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Gated Residential Capture of Metro Station Catchments: Persistent Land Absorption and Public Accessibility Loss in Nanchang, China

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Abstract
Whereas metro investments are anticipated to increase public accessibilities, the development of residential areas near metro stations can lead to the internalization and external impermeability of some of the publicly generated advantages. This paper investigates the limited residential footprints in Nanchang, China, using the concept of station catchment to analyze the losses of public routings. The research question seeks to know whether the accessible station catchment area operates as a public-access space or whether there is a measureable portion of the area being internalized into the morphology of gated residential areas. Whether such an absorption is done through the presence of above-control stock, intensive construction, cohort transition in compound sizes, or persistence after peaking is also investigated. The investigation makes use of five calculations: station catchment conversion, control referenced forfeiture account, footprint intensity gradient estimation, morphological transition in cohorts analysis, and effect mass retention analysis. The 27-row ledger contains the station category stock, five-year event window value, treatment estimator, construction cohorts effects, and calendar year treatment effects. The treated catchments have 14.08 gated communities with $754\,801.87\,\mathrm{m}^2$ of gated footprint that equates to 1.75 gated communities per square kilometer and 9.39% of the 1600 m catchment. In relation to the composite control, there are 7.62 gated communities and $363\,285.72\,\mathrm{m}^2$ of gated footprint which amount to 54.12% of the gated community count effect and 48.13% of the gated footprint effect. The five-year construction window exhibits the strongest land absorption with the footprint intensity gradient of 5.98 percentage points of catchment land per additional gated community per square kilometer. While the cohort values reveal the 2017 cohort retains only 45.83% of the 2009 count effect, it retains 101.79% of the footprint effect, resulting in the implied unit footprint ratio of 222.09%. The calendar values reveal the 2023 footprint effect retains 54.12% of the 2016 peak effect compared to the 44.42% of the count retention. The findings provide an answer to the research question that the Nanchang station catchment is not only characterized by more gated communities but also a persistent and land intensive and shifting restricted footprint effect.

Keywords: public permeability; gated communities; metro catchment; station-area planning; footprint-intensity gradient; treatment-effect conversion; Nanchang

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1. Introduction

Construction of metro infrastructure is typically framed in terms of improved public accessibility. New station should provide reduced travel-time friction, increased area of reachable job and service opportunities, reinforced non-motorized movement, and facilitate compact urban development. All these outcomes are not achieved through railway infrastructures alone. The accessibility of station catchment depends on its traversability. The catchment is the space, where streets and pathways are interconnected, the parcels are passable, the frontages are visible, and the land around the station takes part in the public pathway system instead of privatizing its advantages. Node-place theory is separating the transport role of a station from the qualities of the surrounding urban places [1]. Accessibility research, in turn, stresses the usability of the opportunities rather than presence of a transport node [2]. Research on urban morphology and transport proves the interdependence of density, diversity, and design in terms of travel behaviour [3]. Furthermore, meta-analytic evidence proves the joint interpretation of urban-morphology dimensions rather than substitution [4]. A dense station catchment can be considered a bad accessibility environment if it includes large parcels, blocking walking route, reducing direct movement opportunities, and disconnecting internal circulation from the public streets.

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The problem is important since the construction of metros is usually accompanied by rising land value before becoming a complete public environment. Transport infrastructure is creating locational advantages which can be capitalized into higher housing prices, rents, redevelopment incentives, and land revenues of municipal authorities. Meta-analytic evidence proved the economically important nature of rail accessibility [5]. More recent synthesis of empirical evidence confirmed that the strength of this relationship can differ depending on various contextual features [6]. Evidence on the impact of Chinese metro development proves that rail accessibility can also be capitalized in the adjacent land and housing markets [7]. In cases, where public authorities rely on land conversions and development rights to cover infrastructure costs, the logic of value capture may conflict with the logic of accessibility. The station catchment will become not only the movement field, but also the investment field. If the value is captured through enclosed residential morphology, then the public benefit of rail accessibility will be undermined by private control over the land used for access.

The concept of transit-oriented development (TOD) provides useful terminology for the problem. However, the issue investigated in this paper is narrower and more morphological in its nature. Development located near a station does not have to be transit-oriented [8]. Proximity alone is no guarantee of walkability, mixing, permeability, and social usability [9]. Rail-property system can be used to finance infrastructure and intensify land use [10]. Similar value-capture mechanisms in relation to bus rapid transit infrastructure can be considered the examples of how the development can prioritize the internal efficiency over public accessibility [11]. The quality of a station catchment has to be evaluated not only in terms of development volume, but also in terms of route preservation, crossings, and public movements choices.

The recent TOD reviews highlight this fact proving that the outcomes in station catchments depend on the interaction of transport engineering, land-use planning, urban design, real-estate dynamics, and governance instead of mere proximity [12]. The study on Shanghai station areas highlights the importance of pedestrian network quality and street connectivity [13]. More recent evidence on Nanjing stations confirms the same idea proving that accessible interfaces affect the practical value of station proximity [14]. The built environment studies prove the similar relationship proving that walking conditions matter for the usability of rail access [15]. This literature provides a different understanding of the 1600 m radius used in Nanchang calculations. The radius is a useful denominator, but not the proof of public access. Circular catchment may overestimate accessibility in case of large parcels, canal edges, wide roads, or enclosed residential districts limiting the number of realistic walking paths to the station.

Urban-morphology studies provide conceptual tool to link the Nanchang numerical evidence and the planning evaluation discussed in this paper. Permeability depends on the routes and access choices rather than land area of the catchment [16]. Interface-catchment research proves the same idea confirming that public spaces, frontages, and entries are crucial for walkable urban environments [17]. The studies on station-area walking environments prove the importance of network quality for the practical accessibility [18]. Transit-access studies prove the existence of barriers making physically close stations unreachable [19]. The studies of alleys and narrow routes prove that local network structure influences pedestrians' access to destinations [20]. The current paper, therefore, treats the Nanchang footprint ledger as the evidence on route opportunity and interface capacity of station catchment. It does not observe each walking choice, but it shows the amount of catchment space consumed by spatial form, potentially restricting these choices.

Gated communities are a particularly illustrative example of this problem. Gated residential territories provide managed environment, amenities, security services, and identity to their inhabitants, but also create the conditions of access for non-residents. Walls, gates, guarded entrances, and internal street networks are the reasons why pedestrian can cross the block, reach the station via shortest path, or find out whether a station catchment becomes connected urban neighbourhood or fragmented into islands. Early research on the topic highlighted the difference in form and restricted access as the main attributes of gated communities [21]. Later analysis showed the importance of governance, market segregation, and the production of private collective goods in the definition of the term [22]. In terms of urban design, the issue is not in the necessity of all residential parcels to be publicly accessible. The problem is in the fact that the station catchments get their planning justification due to accessibility of a wider area, and that this justification weakens if the surrounding land becomes less accessible to the general public.

The problem has a distinctive institutional form in China. Gated residential territories are developing as the transformed work-unit compounds and housing estates [23]. Following research linked the process with suburban branding, commodification of housing, and changes in neighbourhood governance [24]. More recent literature stresses the role of the state in production and management of the gated residential spaces [25]. Thus, gate is not just an architectural form. It is incorporated into housing commodification, neighbourhood governance, planning regulation, and historical organization of urban residential spaces. The recent research on Chinese gated communities also proves that the boundary is not just the obstacle preventing public integration, but also the space where new modes of opening, management, and urban repair must be negotiated [26]. The above-listed conditions make station catchment in Chinese metro a good case for measuring not only the prevalence of the gated development, but the extent of the public-funded accessibility translated into restricted residential morphology.

The current Nanchang case differs from the broader debates on compact growth since the relevant object is not the city-wide density, but station-accessible residential footprint. The evidence on Beijing shows the impact of metro investments on the land values around the stations [27]. The recent evidence on Chinese metros also highlights the property market response to the rail accessibility [7]. Research on Nanjing stations proves that the pedestrian environment and built environment vary across the station catchments [14]. This paper investigates the following question: what is the structural part of the station catchment available as part of the public movement field, and what is absorbed into internally restricted residential form? The question is more spatial than general TOD evaluation and less straightforward than mere analysis of housing price or ridership.

The current paper investigates the problem through the concept of public permeability forfeiture. Public permeability is the capacity of station catchment land to support route choices and connections. The concept does not assume the right to enter the privately-owned residential land. Instead, it defines the planning loss associated with transformation of the accessible space in station catchments into the land of privately owned form. The loss is measured indirectly based on the count density, footprint share, treatment/control difference in counts, treatment/control difference in footprint, land-consumption gradients, changes in cohort scale of compounds, and long-term retention of treatment effects. The analysis links the transport planning and urban morphology, treating the station catchment as a public-accessibility field where the value depends on the land parcel structure and boundaries as well as the radial distance to the station.

The core question of this paper is not in the association of metro construction and the increase in gated residential territories. This relationship is important, but not enough for the planning evaluation. Count increase may overestimate the problem if the additional compounds are small and spatially absorbable. Conversely, the count increase may underestimate the problem if few compounds consume much larger land areas. Footprint share will measure the amount of the restricted residential land, but it will not differentiate the background enclosures from the metro-associated excesses. Treatment estimate will define the average effect, but it will not tell whether the effect is concentrated in the short construction period, carried by a particular cohort, or retained for a long time as a spatial residue. For a planning-relevant analysis, it is necessary to interpret the same evidence in terms of public permeability.

The current paper provides this interpretation. Based on the Nanchang station-catchment values, the paper investigates how much of public permeability is forfeited in metro catchments in terms of gated residential footprints; whether the forfeiture is mainly a count, a footprint, or a persistence phenomenon; and how the interpretation changes if the treatment estimates are translated into the count/density, share, compound size, land-consumption gradients, cohort morphology, and the residual effect mass. The methodological and substantive contributions are made by the paper. The methodology organizes the station-buffer values into the catchment-forfeiture ledger. The substantive contribution is not in the observation that there are more gated communities in metro catchments, but in the identification of the fact that a substantial and persistent share of station-accessible land is turned into the internally restricted residential form.

2. Research Question and Analytical Design

The paper poses the following research question: what amount of public permeability is lost in terms of the growth in footprints of gated communities in the catchments of metro-accessible stations, and is the process driven by the multiplication of gated residential compounds, expansion of their footprint area or temporal persistence of post-construction effects? This research question focuses attention on the interpretation of associations in planning terms. Station catchment is seen as the spatial unit through which rail access is made operational, and gated residential morphology is viewed as the morphological form that may consume the accessibility while constraining publicly available route options. This research question is explored using the integration of transport economics, urban morphology and causal-treatment interpretation. Transport economics provides an account of why rail accessibility can be capitalized in the land and housing markets. Urban morphology provides an account of why the public value of accessibility hinges on blocks, routes, interfaces and boundaries instead of distances alone. Causal-treatment interpretation provides an account of why the estimated effects should be carefully interpreted taking into consideration differences in years of construction among station categories. These three perspectives have one role: to convert the Nanchang station count and footprint values into planning quantities that can be evaluated on a common catchment denominator. The analysis makes use of the nominal 1600 m station catchment as the conversion field. Gated community count is expressed in density per sq.km; footprints are expressed in the share percentage of the catchment area; treatment effects are translated into density and footprint share equivalents. The analysis then addresses four questions that remain open under the standard count-based evaluation. How much of the treated stock is above the control condition? How much of the footprint is tied to each increment in the gated community density? Are there differences in construction cohorts concerning the scale of induced compounds? What share of the treatment effect survives after the peak year? The above diagnostics are intentionally simple as they are designed to communicate. They make the planning cost of gated station catchment development transparent without requiring information about parcel geometries other than Nanchang station catchment values.

Public permeability is a spatial rather than a legal concept in this case. The analysis does not assume that private residential lands should become public rights-of-way. Instead, it examines whether the catchment that receives public rail investment is organized through the spatial forms that restrict the public movements and concentrate the accessibility benefits within privately owned territories. The network-oriented urban theory defines permeability as a property of the route configuration and movement choices [16]. Interface theory extends the concept and says that public/private boundaries actively structure the urban performance [28]. The walkable urbanity research also indicates that routes, entries and interfaces affect encounters and access [17]. The primary empirical question is, therefore, whether the treated catchments exhibit a restricted land burden that is substantial, excessive, footprint intensive, cohort-specific, and temporally persistent.

3. Data and Derived Catchment Ledger

3.1 Primary numerical material

The empirical record includes tabulated values for the 1600 m station catchments in Nanchang. The values comprise station category stocks, five-year pre- and post-construction values, two treatment-estimator records, three construction cohort records, and the annual treatment effects from the analysis of Sun, Lee, He, and Webster [29]. The analysis converts the Nanchang station-catchment values into the catchment-permeability ledger. The calculation requires no parcel geometries and station-level micro data, because it translates station buffer quantities into count density, footprint share, unit footprint, excess over the control condition, land consumption intensity, cohort transition ratios and annual retention shares. The unit of spatial interpretation is the nominal 1600 m catchment. Its circular area is

$$A_b = \pi r^2 = \pi(1600)^2 = 8\,042\,477.19\,\mathrm{m}^2 = 8.042\,\mathrm{km}^2. \quad (1)$$

The space below has been provided solely for the purpose of expressing counts and footprints as comparable catchment densities and shares. This space makes no assertion regarding the fact that access occurs in actuality by way of a perfect circle. The buffer is a constant denominator and is not meant to describe actual pedestrian routes. This is relevant in that there may be spaces within the buffer that are close to the station but that are not easily navigable. As such, the calculation uses the buffer to create comparable values, which are then analyzed based on permeability.

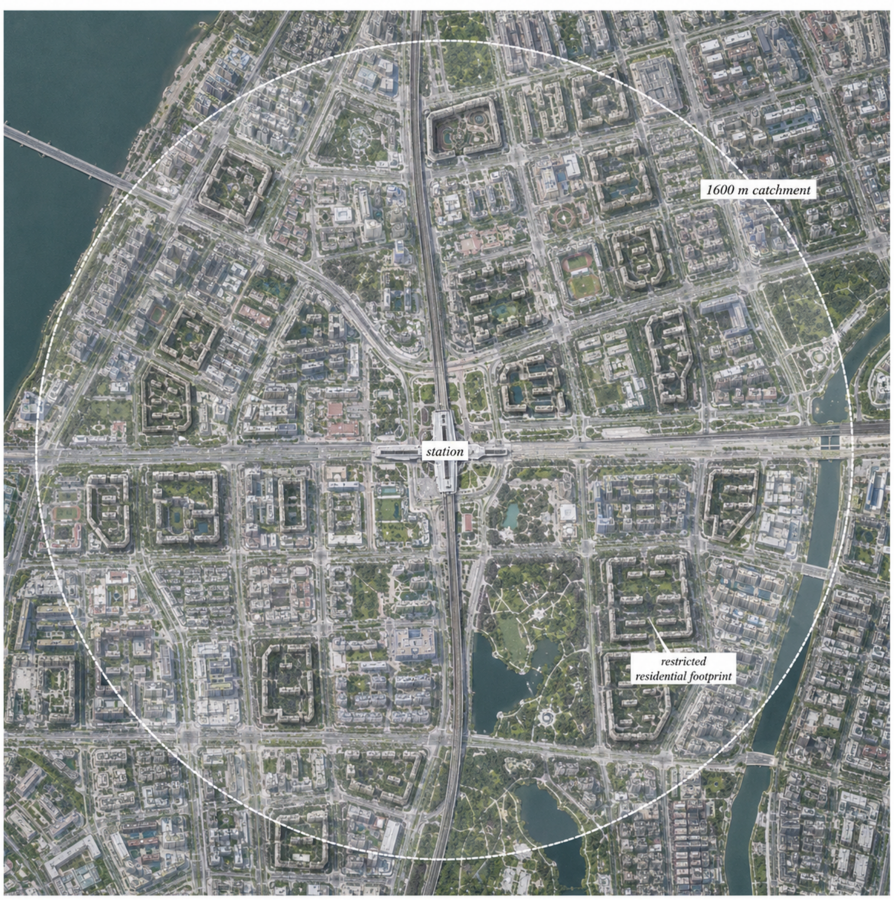

Figure 1. Station catchment field.

The inclusion of the station-field image in Figure 1 places the calculation in an urban context and supports the use of the 1600 m denominator while reminding the reader that the public access depends on street networks, parcel borders, waterways, and restricted residential footprints contained within the nominal catchment area. The significant factor to bear in mind here is that each square meter of the circle is not equally accessible to public movement.

3.2 Catchment-forfeiture ledger

The data is structured into a catchment-forfeiture ledger with four analytical panels. In Panel A there are station-category records: total sample, never-treated, not-yet-treated, composite control, and treated catchments. In Panel B there are event-window records: the state of the catchment one year before construction, the state four years after construction, and the five-year difference. In Panel C there are treatment records: two-way fixed-effect, staggered-treatment, and construction cohorts for 2009, 2013, and 2017. In Panel D there are calendar records from 2009 to 2023. There are 27 primary analytical records in the ledger, each one transformed into one or more derived quantity: count density, footprint share, unit footprint, control excess, footprint-intensity gradient, cohort transition ratio, and retention share.

This structure transforms the empirical object into a spatial planning diagnostic. From the station-category record, it can be seen that treated catchments have 14.08 gated communities and 754 801.87 m^2 of gated footprint while the equal-weighted control only has 6.46 gated communities and 391 516.16 m^2. The treatment record uses equivalent density, footprint share, and unit footprint to express the treatment values. The calendar record indicates the amount of the 2016 peak remaining in 2023. The ledger is the spatial interpretation of the Nanchang count and footprint in public-permeability terms.

Table 1. Structure of the catchment-forfeiture ledger.

Panel	Record type	Records	Main quantities	Analytical role
A	Station-category stock	5	N, F, D, S, U	Catchment state
B	Five-year event window	3	Change, multiplier, gradient	Conversion speed
C	Treatment and cohort effects	5	D_τ, S_τ, U_τ	Induced burden
D	Calendar effects	15	Peak, mean, mass, retention	Temporal residue

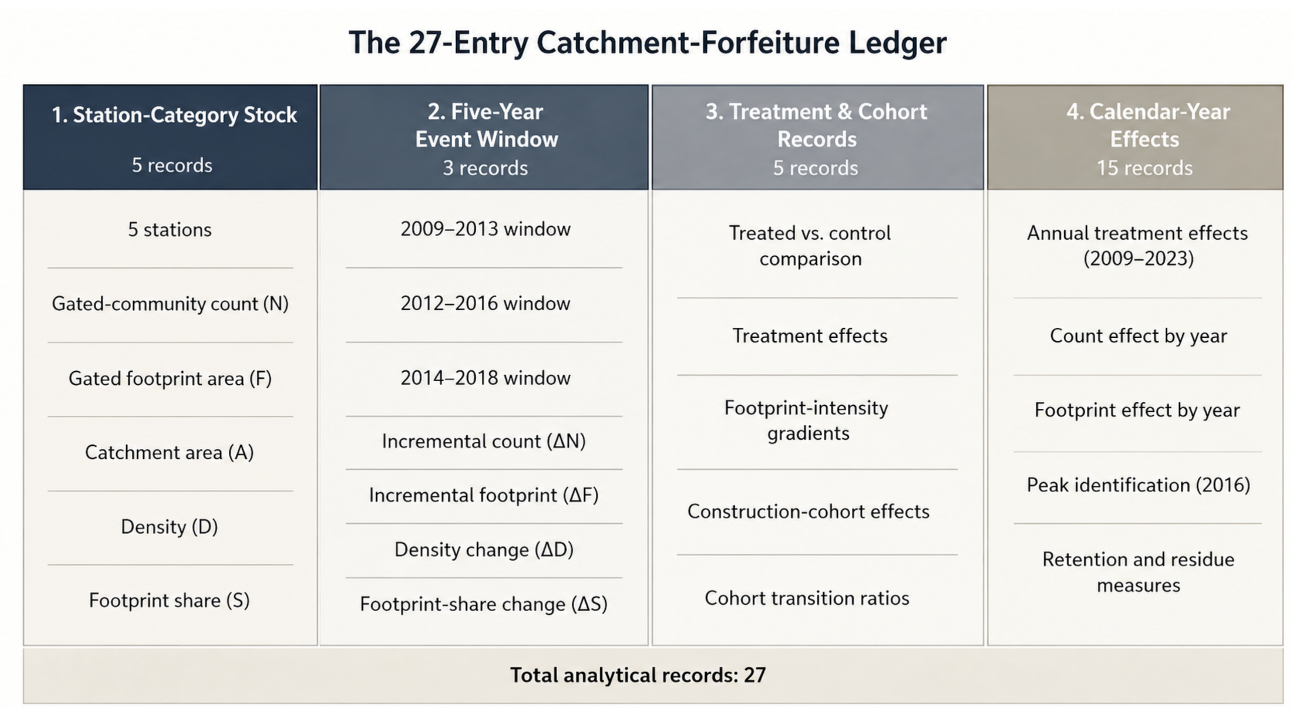

Figure 2. Catchment-forfeiture ledger.

The visual ledger of Figure 2 condenses Table 1 in terms of the distribution of 27 records across four analytical categories. This visualization technique is valuable, since the same Nanchang values are used multiple times as station stocks, event-window changes, treatment effects, and cohort residues. This format ensures the integration of the results into a connected set of coefficients, each of which can be traced to its record group and planning question regarding stock, speed, scale, or persistence.

While the ledger table of Table 1 provides a transparent number-based framework for the analysis, the station-category panel sets up the restricted-residential stock, the event-window panel shows short-term conversion, the treatment panel calculates the effects and the calendar panel tests their persistence. With the consistent use of one catchment area throughout the analysis, the differences in count, footprint, density, and share can be consistently evaluated across the panels.

The ledger of Table 1 also highlights the scope of inference of the study. Neither pedestrian paths, nor gate access, nor resident preferences have been measured in this study. Instead, this study evaluates the spatial consequence of the Nanchang catchment counts and footprints. The derived values should therefore be understood as planning diagnoses rather than behavioural measures. Their value lies in the fact that they can show how much restricted residential form exists, how much above the control condition it is and how persistent the effect is.

4. Methods

4.1 Station-catchment enclosure conversion

Let N_i denote the average number of gated communities in catchment record i, and let F_i denote the corresponding gated-community footprint in square metres. Count density is

$$D_i = \frac{N_i}{A_b/10^6}, \tag{2}$$

where D_i is measured in gated communities per square kilometre. Footprint share is

$$S_i = 100\frac{F_i}{A_b}, \tag{3}$$

where S_i is the percentage of the nominal catchment occupied by gated-community footprint. Unit footprint is

$$U_i = \frac{F_i}{N_i}. \tag{4}$$

For treatment records, equivalent quantities are calculated from the treatment estimates $\widehat{\tau}_N$ and $\widehat{\tau}_F$:

$$D_\tau = \frac{\widehat{\tau}_N}{A_b/10^6}, \tag{5}$$

$$S_\tau = 100\frac{\widehat{\tau}_F}{A_b}, \tag{6}$$

$$U_\tau = \frac{\widehat{\tau}_F}{\widehat{\tau}_N}. \tag{7}$$

This transformation addresses the first element of the research question by converting quantities and square meters to catchment density and catchment share. It also ensures that any simple numerical treatment effect does not exist independently from its spatial translation. A coefficient of 3.52 gated communities acquires a very different planning implication when expressed in terms of an extra 0.44 gated communities per square kilometer and an increase in station catchment share by 2.32 percentage points. Spatial difference-in-differences literature highlights the benefit of translating transportation effects to a geographically intelligible outcome [30]. Methodology related to the subject explains how spatial dependence may be incorporated into the treatment effect analysis [31]. Railway impact literature provides additional examples of the benefits of the translation of causal effects to urban units [32].

4.2 Control-referenced forfeiture accounting

The first diagnostics reveals what share of the treated catchment stock can be considered excess compared to control catchments. The equal-weighted composite control is defined as

$$C = \frac{1}{2}(C_{never} + C_{notyet}), \tag{8}$$

where C_{never} is the never-treated control and C_{notyet} is the not-yet-treated control. For counts and footprints, the treated-control excess is

$$\Delta_N^C = N_T - N_C, \tag{9}$$
$$\Delta_F^C = F_T - F_C. \tag{10}$$

The treated-stock excess shares are

$$E_N = 100\frac{\Delta_N^C}{N_T}, \tag{11}$$
$$E_F = 100\frac{\Delta_F^C}{F_T}. \tag{12}$$

A compact forfeiture share is then defined as

$$\Phi = \frac{E_N + E_F}{2}. \tag{13}$$

The quantity Φ does not reflect legal access to information. The quantity Φ represents the fraction of the treated catchment area enclosure above the equal-weighted control condition, taking into account count and footprint together. The diagnostic is intentionally conservative. Every treated component cannot be attributed to metro infrastructure construction. What is the share of the treated components relative to the equal-weighted control condition of 6.46 communities and 391 516.16 m^2 of footprint?

4.3 Footprint-intensity gradient

The second diagnostic checks if there is a modest or large footprint expansion associated with an increase in the number of gated-communities. For each comparison j, the footprint-intensity gradient is

$$G_j = \frac{\Delta S_j}{\Delta D_j}, \tag{14}$$

where ΔS_j is the change in share of footprints, and ΔD_j is the change in density of gated communities. The unit of measure is percentage points of catchment footprint per additional gated community per square kilometre. A larger coefficient implies greater land occupation per each additional increase in count density. The gradient is computed for the treated-control difference-in-stock, five-year event window, two-way fixed-effects estimator, and staggered treatment estimator.

4.4 Cohort morphology transition

The third diagnostic is concerned with the test of whether construction cohorts are distinct by morphology of their induced gated development. Let c_0 denote the 2009 cohort, and c_k any other subsequent cohort. Transition ratios are

$$R_N(c_k) = 100\frac{\widehat{\tau}_{N,c_k}}{\widehat{\tau}_{N,c_0}}, \tag{15}$$
$$R_F(c_k) = 100\frac{\widehat{\tau}_{F,c_k}}{\widehat{\tau}_{F,c_0}}. \tag{16}$$

The unit-footprint transition is

$$R_U(c_k) = 100\frac{U_{\tau,c_k}}{U_{\tau,c_0}}. \tag{17}$$

This shows whether the next generation has less induced substance, comparable footprint, or bigger footprint. The cohort diagnostic is vital since a declining count effect will seem to imply that there is a waning planning problem, whereas an increasing or steady footprint effect implies a shift towards a bigger compound.

4.5 Effect-mass retention analysis

The fourth diagnostic shows whether the treatment effect dies out after its peak or persists as residual spatial effect. For the series of effect per year Y_t, the peak is

$$P = \max_t Y_t, \tag{18}$$

and terminal retention is

$$R_T = 100\frac{Y_{2023}}{P}. \tag{19}$$

Effect mass is calculated as the sum of yearly effects across the calendar record:

$$M = \sum_{t=2009}^{2023} Y_t. \tag{20}$$

The post-peak mass is the share of M after the peak year, while the late-window mass is the share of M between 2020 and 2023. In this framework, persistence is viewed as an issue of planning. Even a small annual effect can be important if it persists in the landscape after the main construction wave.

In addition, the use of staggered treatment records and calendar effects calls for additional attention. Inconsistencies can arise in the two-way fixed-effect estimation for settings with treatment times that differ across groups [33]. Moreover, event study coefficient estimation can be affected by the presence of heterogeneous time effects in treatment effects [34]. Group-time estimators can be used to address this challenge properly [35]. Finally, design-based methods allow us to clearly understand the assumptions in staggered adoption settings [36]. Contemporary literature pays significant attention to careful testing of pre-trends and heterogeneous dynamic effects [37]. The current analysis does not estimate the treatment model but transforms treatment records into meaningful geographic information. Therefore, the transformation procedure is a post-estimation planning interpretation of results.

5. Results

5.1 Catchment state after conversion

The converted state values in Table 2 indicate that the treated catchment has the highest enclosure condition. Treated station has 14.08 gated communities and 754 801.87 m^2 of gated footprint. This corresponds to 1.75 gated community per 1 km^2 and 9.39% of the 1600 m catchment area. The composite control station has 6.46 gated communities and 391 516.16 m^2 of gated footprint. This corresponds to 0.80 gated communities per 1 km^2 and 4.87% of the catchment area. Thus, the treated station has more than two times the density of the composite control station in terms of count. Also, its share of footprint is about twice larger.

Table 2. Station-category state after catchment conversion.

Category	N	F (m^2)	D (per km^2)	S (%)	U (m^2)
Total sample	11.44	586065.86	1.42	7.29	51230
Never-treated	6.96	546297.43	0.87	6.79	78491
Not-yet-treated	5.96	236734.88	0.74	2.94	39721
Composite control	6.46	391516.16	0.80	4.87	60606
Treated	14.08	754801.87	1.75	9.39	53608

The unit footprint values show that the relationship between count and footprint varies. The never-treated category has a larger mean value of the unit footprint than the treated category. On the other hand, the not-yet-treated category has a smaller value. This variation makes it impossible to use an explanation in which treated means large compounds. Treated category is unique because it combines both high count density and high footprint share. It is not the category with the largest average compound size but it is the category where numerous restricted residential units form a high share of the station accessible field.

The converted state values reveal that a stock statistic is not enough. Treated category is the most dense category and the largest footprint share category at the same time. This combination prepares the ground for the comparison of control and above control components below using the 14.08 count and 754 801.87 m^2 footprint.

As seen in Table 2, the treated category has a lower implied unit footprint than the never-treated category. However, its footprint share is much higher than the share of the never-treated category. The distinction is critical for the argument in this paper. Public route loss may come not only from few large enclosed compounds but also from many medium-sized enclosed compounds. Treated catchment reflects the second scenario in the stock terms: many compounds form a large share of restricted land. Then, the cohort results below reflect another mechanism where the induced compounds grow in size but lose count importance.

5.2 Control-referenced forfeiture

The change of the interpretation brought on by forfeiture accounting consists in making the treated category special not only in the sense of containing 14.08 gated communities. The excess over the composite control amount is 7.62 communities, which is 54.12% of the treated number of gated communities. In terms of footprint, the treated catchment has an excess of 363 285.72 m^2 of gates, which is 48.13% of the total gated footprint. The share of compact forfeiture Φ from Eq. 13 is therefore 51.12%.

Table 3. Treated-control excess and forfeiture share.

Quantity	Treated	Composite control	Excess	Excess share (%)
Gated communities	14.08	6.46	7.62	54.12
Footprint area (m^2)	754801.87	391516.16	363285.72	48.13
Count density (per km^2)	1.75	0.80	0.95	54.12
Footprint share (%)	9.39	4.87	4.52	48.13

Figure 3 provides a visualisation of the treated-control burden split, thereby making the distinction between the treated and control conditions explicit in terms of separating each burden in the treated condition into a control component and an excess component. The count comparison demonstrates that more than half of the gated community stock of the treated condition is above the composite control, while the footprint comparison demonstrates that almost half of the gated footprint is above the composite control. The point here is that the pairing of the two comparisons is important in making sure that the treated-control difference is not interpreted numerically, because it is a treated condition that is more developed not only in numbers, but also in land area.

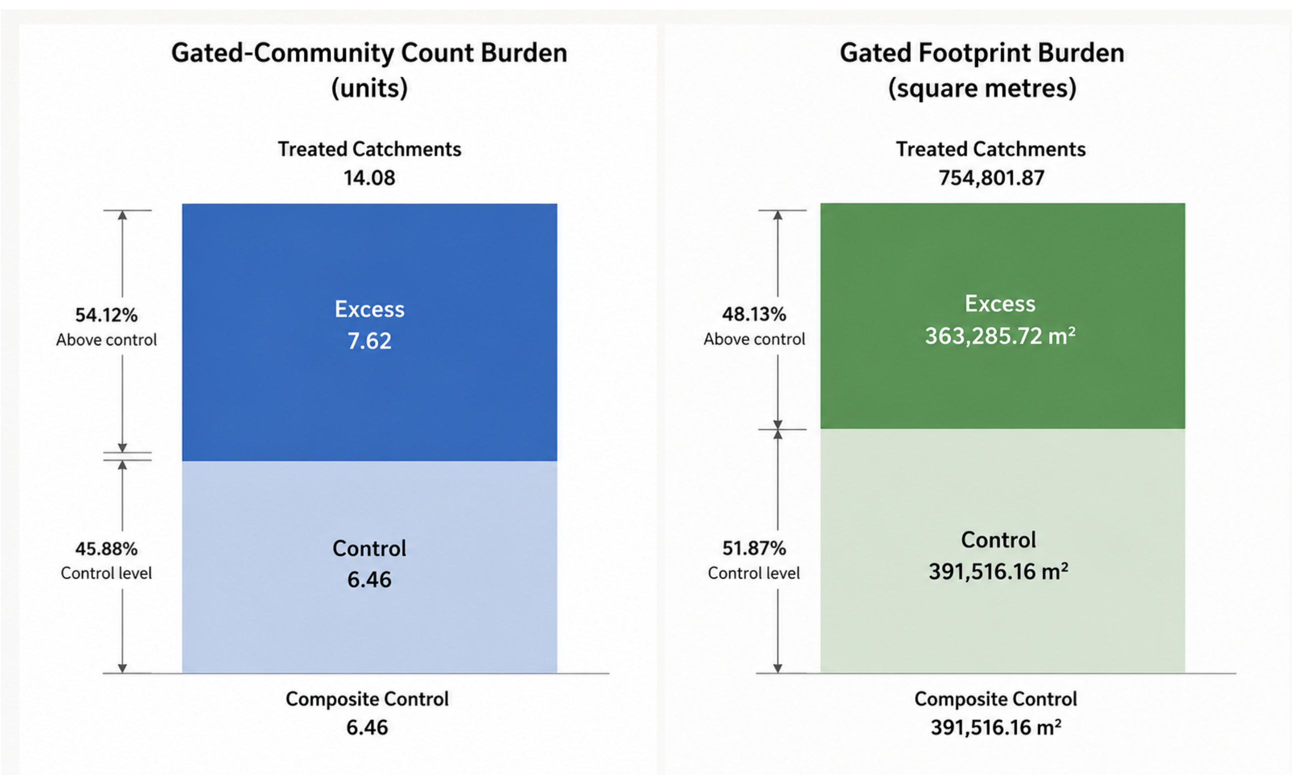

Figure 3. Treated-control burden split.

This difference leads to a conclusion that no standard treatment reading would make. More than half of the treated enclosure burden, in the count and footprint comparisons, is above the equally weighted control condition. From the standpoint of actuality, the treated catchment is not just a more developed version of the control catchment, but also a catchment that carries a substantial excess of the restricted-residential component of development that is spatial in terms of station access. The count excess specifies the number of additional enclosed territories in the catchment, whereas the footprint excess specifies the land surface area involved. The difference between the excess shares also carries a piece of information, since the count excess is larger than the footprint excess, which means that the treated-control comparison is slightly more count-heavy than footprint-heavy at the stock level.

The same numbers can also be read as an urban-design statement. An excess of 0.95 gated communities per square kilometre is not much as a density increase, but, in a station catchment, it means that there are interruptions of the movement field again and again. An excess of 4.52 percentage points of footprint share is more immediately spatial. It means that almost one-twentieth of the nominal catchment is additional restricted residential footprint above the composite control. This is quite a lot of area in terms of the routes, blocks, entrances and interfaces, even considering the possible differences in the compound designs.

The result also makes it clear why the composite control is analytically helpful. The never-treated and not-yet-treated categories contain gated communities as well, so the paper does not assume gated development to be absent from the city. The forfeiture accounting instead tells us what makes the treated catchments special compared to ordinary background enclosure. The answer is a substantial excess above the control in both the count and footprint comparisons, which makes the treated category spatially special rather than merely numerically higher.

As can be seen from the forfeiture badge shown in Figure 4, two excess shares have been condensed to produce a value for the public route loss without concealing the imbalance in its components. It is count biased at the margin since the count excess is greater than the footprint excess, although the footprint component is substantial enough to establish that this forfeiture is an issue on the surface, as well as numerically. 51.12% must therefore be considered to be a concise description of restricted morphology above the control threshold.

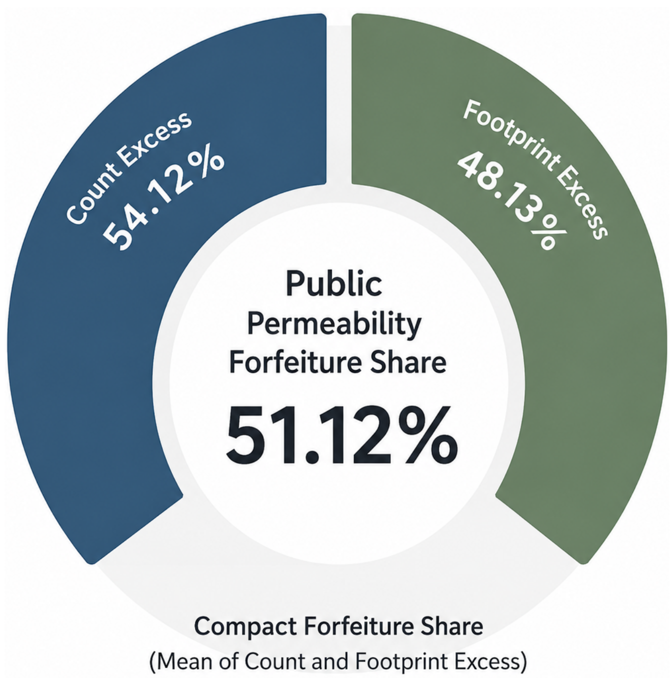

Figure 4. Forfeiture share.

5.3 Five-year conversion and footprint-intensity gradient

This five-year event window is quite persuasive, yet the gradient calculation highlights its land-impact properties. Over $T-1$ to $T+4$, the count of gated communities rises by 8.35 and their footprint by $499\,696.50\,\mathrm{m}^2$. That results in a count-density increment of 1.04 gated communities per square kilometre and a footprint-share increment of 6.21 percentage points. The footprint-intensity gradient here is 5.98. The event-window gradient is thus greater than both the treated-control stock gradient of 4.77 and the staggered-treatment gradient of 5.30.

From the comparison above, it becomes apparent that the construction-window gradient is greater than the general stock gradient because of greater land intensity. According to the preferred staggered-treatment estimation, the establishment of each new gated community per square kilometre leads to a 5.30-percentage point increment of catchment footprint share. Using a five-year event window raises the intensity to 5.98. Such a result means that in addition to the gated-community establishment being more intensive around the time of metro construction, the establishment is characterized by higher land consumption. For station area planning, the timing of intervention is critical here. When significant gated community footprints are created in the initial stage after construction, subsequent permeability restoration will involve altering existing boundaries rather than creating land parcels before development.

Table 4. Event-window conversion and gradient values.

Comparison	ΔN	ΔF (m^2)	ΔD	ΔS	G
Treated minus composite control	7.62	363285.72	0.95	4.52	4.77
Five-year event window	8.35	499696.50	1.04	6.21	5.98
Two-way fixed effect	3.16	167049.40	0.39	2.08	5.29
Staggered treatment estimate	3.52	186506.39	0.44	2.32	5.30

As can be seen from the land-absorption meter on Figure 5, the land-absorption capability of the four gradients is ordered. The highest value is provided by the five-year window, with 5.98 percentage points of catchment footprint per additional gated community per square kilometre, followed by the staggered-treatment and two-way fixed-effect gradients. This ordering supports the interpretation that the construction window is the most land-intensive form of metro-adjacent gating. Also, it clearly shows why planning should not wait until the whole stock matures before taking measures: the maximum land-impact signal comes from the shortest time period around construction.

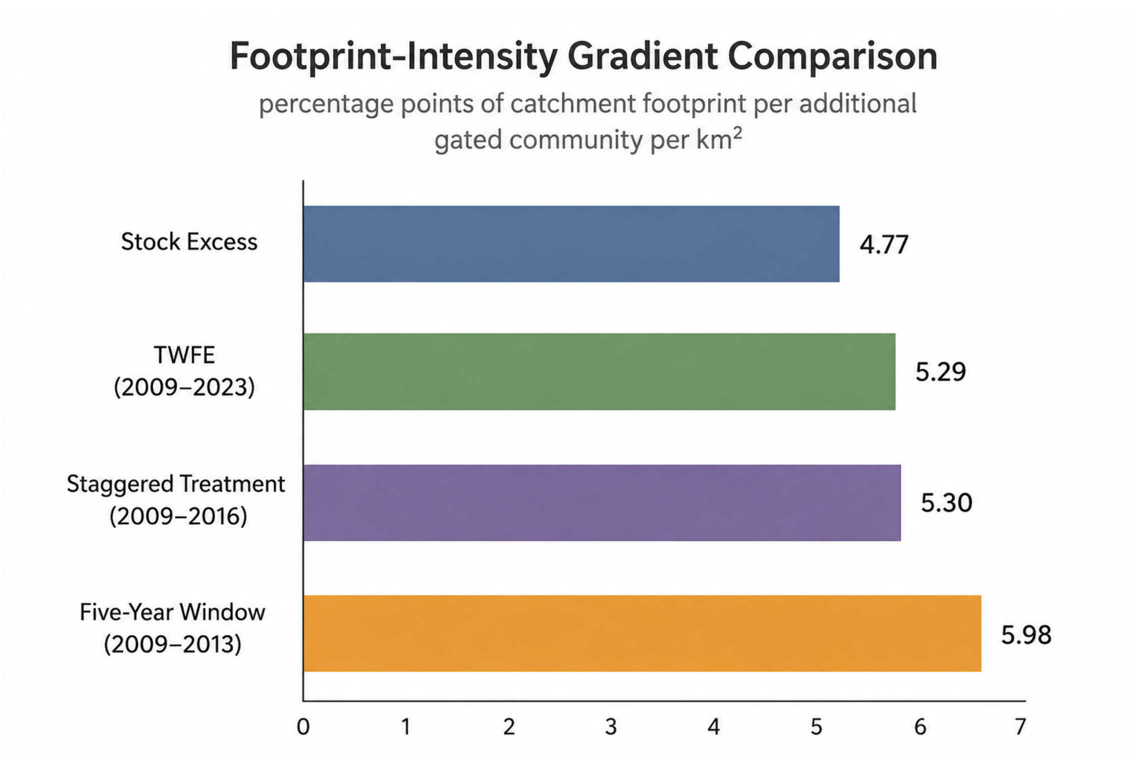

Figure 5. Footprint-intensity gradient.

The gradient table and the land-absorption meter, Table 4 and Figure 5, should be considered together. The table shows the numerical conversion, whereas the meter provides the gradient ordering based on land absorption. The small difference between the two-way fixed-effect gradient of 5.29 and the staggered-treatment gradient of 5.30 shows that the spatial interpretation does not depend on one particular estimator. However, the larger value obtained using the five-year window shows how the event timing affects planning: the immediate construction window carries a stronger footprint penalty than the general treatment record.

5.4 Treatment-effect conversion and cohort diagnostics

The treatment values in Table 5 convert the estimated impacts into catchment quantities. The table is valuable because it provides a comparison of the average treatment effect and cohort effects on the same spatial scale. This allows the reader not only to determine whether an impact occurs, but also whether the impact is quantified as density, footprint share or compound size. The two-way fixed-effect estimator implies 0.39 more gated communities per km^2 and 2.08 percentage points of additional catchment footprint. The staggered-treatment estimator implies 0.44 more gated communities per km^2 and 2.32 percentage points of additional catchment footprint. The implied unit footprints are virtually identical: 52 864 m^2 for the two-way fixed-effect estimator and 52 985 m^2 for the staggered-treatment estimator. The similarity suggests that the two treatment estimators are different primarily in scale rather than implied unit compound size.

Table 5. Treatment and cohort records after conversion.

Record	$\widehat{\tau}_N$	$\widehat{\tau}_F$ (m^2)	D_τ	S_τ	U_τ (m^2)
Two-way fixed effect	3.16	167049.40	0.39	2.08	52864
Staggered treatment	3.52	186506.39	0.44	2.32	52985
Cohort 2009	4.32	144933.22	0.54	1.80	33549
Cohort 2013	3.63	227768.44	0.45	2.83	62746
Cohort 2017	1.98	147527.25	0.25	1.83	74509

The cohort results reveal a more pronounced morphological shift. While the 2009 cohort produces the greatest count effect, 4.32 gated communities, it produces the lowest implied unit footprint, 33 549 m^2. The 2013 cohort produces a lower count effect, 3.63 gated communities, but the highest footprint effect, 227 768.44 m^2 and thus the highest implied unit footprint, 62 746 m^2. The 2017 cohort produces the lowest count effect, 1.98 gated communities, but an implied unit footprint of 74 509 m^2. The order reveals that later construction is not simply weaker. It is morphologically distinct.

The morphology of cohorts illustrated in Figure 6 provides an interpretation of this sequence in the language of urban form. The 2009 cohort represents a more numerous, smaller-footprint pattern of development, whereas the 2017 cohort represents a less numerous but larger land-absorbing compound pattern. Thus, it further confirms the finding that a smaller count effect can imply a significant footprint burden. For station planning, it means that later development cannot be evaluated in terms of the number of new compounds. Parcel scale and land consumption become the crucial factors.

Figure 6. Cohort morphology shift.

In comparison to the 2009 cohort, the 2017 cohort keeps only 45.83% of the count effect, but 101.79% of the footprint effect. The implied unit footprint of the latter is 222.09% of the former. This is the most important of the cohort results. It demonstrates that a declining count effect can be accompanied with a stable footprint effect when the induced compounds grow larger. In terms of public permeability, a smaller number of new compounds does not imply a smaller planning burden. A later cohort may create fewer interruptions but use up a comparable amount of the land. Thus, the urban design implication will be different: the 2009 pattern implies more numerous but smaller restricted territories, while the 2017 pattern implies fewer but larger land-absorbing compounds.

The transition ratios illustrated in Figure 7 express the same transition numerically. The 2017 cohort reduces the 2009 count effect to 45.83%, keeps the 2009 footprint effect at 101.79%, but increases the 2009 implied unit footprint to 222.09%. The ratio display makes it clear that the planning burden moves from multiplication to compound scale. It is precisely what makes a simple count-based monitoring system insufficient for the later cohort evaluation.

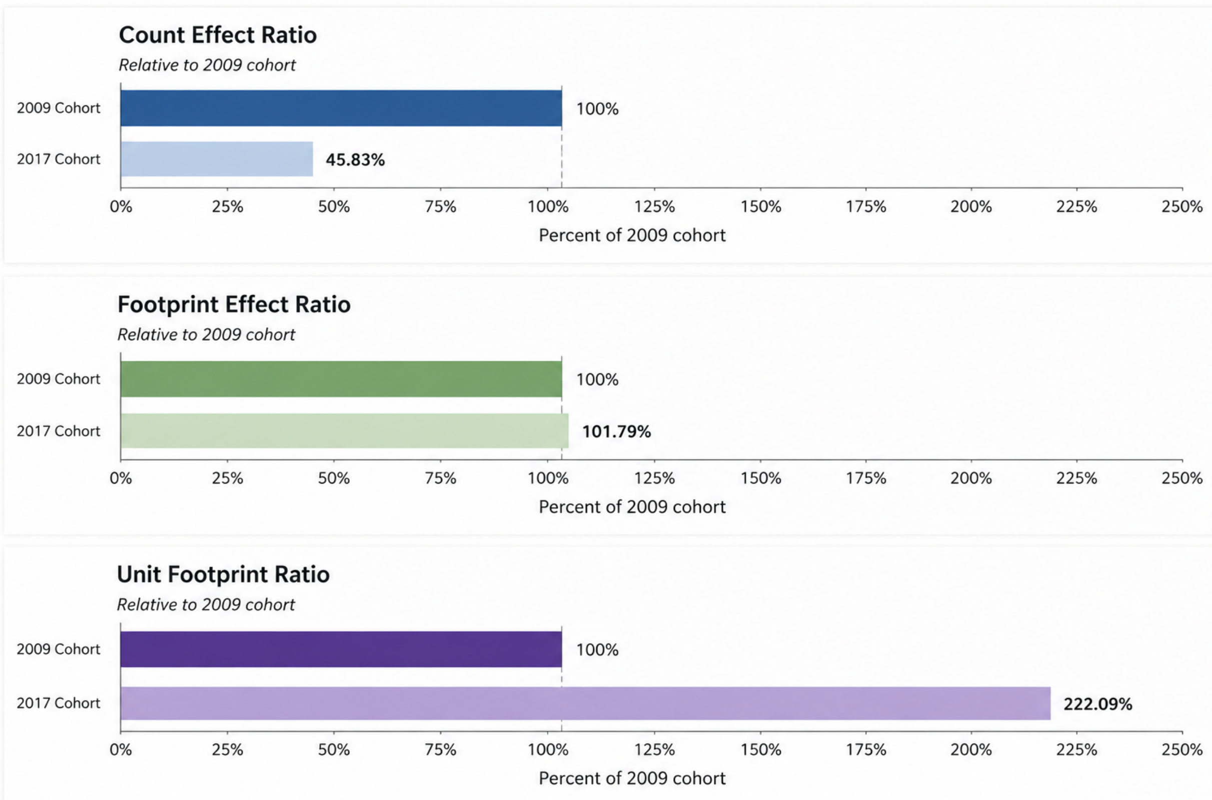

Figure 7. Cohort transition ratios.

5.5 Calendar retention and residual effect mass

From Table 6, we can see that 2016 is the peak year for count and footprint effects. The count effect peaks at 4.84 gated communities and the footprint effect peaks at 2.55×10^5 m^2. For 2023, the count effect is 2.15 gated communities, and the footprint effect is 1.38×10^5 m^2. Those terminal values are not trivial. They represent 44.42% of the count peak and 54.12% of the footprint peak. Therefore, the footprint effect lasts more than the count effect.

Effect-mass analysis confirms this interpretation. More than half of the mass of count effect happens after the peak year of 2016, and more than two-thirds of the mass of the footprint effect happens after the peak year. For the late window period of 2020 to 2023, there is 20.33% of the count effect mass and 24.40% of the footprint effect mass. Therefore, we see that even when the strongest construction period is done, the effect does not vanish; it continues as a residual effect. That the mass of footprint effect is larger in the post-peak and late window period compared with count effect is in agreement with our cohort analysis: later effects are less count-dominated and more land-consuming.

The calendar bar chart in Figure 8 plots the annual effects in the form of peak and residue instead of trajectory. Both count and footprint effects peak in 2016, but 2023 footprint retention (54.12%) is larger than the 2023 count retention (44.42%). In addition, Figure 8 shows that post-peak and late window shares are not negligible. Thus, we conclude that the residual effect is an ongoing occupation of land, not a short-term construction echo. The larger footprint retention is important since it is harder to reverse the land parcel, walls, and estate management boundaries than the construction timeline.

Table 6. Retention structure of calendar treatment effects.

Retention quantity	Count effect	Footprint effect
Mean annual effect, 2009–2023	3.35	1.67×10^5 m^2
Peak year	2016	2016
Peak value	4.84	2.55×10^5 m^2
Terminal value in 2023	2.15	1.38×10^5 m^2
Terminal retention of peak	44.42%	54.12%
Post-peak share of total effect mass	55.15%	63.94%
Late-window share, 2020–2023	20.33%	24.40%

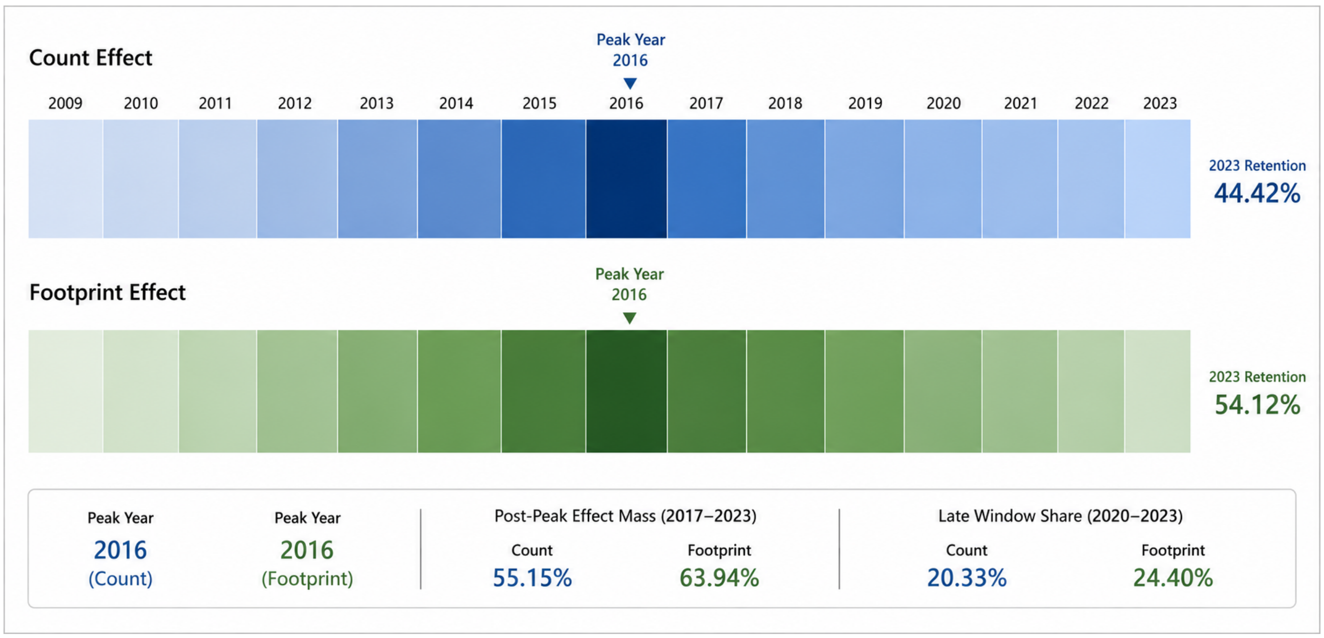

Figure 8. Peak and residue.

6. Discussion

6.1 Answer to the research question

The research question asked whether Nanchang's metro-accessible catchments function as public route fields or whether some of their accessibility value gets absorbed into the restricted residential morphology. The answer is that the treated catchment experiences an above-control public route loss burden. It is not only about the number of gated communities. The treated category has 14.08 gated communities, 754 801.87 m^2 of gated footprint, 1.75 communities per square kilometre, and a 9.39% gated footprint share. Using the equal-weighted control as the basis of comparison, 54.12% of the treated count and 48.13% of the treated footprint belong to the above-control burden. It means that the public accessibility created by station proximity goes hand in hand with an appreciable share of restricted residential stock.

The results also indicate which part of the burden has the highest planning significance. The stock comparison is somewhat count-oriented, but the event-window and cohort diagnostic shows that land absorption turns out to be the more significant problem. The five-year construction window displays the highest footprint-intensity gradient, and the 2017 cohort maintains almost the same footprint effect as the 2009 cohort even with the lower count effect. The annual analysis further shows that the footprint effect loses less of its 2016 peak compared to the count effect. Therefore, the research question can be considered answered in multiple layers. Count multiplication starts the enclosure burden; footprint intensity makes that burden land surface-weighty; cohort transition changes the burden morphology; and temporal retention maintains the burden in the catchment past the peak.

The answer makes the analysis different from the evaluation of a wide range of TOD cases. The paper does not consider whether metro investment is good or bad in general, nor does it evaluate all the aspects of station-area urbanism. The isolation of one specific contradiction between the publicly funded accessibility supporting compact station-area development and the residential morphology reducing public route choice makes the analysis unique. That contradiction becomes measurable due to the conversion and retention calculation presented in the paper.

6.2 Density without permeability

The results confirm an important distinction in the planning of station areas. Density alone cannot guarantee public accessibility. A station district with high density may have poor functional characteristics when the blocks of this area are closed, the number of entrances is low, and there is no circulation available to the non-residents. Permeability studies show that route configuration is a vital part of the urban performance [16]. Interface studies reveal the role of public/private edges in movement and accessibility [28]. Research of walkability adds the importance of entries and active frontages in shaping encounter potential [17]. In the Nanchang case, the treated catchment is not only denser in gated-community count; it is characterized by 9.39% gated footprint share and 4.52 percentage points of above-control footprint effect. It means that the public access could be substituted by the parcel arrangement with internally realized benefits.

Such interpretation is in line with the research treating station walkability as a network condition rather than as a radius alone [16]. The interface-catchment research focuses on the location and accessibility of entries and frontages [17]. The recent station-area studies demonstrate the dependence of pedestrian accessibility on the built form and connectivity of the surrounding catchment [14]. Although the Nanchang calculations do not provide the map of all the pedestrian routes, the footprint values reveal the parcels which can influence route continuity. It is not a trivial fact that the 9.39% restricted footprint share is characteristic of a station catchment. It is a land allocation signal that can change the block permeability, entrance spacing, and frontage legibility at the actual scale of approaching the station.

The issue is vital for the evaluation of the policies since many station-area indicators value proximity, intensity, and development volume without taking permeability into account. A catchment can look successful with respect to attracting residential investment, raising the land value, or increasing the population density. At the same time, the same catchment can lose its value as the public movement field when large gated compounds make the walking paths longer and decrease route choice opportunities. It is the practical meaning of the public permeability forfeiture. It does not mean that residents within gated compounds do not benefit from the metro proximity. It just asks whether the wider city obtains the route-level accessibility that justified the infrastructure investment.

The gradient result provides a measurable representation of such issue. The five-year event window adds 6.21 percentage points to the gated footprint share, and the footprint-intensity gradient equals 5.98. It means that the immediate construction window is the period with the high land absorption. In planning terms, the most crucial decisions are made before and during that interval: parcel subdivision, street reservation, entrance spacing, public passage requirements, and the relation between development approvals and station access routes. When a compound is constructed as an internally managed entity, it becomes more challenging to improve its public permeability. Retrofitting is still possible, but it requires negotiating property rights, residents' concerns, management practices, and municipal design priorities.

The result brings forward the difference between Euclidean and network access. Although a 1600 m circular catchment can include land close to the station in the straight-line distance, a pedestrian access to it depends on the available route network. Network analysis based on OpenStreetMap became easier thanks to OSMnx package [38]. The development of these tools additionally helps with the reproducible evaluation of the route-based accessibility [39]. This study does not calculate network distance, but its results reveal the need in such an approach in the case of station areas with extensive gated footprint.

6.3 Cohort transition and compound scale

The cohort effects show that metro-related gated development takes a different form according to construction cohorts. The 2009 cohort has the highest count effect but the lowest unit footprint. The 2017 cohort has a much lower count effect but a unit footprint more than twice that of the 2009 cohort. This implies that the time variable needs to be understood differently. A decline in the number of induced gated compounds does not mean more permeability. Rather, it can signify a transition from many smaller compounds to few larger compounds, which can have the same or even greater impact on public permeability depending on their location and boundary design.

This finding fits well with the larger literature that views gated communities as heterogeneous urban forms rather than one type of development. Typological research shows that gated communities vary in scale, enclosure level, and relation to streets [21]. Institutional analysis indicates that the effects of such developments depend on the form of governance and the process of producing private collective spaces [22]. The planning effects of gates depend on the scale of the development, edge condition, relations to the street network, and interface activity. Small gated compounds located in a fine-grained street network can cause local restrictions without creating any barriers to movement within the catchment. Large gated compounds can reorganise movement at the catchment scale, especially if such a development blocks the path between residential and station catchments. The transition from the unit footprint of 33 549 m^2 in the 2009 cohort to 74 509 m^2 in the 2017 cohort requires special attention despite a low count effect in the 2017 cohort.

In turn, the cohort effect highlights the governance issue. While the ledger is not capable of revealing the exact mechanism of each construction cohort, it provides a spatial symptom of it. Specifically, count effects become less and unit footprint increases. This symptom is enough to develop a planning measure based on the size of the unit, not only its number.

From a planning perspective, this result suggests that station-area policies must include limits to impermeable edges' length, public passage requirements, and the rules of large-patch subdivision. Development intensification targets can promote compact development around stations, but they do not prevent the emergence of large enclosed compounds. In other words, such a policy must take into account whether each development contributes to the accessible network, whether entrances are frequent enough to allow pedestrian movement, whether edges are active enough and public routes are able to pass through or around the development without detour. These issues are not secondary aesthetic concerns. They define the conversion of rail accessibility into public urban value.

6.4 Residual effects and planning timing

The retention effects analysis proves that the public permeability forfeiture is a persistent phenomenon. In 2023, count effects retain 44.42% of the 2016 peak value. Footprint effects retain 54.12%. Post-peak shares of effect mass equal 55.15% and 63.94%, correspondingly. Thus, the effect continues to matter after the peak year. If a planning authority evaluates only the peak construction wave, it misses the burden of the next years. The footprint effect is especially important since it retains more of the peak effect than the count effect.

Persistence helps to understand the distinction between the timing and the outcome of development. Metro construction is a time-bounded phenomenon, but the gated compounds that appear during this period can stay in existence for decades. Walls, compound boundaries, ownership patterns, and governance systems have a much longer life span than the schedule of construction. Treatment effects can be persistent despite their decline after the peak year. This is why retention analysis is important for planning. It transforms a series of annual treatment effects into an estimation of the stock of restricted land in a public accessibility field.

Finally, the late window values, from 2020 to 2023, are especially important for the contemporary policy. This analysis shows that the phenomenon is not only an early-stage effect of the first metro rollout in a city. Late window retains 20.33% of count mass and 24.40% of footprint mass. Therefore, permeability-sensitive planning remains relevant even after the early build-out period. If station-area policies are developed after the gated compounds mature, planners will face the difficult task of retrofitting already built boundaries. If they are introduced before the start of construction and land assembling, planners will be able to influence parcel form more effectively. Thus, Nanchang values show that the preventive control of parcel form is needed before large footprints emerge.

Methodologically, this result suggests that station-area research should combine the causality estimate with the spatial accounting. The difference-in-differences and event study designs are helpful since they allow separating the treatment effects from background trends. Still, their outputs require interpretation for planners. Group-time methods can be used as one of possible approaches to handle the variation in metro-opening dates [35]. Decomposition shows why two-way fixed effects are a problematic tool under staggered adoption [33]. Recent papers also emphasize the importance of interpreting the dynamics and pre-trend evidence [37]. The treatment coefficient becomes more valuable if it is measured by density, footprint share, unit scale, excess burden, and retention share. This diagnostic tool cannot solve all identification problems, but it can give a direct planning interpretation to the treatment effect.

6.5 Implications for station-area governance

The results suggest that station-area governance should go beyond development intensity and include an explicit test of public routes. Station area plans should check whether a new residential project preserves the public permeability. Measures of connectivity can support an assessment beyond radial buffer zones [40]. The research on walkability shows the need to assess practical pedestrian paths and barriers around transit [18]. It can be done by means of block-size controls, mandatory passages, entrance frequency standards, activation of edges, and integration of pedestrian networks prior to development approval. Such instruments should not be viewed as a general ban on gated residential development. They should be seen as conditions of receipt of the value created by public rail investment. Where the public sector creates accessibility, the development should return it to the public through the route structure.

Nanchang evidence also suggests that value capture and permeability capture should be analysed together. Land-based finance can recover the monetary value of metro investment, but it may fail to recover spatial public value if development around stations turns out to be internally restricted. The municipality can capture revenue while losing public permeability. This is the paradox underlying the case: the same station proximity that increases the value of land may create forms of development that restrict public access. A comprehensive evaluation of the metro development should cover value capture and route capture, interface capture, and public-space capture.

The governance comparison in Figure 9 provides a translation of empirical findings into a planning test. The left part represents monetary value capture via metro investments, land uplift, development intensity, and revenue. The right side reveals instruments of permeability capture such as through-block passages, entrance frequency, block-size control, active edges, and pedestrian-network review. The figure shows the connection between the numerical diagnosis and decision points that are more likely to affect public route value. The main implication of this figure is that station-area development approval should check the public access provided by the project, not only land value or floor area extracted by station proximity.

The same calculations can be made for the station area records that contain counts, footprints, treatment dates, and construction cohorts. This is especially useful when parcel-level network analysis is unavailable or when planners need a communicable diagnostic before detailed route modelling. The ledger points to catchments where the inspection is the most urgent.

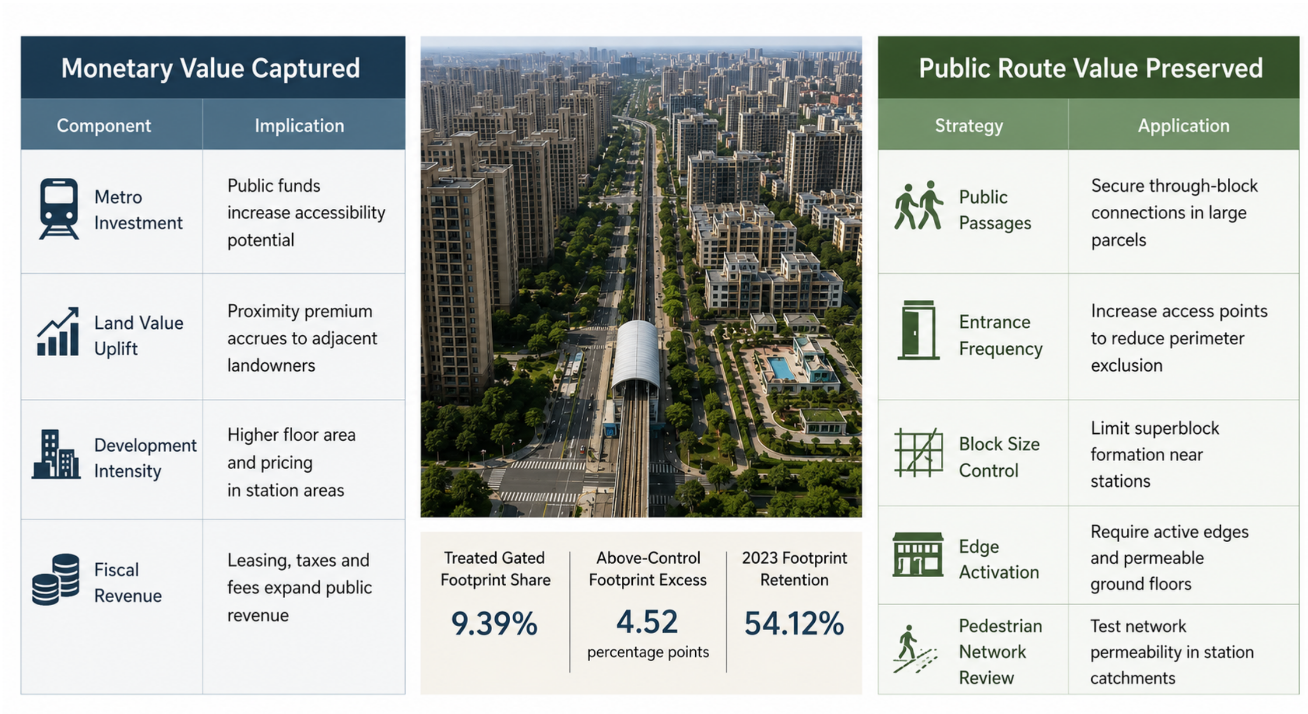

Figure 9. Value capture and permeability capture.

7. Conclusion

Whether the catchments of Nanchang metro stations maintain a generally legible public route network or if a portion of the catchment is ceded to restricted residential morphology has been the research question of this paper. The answer is both specific and quantitative. Treated catchments include 1.75 gated communities per square kilometre, and 9.39% of their footprints are gated. Compared against the composite control, the excess is 7.62 gated communities and 363 285.72 m^2 of gated footprint. Relative to the control standard, 54.12% of the count and 48.13% of the footprint exceed that standard, constituting 51.12% forfeiture share.

The data further indicate that the problem is not just that there are many gated communities. The five-year cohort construction period has the largest footprint-to-count intensity ratio, at 5.98 percentage points of catchment footprint per gated community per square kilometre. The analysis of construction cohorts reveals a morphological shift: the 2017 cohort has just 45.83% of the count effect but 101.79% of the footprint effect of the 2009 cohort, and reaches 222.09% implied unit footprint relative to the latter. The calendar analysis confirms the persistence rather than absence of the problem: by 2023, the footprint effect retains 54.12% of its peak level in 2016, while the count effect retains 44.42%.

These numbers provide a concrete answer to the research question, specifying four conditions of public route value forfeiture. First, treated station catchments have an above-control restricted-residential footprint. Second, the land surface taken up by the footprint is significant enough to influence the functionality of catchment as a public movement field. Third, the construction cohorts indicate a shift in morphology to larger compounds, hence count reduction does not equate spatial recovery. Fourth, the post-construction peak retention of the footprint effect implies persistence of the footprint effect beyond the most active construction phase. The evidence from Nanchang shows that metro accessibility can come hand in hand with enduring restricted footprints that reduce the public route value of proximity to the station.

The answer suggests an implication for urban planning. In addition to the usual value-capture mechanism around the metro stations, permeability capture should be used. Development that benefits from the publicly funded rail infrastructure should be assessed in terms of through-block access, frequency of entrances, block-size limitation, active streets, and continuity of the pedestrian network. This does not negate the idea of residential development near transit. It allows the station area intensification to give back part of the accessibility value created for the public transportation infrastructure.

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