Gwangjin District. MTS: mountains; SU: Sejong University; CGP: Children's Grand Park; KU: Konkuk University; HR: Han River. Source: Shin et al. (2023).

A land readjustment project in the 1970s, which aimed to accommodate rapid industrialization and subsequent urbanization, resulted in massive district-wide land readjustment in Gwangjin, transforming it into a single-family dwelling area for individual households, with an average parcel area of 100–160 m^2 (Lee, 2009). Figure 1 shows the location of the Gwangjin District. Over the next 40 years, land use patterns changed dramatically, underscoring the need for appropriate policy formulation to meet both residential and commercial space demand.

Research Methodology

The data used in this study are balanced panel data tracking developmental activities in Gwangjin District from 2011 to 2018. Considering the dependent variable and the panel data structure, the analysis uses a logistic regression model with fixed effects, random effects, and an HT model (Hausman and Taylor, 1981), depending on the panel characteristics. Below is a description of the models that combine the consistency of a fixed-effects model with the efficiency of a random-effects model.

The regression model that considers the entity's characteristics is shown in Equation (1).

$$\boldsymbol{Y_{it} = \alpha + \beta X_{it} + u_i + e_{it}, \qquad i = 1, 2, \ldots, N \ and \ t = 1, 2, \ldots, T} \qquad (1)$$

Assuming a balanced panel in which all panel observations have the same observation period, the cross-sectional error term varies across panel observations and is time-invariant within each panel. e_{it} denotes the error term, which varies with panel observations and time. The fixed-effects model treats the error term as a parameter to be estimated, whereas the random-effects model treats it as a random variable. To rephrase Equation (1), we have

$$Y_{it} = (\alpha + u_i) + \beta X_{it} + e_{it} \qquad (2)$$

The fixed effects model assumes that the constant term varies across entities but is fixed such that the slope is the same for all entities, but the constant term varies across entities. To estimate Equation (2), we should perform within transformations for each variable. First, we modify Equation (2) as a between estimator with averages across panel groups, as follows:

$$\bar{Y} = \alpha + \beta \bar{X_i} + u_i + \bar{e_i} \qquad (3)$$

Subtracting Equation (3) from Equation (2) provides the model through the within transformation.

$$(Y_{it} - \bar{Y}) = \beta (X_{it} - \bar{X_i}) + (e_{it} - \bar{e_i}) \qquad (4)$$

Equation (4) shows that the term u_i disappears in the fixed-effects model, which allows us to obtain a consistent estimate for β even if $cov(X_{it}, u_i) \neq 0$.

However, the random-effects model adds an additional assumption about $\text{cov}(X_{it}, u_i) = 0$, and the estimation results can be obtained using Equation (5).

$$(Y_{it} - \theta_i \bar{Y}) = \alpha(1 - \theta_i) + \beta(X_{it} - \theta_i \bar{X_i}) + [u_i(1 - \theta_i) + (e_{it} - \theta_i \bar{e_i})] \qquad (5)$$

In short, the random-effects model is a weighted average of the between- and within-estimators. The choice between the fixed- and random-effects models depends on the existence of $\text{cov}(X_{it}, u_i) = 0$ or the systematic differences between the estimates from fixed- and random-effects models. The Hausman test tests the hypothesis of endogeneity in the explanatory variables, leading to the choice between a fixed- or random-effects model. However, fixed-effects models are limited in that time-invariant variables are removed during the demeaning process, whereas in random-effects models, the condition of consistent estimation is difficult to meet due to omitted-variable bias, self-selection, endogeneity, and measurement error.

The HT model is an extension of the fixed- and random-effects models and uses the instrumental variable method to address endogeneity between time-invariant explanatory variables and error terms, enabling consistent model estimation.

Equation (6) demonstrates the basic regression equation for the HT model. The error term u_i is considered an unobserved random effect.

$$Y_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 Z_i + u_i + e_{it} \qquad (6)$$

Z_i is a time-invariant variable, and assuming a correlation between the error term u_i and the explanatory variable X_{2it}, the estimated coefficient cannot be a consistent estimate if Equation (6) is estimated using a random-effects model. In the case of $cov(X_{it}, u_i) \neq 0$, the fixed effects model can be used to obtain a consistent estimate, but it has the limitation that β_3 is not estimated. If the estimation of the effect of Z_i is important, it is not appropriate to choose a fixed-effects model; therefore, the method of obtaining consistent estimates while estimating β_3 is to estimate an HT model with instrumental variables.

Data and Variables

In this study, PD activity refers to new PD entitlement. The data were constructed by combining land characteristics retrieved from the land registration book with information on development approval and occupancy permits from the building registration book. Gwangjin District has 33,103 parcels. First, 6,581 parcels with areas of 10 m^2 or less and an 'agricultural fields' land use classification were eliminated. We then removed 2,350 parcels that were newly created through splitting or deletions via land assembly. Therefore, the analysis uses an 8-year balanced panel from 2011 to 2018 for 24,172 parcels, totalling 193,376 records (parcel * year), as shown in Table 1.

*Tab. 1. Gwangjin field notes (N = 193,376, parcel*year)*

Model 1. Entire completed building plots	Model 2. Completed building plots within 250 m of a subway station
N = 186,832, (parcel* year)	N = 37,576, (parcel* year)

Model 3. Vacant parcels
Vacant parcels in the book, N = 6,544, (parcel* year) ↓ Actual vacant parcels, N = 2,960, (parcel* year)

The analysis method included panel logistic regression. The research samples comprised completed building plots and vacant parcels. Following the Chow test results, the completed building plots and vacant parcels were estimated separately without pooling. The completed building plot samples are divided into entire parcels and subsamples within 250 m of the nearest subway station, following the methods of Shin et al. (2023). Moreover, a vacant parcel sample is constructed for the entire parcel owing to the small sample size (N = 370), but the nearest subway station dummy variable is included. According to the building registration book published at the end of 2018, there were 818 parcels of land with no structures. Of these, 370 (1.53% of all 24,172 parcels) had development potential. Vacant plots with development potential are those whose current land use is car parks, or that were recently unused or demolished.

The dependent variable is the occurrence of development activities, with 1 for new development approval and 0 for the status quo. The research variables include land assembly activity, building age, and vacancy dummy variables, as illustrated in Table 2. The building age variable is used only for the completed building plot sample, and the vacancy dummy variable is used only for the vacant-plot sample. The other independent variables are the same for all three samples. Among the independent variables, vacant land status and land assembly activities are worth mentioning. These activities appear to be in preparation for property development. However, they do not always result in immediate property development, similar to second delinquency and default (third delinquency) in the mortgage risk analysis literature (Deng et al., 2000).

Tab. 2. Definitions and calculations of the variables

Variables		Dummy	Description (Unit)
Control Variable	Development	Yes	1, Development approval
	Tax assessment	Real Number	Tax assessment ($/$m^2$), 1,000 KRW/USD
	The logarithm of tax assessment	Real Number	The logarithm of tax assessment
	Annual growth rate of tax assessment	Real Number	(Current tax assessment/Tax assessment for prior year) – 1
	Area	No	Area size (㎡)
	Area squared	No	Area size squared
	Slope of land parcel	Yes	1, if no or little slope
	Subway station	No	Distance to a nearby subway station (m)
	Shopping centre	No	Distance to the largest shopping centre in Gwangjin (m)

	Number of cluster developments	No	The number of developments within 50 m, 100 m, and 300 m of each parcel	
	Shape of land parcel	Yes	Trapezoid, irregular, sack (base variable: square, vertical rectangle, horizontal rectangle, triangle, inverted triangle)	
	Zone	Yes	Class 3 residential, quasiresidential, commercial (base variable: Classes 1 and 2 residential, natural green, green belt) Class 1 residential is the least dense zone.	
	Street	Yes	Main street, Main street+corner, Main street+small corner, Street+corner, Road+corner, Lane+corner dummies (base variable: street, road, lane) Main street (over 25 m), Street (12–25 m), Road (8–12 m), and lane (less than 8 m)	
	CD rate	No	Current year CD interest rate	
Research Variable	Formal land assembly 0	Yes	The time of legal and formal land assembly	
	Formal land assembly 1	Yes	One year after formal land assembly	
	Formal land assembly 2	Yes	Two years after formal land assembly	
	Building age	No	Completed building plot	The age of a building
	Building age squared	No	Completed building plot	The squared age of a building
	Vacant plot 0	Yes	Vacant plot	The time the land became vacant
	Vacant plot 1	Yes	Vacant plot	Year after the land becomes vacant
	Vacant plot 2	Yes	Vacant plot	Two years after the land becomes vacant

Research Results

Descriptive Statistics

The descriptive statistics for the completed building plots (entire completed building-plot sample and nearest-subway completed building-plot subsample) are shown in Table 3. The following discussion compares the CBP sample (the left part of Table 3) with the overall vacant-parcel sample (Table 4). Over the eight-year period from 2011 to 2018, there were 2,989 developmental activities in the CBP sample (12.55% of 23,802 CBPs) and 131 in the vacant-plot sample (35.40% of 370 vacant plots). The tax assessment of the CBP sample (average KRW 3,046,001) is approximately 19.64% lower than that of vacant plots (average KRW 3,790,720) with lower volatility (standard deviation (SD) = 1,362,223: 1,903,866). In general, the exchange rate is 1,000 KRW/USD during our observation period.

The area of the CBP sample in Gwangjin District (mean = 255 m^2; SD = 1167) is relatively smaller than that of the vacant parcels (mean = 294 m^2; SD = 625), and the CBP parcels are located slightly farther from major subway stations and shopping malls than the vacant plots are. Land assembly is very rare, with an average of only approximately 0.001% per year among the CBP sample, the same as in the vacant-parcel sample (0.001%). For the land assembly variable, we constructed three-year dummies: the year of land assembly, one year after land assembly, and two years after land assembly, and analysed whether land assembly leads to development over three years. From 2011 to 2018, the average CD interest rate was 2.29%, remaining low on average. In terms of the building life cycle, buildings in the Gwangjin District are generally old (27 years old on average). The number of cluster development activity variables shows a spatial and temporal clustering effect of development activity, with clustered development within 50 m in the CBP sample (0.478 cases/lot), which is more pronounced than that in the vacant parcel sample (0.312 cases/lot). To examine the impact of land shape on development decision-making in Gwangjin, we included trapezoidal, irregular, and sack shapes in the model and reported that the land shape of the CBP sample was approximately 18.9% trapezoidal, 6% irregular, and 6.1% sack. When considering the road frontage conditions of the parcels, Gwangjin has the greatest number of parcels with road frontage conditions less than 8 m wide (lane), which may limit the two-way traffic of cars simultaneously, which is again related to the fragmentation phenomenon. The road frontage conditions of the CBP sample are dominated by lane+corner

(14.1%), and the vacant-parcel sample is dominated by main streets (more than 25 m) (12.4%), indicating development-friendly conditions for vacant parcels.

Tab. 3. Descriptive statistics: CBP sample (N = 186,832) and near subway subsample (N = 37,576)

	Overall sample (N = 186,832)				Near subway station sample (N = 37,576)			
Variables	Mean	Standard deviation	Min	max	Mean	Standard deviation	Min	max
Development	0.016	0.125	0	1	0.015	0.121	0	1
Tax assessment ($/m^2)	3,046	1,362	343	28,300	3,703	2,129	1,190	28,300
Annual growth rate of tax assessment	0.049	0.029	−0.640	6.100	0.049	0.026	−0.140	1.240
Area	255.498	1167.280	11.4	87,244	278.019	1,101.448	11.6	40,414.5
Slope of the parcel	0.932	0.252	0	1	0.985	0.123	0	1
Subway station (m)	425	200	7	1,100	158	62	7	250
Shopping centre (m)	1743	943	24	3,810	1,698	994	24	3,783
Formal land assembly 0	0.001	0.035	0	1	0.001	0.029	0	1
Formal land assembly 1	0.001	0.035	0	1	0.001	0.031	0	1
Formal land assembly 2	0.001	0.033	0	1	0.001	0.031	0	1
CD rate	2.290	0.757	1.440	3.440	2.290	0.757	1.440	3.440
Building age	26.841	18.572	0	92.417	27.314	18.165	0	92.417
Number of cluster developments (50 m)	0.478	0.847	0	9	0.435	0.786	0	9
Shape_trapezoid	0.189	0.391	0	1	0.178	0.382	0	1
Shape_ilregular	0.060	0.237	0	1	0.058	0.233	0	1
Shape_sack	0.061	0.240	0	1	0.068	0.252	0	1
Zone_3 residential	0.136	0.342	0	1	0.107	0.309	0	1
Zone_Quasi-residential	0.044	0.205	0	1	0.133	0.339	0	1
Zone_Commercial	0.013	0.115	0	1	0.055	0.228	0	1
Main street	0.034	0.182	0	1	0.052	0.223	0	1
Main street+corner	0.012	0.107	0	1	0.020	0.141	0	1
Main street+small corner	0.022	0.147	0	1	0.028	0.164	0	1
Street+corner	0.025	0.157	0	1	0.020	0.142	0	1
Road+corner	0.054	0.226	0	1	0.063	0.244	0	1
Lane+corner	0.141	0.348	0	1	0.110	0.313	0	1

Tab. 4. Descriptive statistics: Vacant-plot sample (N = 2,960)

Variables	Mean	Standard deviation	Min	max
Development	0.078	0.268	0	1
Near subway station	0.319	0.466	0	1
Tax assessment ($/m^2)	3,790	1,903	324	13,500
Annual growth rate of tax assessment	0.050	0.071	−0.1	2.28
Area	294.708	624.878	11	6,091
Slope of the parcel	0.941	0.236	0	1
Subway station (m)	356.268	202.950	4	904
Shopping centre (m)	1477.816	978.380	123	3732
Formal land assembly 0	0.001	0.037	0	1
Formal land assembly 1	0.001	0.026	0	1
Formal land assembly 2	0.001	0.026	0	1
CD rate	2.290	0.757	1.44	3.44
Number of cluster developments (50 m)	0.312	0.698	0	7
Shape_trapezoid	0.221	0.415	0	1
Shape_ilregular	0.201	0.401	0	1
Shape_sack	0.072	0.258	0	1
Zone_3 residential	0.236	0.425	0	1
Zone_Quasi-residential	0.221	0.415	0	1
Zone_Commercial	0.088	0.284	0	1
Main street	0.124	0.330	0	1
Main street+corner	0.049	0.215	0	1
Main street+small corner	0.087	0.282	0	1
Street+corner	0.020	0.139	0	1
Road+corner	0.049	0.215	0	1
Lane+corner	0.054	0.225	0	1
Vacant plot 0	0.080	0.271	0	1
Vacant plot 1	0.059	0.235	0	1
Vacant plot 2	0.057	0.232	0	1

A comparison of the descriptive statistics of the nearest subway station CBP subsample (CBP subsample) is in the right section of Table 3, and the overall vacant-parcel sample is shown in Table 4. The development activity rates of 1.5% for the CBP subsample and 7.8% for the vacant-parcel sample indicate that vacant parcels are more development-friendly. And sites with at least one side bordered by a main street at least 25 m wide were also more common in the vacant-parcel sample.

Estimation Results

Panel logistic regression models are estimated using a panel HT model (overall CBP sample and nearest subway station CBP subsample model) and a panel random effects model (vacant-parcel sample with a subway station dummy) on the basis of the Hausman test results.

Estimation Results of the CBP and Vacant-Parcel Samples

First, the null hypothesis of the Hausman test was rejected (Prob > chi2 = 0.9965) for the overall CBP sample. However, to account for endogeneity in the model (Jaeger, 2013; Tepe and Guldmann, 2017), an additional panel

HT model was estimated. We introduced the variable ‘distance to subway station’ as an endogenous, time-invariant variable, and the time-varying endogenous variables ‘tax assessment appreciation rate’, ‘land assembly’, and ‘commercial zone’. Logically, it is reasonable to expect subway stations to be located where there is more development, and PD activities may endogenously increase tax assessments, induce land assembly, and drive zoning changes. The vacant-parcel sample was estimated using a panel logistic random-effects model. The Hausman test accepts the null hypothesis (Prob > chi2 = 1.0000).

The results of the overall CBP sample analysis, as shown in Table 5, are as follows: tax assessment increase rate (+), area size (−), area size squared (+), slope of parcel (−), distance to subway station (−), distance to shopping mall (−), CD interest rate (−), building age (−), building age squared (+), number of cluster developments within 50 m (+), land shape_trapezoid (−), land shape_sack (+), Class 3 residential (+), quasiresidential (−), main street+small corner (+), street+corner (+), and lane+corner (−) were statistically significant at the 1% significance level; land shape_irregular (−) and road+corner (−) were statistically significant at the 5% significance level; and the first year of land assembly (+) and main street (+) were statistically significant at the 10% significance level.

Tab. 5. Estimation results

	Overall completed building plot sample		Near subway station completed building plot subsample		Vacant-plot sample	
	Panel Hausman–Taylor				Panel random effect	
Variable	Coefficient	Z	Coefficient	Z	Coefficient	Z
Constant	1.123***	23.630	0.780***	7.730	0.285	0.150
Annual growth rate of tax assessment	0.041***	3.770	0.106***	4.060	0.096	0.040
Area	−0.000***	−5.190	−0.000**	−2.270	0.002***	3.050
Area squared	0.000***	4.520	0.000*	1.780	−0.000***	−2.800
Slope of the parcel	−0.159***	−12.640	−0.086*	−1.670	0.722	0.870
Subway station (m)	−0.001***	−15.530	−0.001***	−2.720	-	-
Shopping centre (m)	−0.000***	−14.450	−0.000**	−2.010	0.000	−0.570
Formal land assembly 0	−0.005	−0.620	−0.025	−1.220	0.554	0.160
Formal land assembly 1	0.015*	1.810	0.040**	2.040	(omitted)	(omitted)
Formal land assembly 2	−0.006	−0.700	−0.010	−0.500	0.845	0.340
CD rate	−0.027***	−58.420	−0.032***	−31.400	−3.965***	−3.790
Building age	−0.022***	−97.830	−0.028***	−49.730	-	-
Building age squared	0.000***	99.780	0.000***	50.600	-	-
Number of cluster developments (50 m)	0.031***	86.420	0.030***	37.350	1.039***	6.570
Shape_trapezoid	−0.016***	−3.890	−0.017	−1.470	0.040	0.110
Shape_ilregular	−0.012**	−2.060	−0.017	−1.200	0.852**	2.140
Shape_sack	0.026***	4.110	0.024	1.420	0.595	1.160
Zone_3 residential	0.041***	7.700	0.045**	2.420	0.849**	2.040
Zone_Quasi-residential	−0.182***	−11.780	0.021	1.260	0.730*	1.680
Zone_Commercial	−0.013	−1.180	0.014	1.290	1.278**	2.300
Main street	0.019*	1.950	−0.003	−0.120	−0.057	−0.130
Main street+corner	0.014	0.940	−0.023	−0.600	1.320**	2.160
Main street+small corner	0.035***	2.980	−0.026	−0.790	−0.806	−1.440
Street+corner	0.045***	4.200	−0.019	−0.560	−0.608	−0.410
Road+corner	−0.017**	−2.220	−0.024	−1.210	−0.743	−1.200
Lane+corner	−0.031***	−6.640	−0.055***	−4.220	−0.485	−0.740
Vacant plot 0	-	-	-	-	6.133***	17.580

Vacant plot 1	-	-	-	-	(omitted)	(omitted)
Vacant plot 2	-	-	-	-	(omitted)	(omitted)
Near subway station	-	-	-	-	−0.532	−1.430
N	186,832		37,576		2,615	
Wald chi2	20271.9		4655.51		359.28	
Prob > chi2	0.000		0.000		0.000	

* p < 0.1; ** p < 0.05; *** p < 0.01.

The results of the overall vacant parcel model shown in Table 5 are as follows: area size (+), area size squared (−), CD interest rate (−), number of cluster developments within 50 m (+), and vacant plot 0 (+) were statistically significant at the 1% significance level; land shape_irregular (+), Class 3 residential (+), commercial zone (+), and main street+corner (+) were statistically significant at the 5% significance level; and quasiresidential (+) was statistically significant at the 10% significance level.

In the CBP sample, the tax assessment appreciation rate variable demonstrated a statistically significant positive effect on developmental behaviour. This can likely be attributed to the greater incentive for parcels in the CBP sample to react to market timing than for those in the vacant-parcel sample to maximize development profit. In general, the incentive to wait for a more certain market by placing a higher value on the waiting option than on the cash-out strategy for immediate development is greatest for parcels that have been vacant for a long time (Cunningham, 2006; Titman, 1985). With respect to the CBP sample, increasing tax assessments may imply a rent gap. A developer may agree to develop the parcel if the revenue generated from newly developed land exceeds the value of existing land use (Capozza and Helsley, 1989).

The area size variable may determine the scale of development; however, the relationship is not always linear and depends on the location and current use (Colwell and Sirmans, 1978). The results of the analysis show that the overall CBP sample and the vacant-parcel sample models exhibit nonlinearity in the area–size variable, but the coefficients have opposite signs. In the CBP model, the downwards convex quadratic function indicates that increasing the area reduces the likelihood of development (−) at the beginning, and the effect reverses at some point. In contrast, for vacant parcels, an increase in the area increased the likelihood of development, indicating that vacant parcels are a prerequisite for development. In general, urban residential areas have very high land assembly costs due to the irreversibility of land size changes and the presence of a holdup premium. Developers may not favour large tracts of land if larger land requires high land assembly costs (Tabuchi, 1996). The result of the slope of the land variable (−) does not indicate that sloping land is preferred for development; rather, the practical limitation is that the best practice development sites are those with slopes, as the best flat land has already been developed and used.

The estimation results of the three land assembly dummies reveal that the one year after the land assembly dummy has a statistically significant positive effect on development decisions in the CBP sample (it is omitted in the vacant parcel model). This can be interpreted as the developer obtaining development approval in the year following land assembly, and given that PD is a process that commences with land acquisition work and ends with construction, completion, and operation management, the thoroughness of preparation reflected by early land assembly has a significant impact on future development processes (Lee, Shin, 2021). In addition to the preparation aspect, under the concept of plottage, which states that the combined development of small parcels of land increases the value of land as a whole to a greater extent than the simple sum of the values of the individual parcels, land assembly can be a means of achieving this; however, this is rarely done (Brooks and Lutz, 2016; Eckart, 1985; Huang et al., 2023; Isakson, 2013; Portillo, 2017). In practice, this is because the development benefits of land assembly on UL may not outweigh the costs of landowner negotiation, zoning issues, and so forth. Many scholars have recommended the need to create an enabling environment that encourages land assembly (Brooks and Lutz, 2016; Eckart, 1985; Portillo, 2017). The results of the vacant parcel model can be interpreted as a consequence of insufficient land assembly to influence development decisions independently. Parcels that have been vacant for a long time are less likely to be assembled in the vacant-plot sample.

CD interest rates have been found to affect developmental behaviour negatively. As a financing component of PD costs, CD rates can influence construction activities (Murphy, 2018). An increase in CD rates reduces the feasibility of PD. The age of the building on site has a nonlinear effect on development behaviour (note that this variable is not included in the vacant-parcel model). The effect of new construction on development decisions is negative up to 43.8 years, then becomes positive thereafter. Older buildings face issues such as obsolescence and deterioration in terms of design and function. If conversion or remodelling is more cost-effective than new construction, new construction may not occur. New construction is more resource-intensive than conversion and remodelling, requiring more resources and time, from land acquisition to new design (Remøy, avn der Voordt, 2007). As such, a specific building age cannot be considered a threshold, as the decision to demolish or build new buildings can depend on local policies, changes in building and housing codes, and urban planning (Aksözen et al., 2017), but the building age variable shows that new construction can be a recurring feature of redevelopment or reconstruction (Geltner et al., 2020). The number of cluster developments within 50 m had a positive effect (0.031***) on development behaviour. The magnitude of the coefficients decreased as the radius increased (e.g., within 100 m, 0.008***; within 300 m, 0.001***).

The results show that main street+corner, road+corner, and lane+corner negatively affect development activities, whereas street+corner positively affects development activities. This suggests that favourable locations are already developed (burnout effect), have higher land value, and are not subject to new construction. For the road frontage condition, the best practice seemed to be street+corner (12–35 m wide). Parcels with desirable road frontages are valued higher than parcels in inner locations with similar characteristics because of better physical accessibility and connectivity to infrastructure services. However, a higher potential value may create an incentive to wait for the right time to develop, thereby preventing development. Distance to the subway and shopping centres had a negative sign, confirming the ‘burnout’ phenomenon inherent in established downtown areas. Although high-density development in subway station areas seems desirable, reality differs (Fredrickson et al., 2016; Miceli and Sirmans, 2007). Finally, the statistically significant positive effect of Class 3 residential zone variables reflects the inconvenient reality, as Dong (2021) explains. Therefore, this study suggests a policy of upzoning Class 1 and Class 2 residential zones to Class 3 or quasiresidential zones, combined with a value capture mechanism for these benefits.

Comparison of the Estimation Results of the Near the Subway Station CBP Subsample and Vacant-Parcel Sample

Based on the results of the Hausman test (Prob > chi2 = 0.9684), we estimate a panel logistic HT model for the near the subway station CBP subsample. The Wald chi2 value is 4655.51, and the model is statistically significant. The estimation results revealed that the following variables were statistically significant, as shown in Table 5: tax assessment increase rate (+), distance to subway station (−), CD interest rate (−), building age (−), building age squared (+), number of cluster developments within 50 m (+), and lane+corner (−) at the 1% significance level; area size (−), distance to shopping mall (−), one year after land assembly (+), and Class 3 residential zone (+) at the 5% significance level; and area squared (+) and tax assessment (−) at the 10% level. The results of the analysis of the other variables were similar to those of the overall CBP sample, except that most of the land-shape and road-frontage-condition-related dummy variables were not statistically significant.

The CD rate, which is an indicator of the PD cost environment, has the same statistically significant sign (−) in all three models (1%), and the magnitude of the coefficient increases with the parcel size in the overall CBP sample (−0.027***), nearest-subway station CBP subsample (−0.032***), and vacant-parcel sample (−3.961***). These results indicate that vacant parcels represent situations in which land acquisition or demolition of existing buildings has already occurred, development funds have been committed (at least partially), and financing costs have accrued. Therefore, the vacant parcels may be much more sensitive to interest rates than the CBP parcels are. We performed an experiment after pooling the CBP and vacant-parcel samples, removing the younger CBP parcels year by year until only those 70+ years old (2367 parcels) remained, to assess the convergence of the CBP model to the vacant-parcel model. We found that the CD rate was significantly different even in the last trial. The Korean government also treats unoccupied houses systematically differently from vacant land (Act on Special Cases Concerning House or Small-scale Housing Improvement). According to Gedal and Ellen (2018), demolition costs in New York City account for only 1.8% of the cost of a purchased building. It is inappropriate to assume that the difference between vacant parcels and CBP parcels is simply a matter of demolition costs, at least in Gwangjin. There was a systemic difference in the CD rate variable between these parcel types in Gwangjin. The area size and area size squared variables also exhibited nonlinearity in the form of a downwards-convex quadratic function. The larger the area, the more challenging it is to assemble land, making large-scale development more complicated.

Using dummy variables for the year of vacancy status —namely, the vacant plot 1 and vacant plot 2 dummy variables —we found that the optimal time to develop a vacant parcel is the year it becomes vacant, i.e., the vacant plot 0 dummy variable, as expected.

Performance Power Comparison with Machine-Learning Models

For the 46,708 parcels tested (477 developed and 46,231 status quo), power comparisons were conducted for the econometric and machine-learning models, as shown in Tables 6 and 7. Econometric modelling provides empirical content on the mechanisms underlying economic phenomena, operating under rigorous statistical assumptions, and aims to provide unbiased estimates of causal parameters rather than precise outcome predictions (Athey, 2018). However, government agencies and regulators often make policy decisions based on forecasts of key economic variables, and businesses may rely on forecasts for inventory management and production planning, necessitating new approaches to improve their predictive power (Giacomini and White, 2006).

Tab. 6. Confusion matrix by model: CBP model

Completed building plots		186,832	2011–2018
	Train	140,124	2011–2016
	Test	46,708	2017–2018

Hausman–Taylor (Panel HT)				
Test		Forecasted		
		Nondevelopment	Development	Total
Actual	Nondevelopment	**23,092**	23,139	46,231
	Development	96	**381**	477
	Total	23,188	23,520	46,708

Pooled Logit				
Test		Forecasted		
		Nondevelopment	Development	Total
Actual	Nondevelopment	**46,219**	12	46,231
	Development	451	**26**	477
	Total	46,670	38	46,708

Multilayer perceptron (MLP)				
Test		Forecasted		
		Nondevelopment	Nondevelopment	Total
Actual	Nondevelopment	**46,169**	62	46,231
	Development	312	**165**	477
	Total	46,481	227	46,708

Random forest (RF)				
Test		Forecasted		
		Nondevelopment	Development	Total
Actual	Nondevelopment	**46,173**	58	46,231
	Development	310	**167**	477
	Total	46,483	225	46,708

Tab. 7. Performance metric results comparison across models

	Panel HT	Pooled Logit	MLP	RF
Recall	**0.799**	0.055	0.319	0.346
Precision	0.016	0.684	**0.792**	0.727
F1	0.032	0.101	0.454	**0.469**

Note: Recall: Reproducibility indicates how well the model predicts true positives.
Precision: Indicates the accuracy of the predicted positive cases.
F1 Score: Combines the recall and precision values to demonstrate the overall accuracy of the model.

A confusion matrix was used to evaluate the performance of the classification model. The results of the key performance metrics are listed in Table 7. The importance of each performance metric depends on the specific context and purpose for which the model is being used. Among the three performance metrics, the HT model was most effective in recall. Recall is the percentage of times the model accurately predicts that a development has occurred when it actually did, indicating that the model effectively classified the actual development without missing many cases. Overall, however, the machine learning models performed well.

Despite their predictive power, machine learning models are difficult to apply in the real economy because they emphasize a data-driven rather than structure-based approach to economic theory. However, machine learning algorithms, which aim to maximize predictive power, are more flexible than econometric models in handling the complexity and nonlinearity of large, real-world economic data. Therefore, an ensemble approach has been proposed (Kim and Shin, 2021).

Conclusion

This study analysed the determinants of development behaviour in Gwangjin District, Seoul, from 2011 to 2018 at the parcel level by constructing an overall CBP sample, a CBP nearest subway station subsample, and a vacant-parcel sample and applying land characteristic, building characteristic, and PD environment characteristic variables.

The analysis revealed that the factors positively influencing PD are the building's age and the number of clusters within 50 m. The age of the economic life of existing buildings is a factor that triggers PD, and Gwangjin still needs to improve the residential environment owing to old buildings (Tsai and Wang, 2022). The CD rate, which is an indicator of the PD cost environment, had the same statistically significant sign (−) in all three models

(1%), and the magnitude of the coefficient increased with the size of the CBP sample (−0.027***), nearest-subway station CBP subsample (−0.032***), and vacant-parcel sample (−3.961***). Class 3 residential zones with appropriate density bonuses seem to be the best option for development, rather than the areas around subway stations, where land prices have already skyrocketed.

Although development activities are clustered, not all parcels in the region can be subject to redevelopment. The findings of our study suggest that land assembly can be a viable tool for sophisticated urban regeneration, provided that the incentives are sufficient to justify the cost of acquiring adjacent land. In this sense, as of 2024, the Seoul Metropolitan Government (2024) announced the 'Human Town 2.0' policy, designating old low-rise residences as 'special building zones, architectural agreement concentration zones, and remodelling activation zones' to promote reconstruction, redevelopment, or remodelling into non-high-rise but medium-scale mid-rise townhouses. Such a policy, which aims to create sophisticated, fine-tuned planning tools by reducing the scale of planning units to the level of individual parcels, can be considered appropriate for the times. However, it seems that, historically, it has not guaranteed sufficient voluntary redevelopment activities across the town (Li et al., 2019; Tang and Tang, 1999).

We propose land assembly- and developer-friendly measures. In addition to the density bonus proportional to area size (Shoup, 2008; Tang and Tang, 1999), we propose a density bonus proportional to the number of parcels assembled within ten years. With respect to developer-friendly measures, a corporate income tax reduction, such as a tax credit, can be a direct, effective measure. This is simply because developers are the primary drivers of development, and development tends not to be initiated by elderly landlords who list their properties for sale in Gwangjin.

Our study has certain limitations. Even with a large rent gap, not all parcels are developed in the same small block. Landowners' decisions to sell their properties seem relatively random in Gwangjin. Therefore, future research should focus on who the first seller is and why, and who is the next in the same gentrifying block with a sufficient rent gap.

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