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Abstract

Since the early-1970s, Transit oriented development (TOD) has been touted as a solution to a variety of urban problems, including traffic congestion, air pollution, and urban poverty. Subsequently, urban scholars have scrutinized "green" development like TOD to measure potential social costs – like the displacement of incumbent neighborhood residents. However, the methodological approach of these empirical studies has come under scrutiny recently, questioning the connection between gentrification and TOD. Following critics' calls for a better understanding of *who* may be impacted by TOD, my project addresses previous studies' methodological shortcomings by focusing on the socioeconomic characteristics of neighborhood residents rather than property values to measure gentrification. I employ statistical analyses on the Longitudinal Tract Database provided by Brown University to investigate the extent to which Washington Metropolitan Area Transit Authority's TOD projects have induced or accelerated displacement in Washington, DC. This paper can aid policy makers and urban planners seeking to ensure that sustainable development does not impose excessive burdens on some in society.

Keywords

Gentrification, Transit-Oriented Development

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The Social Aspects of Sustainable Development: Transit-Oriented Development and Gentrification in Washington D.C.

Vincent Hanrahan, American University

Executive Summary
Since the early-1970s, Transit oriented development (TOD) has been touted as a solution to a variety of urban problems, including traffic congestion, air pollution, and urban poverty. Subsequently, urban scholars have scrutinized "green" development like TOD to measure potential social costs – like the displacement of incumbent neighborhood residents. However, the methodological approach of these empirical studies has come under scrutiny recently, questioning the connection between gentrification and TOD. Following critics' calls for a better understanding of *who* may be impacted by TOD, my project addresses previous studies' methodological shortcomings by focusing on the socioeconomic characteristics of neighborhood residents rather than property values to measure gentrification. I employ statistical analyses on the Longitudinal Tract Database provided by Brown University to investigate the extent to which Washington Metropolitan Area Transit Authority's TOD projects have induced or accelerated displacement in Washington, DC. This paper can aid policy makers and urban planners seeking to ensure that sustainable development does not impose excessive burdens on some in society.

Proposed and Overview

Since the early-1970s, Transit-Oriented Development (TOD) has increasingly become the dominant environmentally-sustainable urban development strategy theorized about, advocated for, and implemented by "green" urbanists and policy-makers alike as a solution to a variety of urban problems, including traffic congestion, air pollution, and urban poverty (Revington 2015; Soursourian 2010; Dawkins and Moeckel 2016; City of Chicago 2020; Washington Metropolitan Area Transit Authority 2022). The potential silver-bullet quality of TOD has inspired many urban scholars to turn critical eyes on sustainable development projects like TOD in an effort to identify the potential social costs (like the displacement of incumbent neighborhood residents) of such sustainability projects and the leveled-up neighborhood amenities that attend them (Dawkins and Moeckel 2016). However, the methodological approach of these studies have come

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under great scrutiny of late (Padeiro et al. 2019; Chava and Renne 2021; Rayle 2014; Baker and Lee 2017).

Following these critics' calls for a better understanding of "*who* may be impacted by station developments rather than *what* may be impacted," this paper attempts to address previous studies' methodological shortcomings by focusing on the socioeconomic and demographic characteristics of neighborhood residents rather than property values in measuring gentrification (Baker and Lee 2017, 35). I employ statistical analyses to investigate the extent to which Washington Metropolitan Area Transit Authority (WMATA) TOD projects have induced or accelerated displacement in Washington, D.C. I show there was significantly more neighborhood change across four gentrification indicator-variables in census tracts with more TOD projects between 1970 and 2019. My paper offers guidance to policy makers and urban planners seeking to ensure that sustainable development does not impose excessive burdens on some in society.

Literature Review

Drawing exclusively from refereed books, journals, and articles, I begin by laying out the historical premises of TOD as a practice of sustainable urban development. This historical context underscores the potential benefits of TOD to clarify the difference between neighborhood "upgrades," which take the form of changes to the built environment (neighborhood land- and house-values can be measured by the cost of rent or mortgage), and the potential displacements these upgrades might usher in (Teernstra and Van Gent 2012).

Second, I examine why conventional planning wisdom has long assumed gentrification and displacement as subjects worthy of academic consideration. Following Marcuse's (1985) guidance, I understand that displacement is a symptom of gentrification. According to Marcuse, (1985, 198–99) gentrification occurs when new residents – "disproportionately young, white,

professional, technical, and managerial workers with higher education and income levels" – replace older residents – who are "disproportionately low-income, working-class and poor minority-ethnic group members, and elderly" – "in a spatially concentrated manner," that differs "substantially from the general level of change in the community or region as a whole." Lastly, I explore why urban scholars have struggled to empirically identify TOD as one of the instrumental causes of gentrification and the subsequent displacement of incumbent neighborhood residents. I conclude with my hypothesis and the scholarly contribution it makes.

Sustainable Urban Development

In attempting to mitigate the apocalyptic consequences of global warming, American urban planners have been forced to confront the fact that the United States and its fossil fuel culture have disincentivized the adoption of many solutions to climate change, like mass public transportation and high-density residential spaces (Nader and Beckerman 1978). Acknowledging this fact has resulted in exponential adoption of a new urban planning paradigm. Urban development (which I define as the construction of new buildings and infrastructure in cities) in the United States and across North America has become increasingly indistinguishable from the language and goals of the newer, more expansive sustainable development movement (Brown et al. 2014; Immergluck and Balan 2018). The sustainable development paradigm has deep theoretical richness, which stems from the varying levels of emphasis its advocates place on different sustainability practices and policies (Brown et al. 2014). Nearly all sustainable urban development aims to reduce energy consumption and greenhouse gas emissions (Wheeler 2016).

Transit-Oriented Development

Transit-oriented development (TOD) is the poster child of sustainable urban development. As a concept and practice, TOD occurs at a large enough rate to have a significant

impact on the social dynamics and built environment of American cities going forward (Grube-Cavers and Patterson 2014; Immergluck and Balan 2018). These high-density private residential spaces are located within walking distance (0.5 miles) of public rail-transit station stops and are understood by their advocates to address traffic congestion, air pollution, and increased cost-of-living in cities (Soursourian 2010; Revington 2015).

TOD emphasizes mixed residential and commercial development that encourages walkability by consolidating daily amenities like grocery stores and entertainment sources in one development area. These consolidations increase energy efficiency by reducing the number of independent housing units on the grid, while decreasing water use and waste-to-landfill (Wheeler 2016). Furthermore, by reducing residents' dependence on driving, development areas see a significant decrease in carbon emissions and air pollution (Dale and Newman 2009). Revington (2015) insightfully points out that these environmental and health benefits are further legitimized by a neo-classical urban economic perspective: TOD projects are seen as valuable insofar as they can attract skilled workers by providing readily accessible transportation to urban centers where more jobs are located (Renne and Ewing 2013). Taking Revington's (2015) argument further, consider how public transit ridership is incentivized in development areas. Increased transit ridership supplements the city's revenue stream, while dense living increases the number of taxable residents living in the city (WMATA 2022). However, Revington (2015) and Gunder (2016) are quick to point out that the neoclassical framework is inherently limited in its ability to consider unjust social costs, like the process of gentrification.

Gentrification and Displacement

Although TOD advocates and other urban planners regularly insist that a crucial tennent of sustainable development is social equity, some critics contend that social equity is too often

overlooked by sustainable development efforts that focus more on environmental sustainability and economic growth within the sustainability paradigm (Soursourian 2010; Wheeler 2016; Immergluck and Balan 2018, Dooling 2009; Checker 2011; Revington 2015; Gunder 2016; Immergluck and Balan 2018). These urban scholars warn that, without precautionary housing policies (like supply side, income-restricted units), the neighborhood amenities provided by TOD – "such as parks, walkability, and higher-density development" – will raise property values in the developed areas, given a rapid increase in demand (Immergluck and Balan 2018, 546; Dooling 2009). Furthermore, the new amenities in the TOD development areas would cater to the new, wealthier residents, not the old. This makes it harder for lower-income residents to continue residing near the projects which have popped up in their neighborhood – a neighborhood that is likely becoming increasingly affluent (Doolin 2009; Checker 2011; Immergluck and Balan 2018). Thus, incumbent residents are priced out of the community "benefits" TOD advocates tout (Gunder 2016; Dale and Newman 2009).

Dawkins and Moeckel (2016) termed this phenomenon "transit-induced gentrification;" Checker (2011) dubs government-sponsored sustainable urban development "environmental gentrification;" and Dooling (2009) talks about "ecological gentrification." Regardless of the term one chooses, this body of literature is united in hypothesizing that the "greening" of neighborhoods can increase desirability, thereby inducing or accelerating gentrification. Empirical studies supporting the TOD-induced gentrification hypothesis present TOD as an instrumental cause of gentrification. Most of these studies operationalize neighborhood change by examining how property values near TOD projects increase at significantly greater rates than other properties in the city of study (Lin 2002; Grube-Cavers and Patterson 2014; Immergluck and Balan 2018).

Methodological Critiques of the TOD-Induced Gentrification Hypothesis

Though the logical stream of reasoning is perfectly clear – rich people move into TOD projects and price-out their incumbent neighbors – empirical studies have struggled to develop a strong connection between TOD and gentrification displacements. In fact, most recent literature on the cutting edge of sustainable development research contradicts traditional transit-induced gentrification wisdom.

Rayle (2014) along with Nilsson and Delmelle (2020) note the inherent difficulty of measuring displacement in gentrified neighborhoods – displaced residents are not around to answer survey questions. Rayle (2014) further suggests that empirical researchers' struggles stem from their insufficient attention to the qualitative aspects of gentrification, such as the social and psychological forms of displacement, as well as methodological shortcomings in existing studies. Renne et al. (2016), extended one of Rayle's (2014) quantitative critiques in their exploration of the potential transportation cost savings associated with TOD to reveal a paradox: TOD projects are expensive places to buy and rent residential property in most places, but in some they are more affordable than urban development projects farther from public transit stations because reduced transportation costs offset rising property values. Similarly, Baker et al. (2017) find no evidence of prevalent gentrification in public rail-transit station areas; rather, they point to different local and regional development efforts that can result in different types of changes in TOD neighborhoods.

The most striking critique is launched by Padeiro et al. in their 2019 paper, which reviewed 35 quantitative research-based studies published between 2000 and 2018 presenting evidence in support of the transit-induced gentrification hypothesis. Padeiro et al.'s (2019) paper uncovers several methodological flaws that render the transit-induced gentrification hypothesis

highly questionable. Padeiro et al. (2019, 733) suggest gentrification and incumbent resident displacement are more closely associated with existing "local dynamics, built environment attributes, and accompanying policies" as they exist in conjunction with TOD.

Conclusion

Historically, urban scholars have primarily focused on the built environment when examining TOD, while neglecting socioeconomic and demographic changes at the local and individual level. My project aims to fill a research gap in related rail-transit gentrification research by incorporating suggestions for alternative measures of neighborhood change.

The studies Padeiro et al. (2019) analyze fail to use an appropriate group of control neighborhoods to test if neighborhood change patterns differ from other similar neighborhoods in the city (Nilsson and Delmelle 2020), thus I will include a random sample of non-TOD project, while neglecting socioeconomic and demographic changes at the local and individual level. My project aims to fill a research gap in related rail-transit gentrification research by incorporating suggestions for alternative measures of neighborhood change.

The studies Padeiro et al. (2019) analyze fail to use an appropriate group of control neighborhoods to test if neighborhood change patterns differ from other similar neighborhoods in the city (Nilsson and Delmelle 2020), thus I will include a random sample of non-TOD project census tracts with planned WMATA Joint Development projects. I assume that TOD tracts will have more residents who (1) are White, (2) highly educated, (3) higher income, (4) and less poor than those without TOD.

Hypothesis

These four socioeconomic and demographic assumptions correspond to four distinct gentrification indicators aligned with Marcuse's (1985) definition, combining to measure

neighborhood change. Guided by Baker and Lee's (2017) suggestion to use census tracts rather than property/land value or mortgage rates, I hypothesize that, in comparing Washington DC census tracts between 1970 and 2019, those with more TOD projects will have more neighborhood change than will those with fewer TOD projects.

Study Design

The extent to which Transit-Oriented Development (TOD) induces or accelerates gentrification remains largely understudied, and as Baker and Lee (2017) and Pediero et al. (2019) note, existing studies are overly reliant on property values as an indicator of neighborhood change (Cervero and Landis 1997; Duncan 2010; Cao and Schoner 2014). Although real estate values can be a good proxy indicator of lower-income resident accessibility expansion, as well as neighborhood upgrading, exclusive focus on price variables fail to account for residential characteristics – that is, the *people* who actually live in TOD neighborhoods (Teernstra and Gent 2012; Baker and Lee 2017). Additionally, very few existing studies employ demographic or economic neighborhood characteristics as secondary variables when examining residential cost changes (Debrezion et al. 2010; Golub et al. 2012; Chatman et al. 2012). However, by Marcuse's (1985) and my definition, an inherent aspect of gentrification is the displacement of incumbent neighborhood residents. The methods I lay out below reflect both how I define gentrification, as well as the gaps in current transit-induced gentrification research.

Theory, Case, and Expectations

Without precautionary policies (like supply-side, income-restricted affordable housing units) the retail, entertainment, and civic facilities provided by TOD risk raising property values in the developed areas given a rapid increase in demand (Immergluck and Balan 2018; Dooling 2009). Furthermore, these new amenities in TOD neighborhoods are likely to cater to the new,

wealthier residents, not the old. The neighborhoods are likely to become more affluent, and thus price-out incumbent residents from the community benefits TOD advocates tout (Immergluck and Balan 2018; Dale and Newman 2009; Gunder 2016).

With this priced-out precedent in mind, in 2018, WMATA announced all future joint TOD projects must comply with local affordable housing requirements, which vary throughout the region (WMATA 2022). However, more than 86 percent of completed joint development projects in DC – 19 of 22 – were built before 2018 (WMATA 2022). The vast majority of existing projects lack local affordable housing provisions (*Greater Greater Washington* 2022). From the priced-out premises uniting the body of transit-induced gentrification literature alongside the temporal particulars of TOD in DC, I expect that the presence of a WMATA joint development project in a neighborhood to be associated with indicators of gentrification in between 1970 and 2019.

My hypothesis – in comparing Washington DC census tracts between 1970 and 2019, those with more TOD projects will have more neighborhood change than will those with fewer TOD projects – assumes that TOD tracts will [1] be whiter, [2] have higher education levels, [3] have higher median incomes, and [4] have lower rates of poverty than those without TOD (i.e., there are four separate hypotheses to be tested). I aim to reject the hypothesis that DC census tracts with WMATA TOD experience no more neighborhood change than those without.

Operationalization and Measurement of Concepts

Like Baker and Lee (2017), I intend to emphasize the residential characteristics of DC census tracts rather than housing characteristics, thus I employ individual, resident-focused displacement indicators based on population demographic information. I use census tracts as the unit of analysis. Although census tracts are somewhat larger than what is commonly considered a

neighborhood, "it approximates an optimal size to analyze socioeconomic changes of residents over time" (Baker and Lee 2017, 44). Studies that find evidence in support of and in contradiction to the transit-induced gentrification hypothesis use census tracts as their unit of analysis (Grube-Cavers and Patterson 2015; Baker and Lee 2017). The Brown University Longitudinal Tract Database (LTDB) provides decennial year census data from 1970-2010 and American Community Survey data from 2011-2019, both normalized to 2010 census tract boundaries (Xu and Stults 2014). The LTDB provides me with the racial make-up, education level, income level, and poverty rate of the total population of DC census tracts and thus the means to operationalize the dependent variable of neighborhood change as Baker and Lee (2017) did: change in percent white, change in percent with a college degree, change in percent with higher income, and change in percent in poverty within census tracts between 1970 and 2019. In compiling my own dataset, I draw out my gentrification indicator variables (which are measured consistently across the two datasets) from the LTDB.

As other scholars have noted, it is difficult to comprehensively measure transit-induced displacement, particularly *why* residents left a neighborhood. This is because, lacking the quantitative data that tracks the movement of incumbent residents themselves, there is no way to survey a population that no longer lives in a neighborhood (Rayle 2014; Nilsson and Delmelle 2020). Nonetheless, changes in my socioeconomic dependent variables serve as a second-best set of displacement indicators. For race, I measure change in non-Hispanic white tract population percentage because gentrification often manifests itself as a racial, as well as an economic, transition (Marcuse 1985; Baker and Lee 2017). Moreover, previous empirical studies often cite an increase in a given neighborhood's White population as a likely indicator of gentrification (Kahn 2007; Smith 2010).

I take a random sample of non-TOD project tracts to quell Padeiro et. al's (2019) concern that the gentrification of transit development areas is not the direct result of TOD, per say, but rather some other lurking variable. I obtain this random control by coding all 2010 Census Tract ID numbers, and then inputting them into a Google random number generator. My control establishes a baseline for neighborhood change across D.C. between 1970 and 2019.

To understand how WMATA TOD impacts gentrification and TOD-related neighborhood change, I run an array of statistical tests using an interval level independent variable that corresponds to the number of WMATA TOD projects in a given census tract. Using the *WMATA 10 Year Strategic Plan for Joint Development* (2022) that lists and maps all joint development projects, I can code the independent variable.

Research Design

Since both my independent variable and dependent variables have interval levels of measurement, I will calculate correlation and conduct a regression analysis to investigate the relationship between WMATA TOD project presence and potential changes in tract residents' socioeconomic and demographic characteristics (including race, income, and education). In 2010, the year to which the LTDB data is normalized, there were 179 census tracts. 12 of these tracts had at least one WMATA TOD project. These 12 tracts, along with a random sample of 18 non-TOD tracts, make 30 cases in all. Using these cases, I will assess my regression results for neighborhood change based on the significance of the correlation coefficients (p-value).

I will know gentrification likely occurred if my regression yields a significant positive coefficient ($P \leq 0.10$) for the gentrification indicator in a WMATA TOD tract. Although I expect this to occur where TOD prices-out low-income and minority households, there is a possibility that possible counter-gentrification occurs in TOD tracts. This would result when there is a

significant negative coefficient for the gentrification indicator in a TOD tract. This is the best possible outcome whereby TOD has possibly attracted low-income and minority households – one of the intended results of WMATA development (WMATA 2022). Based on the statistical significance of the correlation coefficient I obtain from my regression, I will be able to say if there is a strong, moderate, weak, or no relationship between WMATA TOD projects and neighborhood gentrification. If P is greater than ±0.10, I will not be able to reject the null hypothesis that there is no relationship between WMATA TOD and gentrification. However, if there is significantly greater neighborhood change in TOD-tracts than in those without TOD, my transit-induced gentrification hypothesis will be supported.

Implications

If I can reject the null hypothesis and support my alternative hypotheses with this data, I will bolster the growing body of transit-induced gentrification scholarship. By uncovering changes in key indicators of gentrification, my results would reveal that WMATA TOD neighborhoods become occupied by whiter, wealthier, and better-educated residents in place of poorer, minority incumbents. My project also yields crucial insights into the impacts of WMATA planning efforts on local DC contexts for which decision-making relies. If the data display signs of adverse neighborhood change in tracts where TOD has occurred, I will provide critical information for planners seeking to enact policies to address decades of gentrification and displacement. Even if I fail to reject the null, my work empowers policymakers with a better understanding of neighborhood change across DC between 1970 and 2019. Considering that seventy percent of future joint development projects are in or less than ½ mile from low-income and minority communities (WMATA 2022), this project underscores the critical absence of individual, resident-centered displacement research and advances plausible indicators to measure

future socio-demographic changes in TOD neighborhoods.

Analysis

This study aims to investigate the relationship between the presence of Washington Metropolitan Area Transit Authority (WMATA) transit-oriented development (TOD) projects and neighborhood change (including socioeconomic and demographic characteristics like race, education, and income) overtime. Every test conducted uses the total number of WMATA TOD projects per census tract as the independent variable (labeled PROJ_N). I operationalize neighborhood change as the dependent variable to align with my definition of gentrification by tracking change in percent White (CHG_P_WHT), change in percent with at last four years of college (CHG_P_COL), change in median household income (CHG_HINC), and change in percent in poverty (CHG_P_POV) within the same 30 census tracts between 1970 and 2019. The first rounds of tests I conduct [1] determine the level of correlation between WMATA TOD projects and neighborhood change and [2] test for statistical significance. I conduct four linear regressions on every one of my gentrification indicator variables to test for causation and magnitude.

Results and Reflections

Table 1 displays my initial descriptive statistics for each of my gentrification indicator variables.

Table 1: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Δ % White	30	-0.29	0.63	-0.0171	0.24724
Δ % College	30	0.07	0.87	0.4521	0.23239
Δ Income	30	-24829.61	238953.61	50691.9467	59394.84841
Δ % Poverty	30	-0.41	0.33	0.0047	0.15128
# of TOD	30	0	5	0.77	1.331

These baseline findings show the city in transition and indicate that WMATA TOD locations were not chosen for their socioeconomic or demographic composition. However, as the later figures and tables show, the construction of a TOD project in the tract had profound and significant effects on the communities where they were introduced.

Table 2 shows results of the correlation and statistical significance tests run between the independent and dependent variables.

hinTable 2: Correlation and Significance between Gentrification Indicators and WMATA TOD Projects, 1970–2019

		Δ % White	Δ % with at least four-years of College	Δ Median Household Income	Δ % in Poverty	# of WMATA TOD Projects
Δ % White	Pearson Correlation	1	0.297	0.069	-0.5188**	0.677**
	Sig. (2-tailed)		0.111	0.718	0.003	<0.001
	N	30	30	30	30	30
Δ % with at least four-years of College	Pearson Correlation	0.297	1	0.764**	-0.665**	0.516**
	Sig. (2-tailed)	0.111		<0.001	<0.001	0.003
	N	30	30	30	30	30
Δ Median Household Income*	Pearson Correlation	0.069	0.764**	1	-0.537**	0.306
	Sig. (2-tailed)	0.718	<0.001		0.002	0.01**
	N	30	30	30	30	30
Δ % in Poverty	Pearson Correlation	-0.518**	-0.665**	-0.537**	1	-0.596**
	Sig. (2-tailed)	0.003	<0.001	0.002		<0.001
	N	30	30	30	30	30
# of WMATA TOD Projects	Pearson Correlation	0.677**	0.516**	0.306	-0.596**	1
	Sig. (2-tailed)	<0.001	0.003	0.100	<0.001	
	N	30	30	30	30	30

* Median incomes are adjusted to 2019 levels using the Consumer Price Index Inflation Calculator
** Correlation is significant at the 0.01 level (2-tailed).

There is evident correlation between the number of WMATA TOD projects present in the given census tracts and every gentrification indicator variable: for change in percent White, R (the Pearson Correlation) is 0.677; for change in percent with at least four years of college, R is 0.516; and for change in percent in poverty, the R is -0.596. Change in median household income exhibits weak, though significant correlation with the number of WMATA TOD projects present in a given tract. I conduct a linear regression analysis for all four gentrification indicators that I have shown correlate to WMATA TOD projects and display my significant results in Table 3. All four models' visualizations are recorded in Figures 1–4 in the Appendix. These line graphs also show many tracts with 0 TOD that changed too, indicating that the city as a whole has experienced an influx of Whiter, more educated, and richer residents.

Table 3: Results of Regression Analyses of Gentrification Indicators, by Number of TOD Projects per Census Tract from 1970—2019.

	Model A: Change in Percent White	Model B: Change in Percent with at least Four Years of College	Model C: Change in Median Household Income	Model D: Change in Percent in Poverty
Constant	-0.114	0.383	40, 213.78	0.057
Coefficient	0.126	0.090	13,667.18	-0.068
t-score	4.868	3.191	1.702	-3.932
p-value	<0.001	0.003	0.100	<0.001
Adjusted R^2	0.439	0.240	0.061	0.333
N	30	30	30	30

Model A yields the following function for neighborhood change: change in percent White = -0.114 (constant) + 0.126 · X (number of WMATA TOD projects). The y-intercept (constant) of -0.114 clues us into some interesting census tract demographic information between 1970 and

2019: regardless of whether or not a tract has a WMATA TOD project, the White population in these DC tract samples decreased at a rate of 1.14%. Even more interesting is the regression coefficient of 0.126. This value indicates that, for each WMATA TOD project construction in these tracts, there was a 1.26 percent increase in the population that identifies as White. Given that the average population of the tract sample is about 3,856 people, for each TOD project that is constructed, on average nearly 49 White people move into the TOD neighborhood (Open Data DC, 2010). Consider this increase multiplied two, three, or even five times over in neighborhoods with multiple WMATA projects and it can easily be seen how the rapid influx of upwards of 243 White people could drastically change the social dynamic of any neighborhood. The adjusted R^2 value for Model A is 0.439, which means that about 44 percent of the variation in the percent change of a census tract's White population is explained by the presence of a WMATA TOD project. The other 64 percent of variation in percent change of White population in each tract is explained by any number of other factors – for example, the myriad of private TOD projects constructed between 1970 and 2019 that WMATA did not oversee.

In studies attempting to predict human behavior, like this study's focus on individuals' decisions to move in or out of WMATA TOD neighborhoods, an independent variable capable of explaining more than 30 percent of the variation in the dependent variable (measures of association greater than 0.3) indicates a strong relationship. My data therefore describes a strong relationship between the percent change of White people in a neighborhood and the presence of a WMATA TOD project.

Model B (change in percent with at least four years of college) has an adjusted R^2 value of 0.240, indicating a moderately strong relationship (<0.2 but >0.3) between WMATA developments and the percent changes in education level within neighborhoods. This model

yields the following function for neighborhood change: change in percent with at least four years of college = 0.383 (constant) + 0.090 · X (number of WMATA TOD projects). From the regression coefficient of Model B, we know the presence of a WMATA TOD project increases the college-educated population of any given census tract by about 9 percent.

In the regression analyses I conducted, like all the other gentrification indicator variables, Model C (change in median household) achieves significance and yields the following function for neighborhood change: change in median household income = 40, 213. 78 (constant) + 13,667. 18 · X (number of WMATA TOD projects). Model C contributes the weakest causal evidence to my transit-induced gentrification hypothesis (R^2 is 0.061). It is the only gentrification indicator variable to have a weak measure of association (<0.10) with the construction of WMATA TOD projects in DC neighborhoods. With that said, Model C displays tract median incomes adjusted for inflation, showing that even while the city became wealthier in general, TOD tracts changed more than those without TOD.

Model D (change in percent in poverty) contributes to my transit-induced gentrification hypothesis given that it logs an adjusted R^2 value of 0.333 – more than 33 percent of a neighborhood's change in poverty rate can be explained by the presence of a WMATA TOD project. The model also yields the following equation for neighborhood change: = 0.057 (constant) + -0.068 · X (number of WMATA TOD projects) The regression coefficient tells us the presence of TOD projects decrease the rate of total tract population in poverty by nearly 7 percent.

All gentrification indicator variables achieve significance for my small-n cases study (p-values ≤0.10) and exhibit mostly strong causal evidence that supports my transit-induced gentrification hypothesis. For a significance level of $p \leq 0.1000$, the p-value of the relationship is

<0.0010 for Model A, 0.0030 for Model B, 0.0998 for Model C, and <0.0010 for Model D. Assuming the null hypothesis is correct, a regression coefficient of 0.126 (for Model A) and -0.068 (for Model D) is randomly obtained less than 1 percent of the time. Under this same assumption, the regression coefficient 0.090 is obtained, by chance, less than 3 percent of the time in Model B, while Model C randomly acquires a regression coefficient of 13,667.18 less than 9.98 percent of the time. Given that the probability of obtaining these test statistics by chance is less than or equal to 10 percent in all four models, I can confidently reject the null hypothesis that there is no relationship between WMATA TOD and gentrification.

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Conclusion

In lieu of no relationship, this study suggests that Washington, D.C. census tracts with more TOD projects will have more neighborhood change than will those with fewer TOD projects. My project makes clear that WMATA TOD tracts became [1] whiter, [2] with higher

levels of education, [3] higher median household incomes, and [4] lower rates of poverty between 1970 and 2019 than those without TOD. All four of these elements offer support to the vast body of transit-induced gentrification literature and offer critical insights into *who* is moving into TOD neighborhoods – something that has long since alluded urban scholars (Golub et al. 2012; Duncan 2011; Padeiro 2019). By uncovering changes that are key indicators of gentrification occurring, my results reveal that WMATA TOD neighborhoods become occupied by whiter, wealthier, and better-educated residents in place of poorer, minority incumbents. This knowledge empowers policymakers with a better understanding of neighborhood change across DC between 1970 and 2019. My project also yields crucial insights into the impacts of WMATA planning efforts on local DC contexts for which decision-making relies. The data I present above displays signs of adverse neighborhood change in tracts where TOD has occurred, thus I provide critical information for planners seeking to enact policies and plans to combat decades of gentrification and displacement. However, this study has its limitations.

Though I provide a more encompassing picture of the new inhabitants by sorting and analyzing the demographic information of neighborhoods overtime, this study, like all those before it, lacks the ability to capture who is leaving WMATA TOD neighborhoods (Padeiro et al. 2019; Chava and Renne 2022). As other scholars have noted, it is difficult to take a comprehensive account of transit-induced displacement because displaced residents are not around to answer survey questions (Rayle 2014; Nilsson and Delmelle 2020). This gaping hole can only be addressed in the future by an increased emphasis on the qualitative aspects of gentrification and new quantitative surveys (Nilsson and Delmelle 2020). More specifically, this study lacks a set of controls and is limited by its small sample size given my focus on WMATA TOD projects rather than all TOD projects in the District of Columbia. A larger n would grant

future researchers the opportunity to run a means comparison tests between tracts with TOD and those without. Such a study would need at least 60 cases – 30 with TOD and 30 without.

Future research might attempt to measure the aforementioned private developments to increase the sample size of tracts with TOD, however, it should not lose sight of my sharp focus on existing local dynamics, such as the attributes of a city's social and physical environment or accompanying housing policies (Immergluck and Balan 2018; Padeiro 2019). This focus helped me to reject my null hypothesis. Future research might also seek to examine how great a difference WMATA's equitable housing clause has on the neighborhoods it develops in the future. Considering that seventy percent of future joint development projects are in or less than ½ mile from low-income and minority communities (WMATA 2022), this project underscores the critical absence of individual, resident-centered displacement research and advances plausible indicators to measure future socio-demographic changes in TOD neighborhoods. Lastly, entertaining a devil's advocate opinion, it is worth comparing the gentrification induced by WMATA's *sustainable* development with the gentrification caused by urban development bereft of environmental benefits. Such research ought not be used as justification for constructing gentrifying state-sponsored sustainability projects in the future; rather, future studies should seek to draw greater awareness to the glaring lack of attention to issues of social equity such projects have exhibited in the past.

In my provision of alternative hypotheses, I bolster the growing body of transit-induced gentrification scholarship and hope to inspire more just sustainable development policies. Considering that 70 percent of future joint development projects are in or less than ½ mile from low-income and minority communities (WMATA 2022), this project underscores the critical absence of individual, resident-centered displacement research, particularly because there is no

question sustainable, transit-centered urban development is the way of the future (Brown et al. 2014). It must be in order to mitigate the disastrous effects of climate change. However, the sense of urgency propelling modern sustainable development projects must be informed by a more encompassing view of history. There must be increased attention paid to the social aspects of sustainable development and the socio-demographic changes it entails. If future urban planners fail, as those working for WMATA have, to implement precautionary policies, "green" development will certainly place unjust burdens on some in society, while granting too many benefits to others.

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Appendix

Table 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
CHG_P_WHT	30	-.29	.63	-.0171	.24724
CHG_P_COL	30	.07	.87	.4521	.23239
CHG_HINC	30	-24829.61	238953.61	50691.9467	59394.84841
CHG_P_POV	30	-.41	.33	.0047	.15128
PRJ_N	30	0	5	.77	1.331
Valid N (listwise)	30				

Table 2

Correlations

		CHG_P_WHT	CHG_P_COL	CHG_HINC	CHG_P_POV	PRJ_N
CHG_P_WHT	Pearson Correlation	1	.297	.069	-.518**	.677**
	Sig. (2-tailed)		.111	.718	.003	<.001
	N	30	30	30	30	30
CHG_P_COL	Pearson Correlation	.297	1	.764**	-.665**	.516**
	Sig. (2-tailed)	.111		<.001	<.001	.003
	N	30	30	30	30	30
CHG_HINC	Pearson Correlation	.069	.764**	1	-.537**	.306
	Sig. (2-tailed)	.718	<.001		.002	.100
	N	30	30	30	30	30
CHG_P_POV	Pearson Correlation	-.518**	-.665**	-.537**	1	-.596**
	Sig. (2-tailed)	.003	<.001	.002		<.001
	N	30	30	30	30	30
PRJ_N	Pearson Correlation	.677**	.516**	.306	-.596**	1
	Sig. (2-tailed)	<.001	.003	.100	<.001	
	N	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

B.

Paired Samples Correlations

		N	Correlation	Significance One-Sided p	Significance Two-Sided p
Pair 1	PRJ_N & CHG_P_WHT	30	.677	<.001	<.001
Pair 2	PRJ_N & CHG_P_COL	30	.516	.002	.003
Pair 3	PRJ_N & CHG_HINC	30	.306	.050	.100
Pair 4	PRJ_N & CHG_P_POV	30	-.596	<.001	<.001

Table 3: Regression Results for Gentrification Indicator Variables

A. Change in Percent White, by Number of WMATA TOD Projects

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	PRJ_N[b]	.	Enter

a. Dependent Variable: CHG_P_WHT
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.677[a]	.458	.439	.18517

a. Predictors: (Constant), PRJ_N

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.813	1	.813	23.697	<.001[b]
	Residual	.960	28	.034		
	Total	1.773	29			

a. Dependent Variable: CHG_P_WHT
b. Predictors: (Constant), PRJ_N

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.114	.039		-2.898	.007
	PRJ_N	.126	.026	.677	4.868	<.001

a. Dependent Variable: CHG_P_WHT

B. Change in Percent with at least Four Years of College, by WMATA TOD Project

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	PRJ_N[b]	.	Enter

a. Dependent Variable: CHG_P_COL
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.516[a]	.267	.240	.20253

a. Predictors: (Constant), PRJ_N

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.418	1	.418	10.183	.003[b]
	Residual	1.148	28	.041		
	Total	1.566	29			

a. Dependent Variable: CHG_P_COL
b. Predictors: (Constant), PRJ_N

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.383	.043		8.937	<.001
	PRJ_N	.090	.028	.516	3.191	.003

a. Dependent Variable: CHG_P_COL

C. Change in Median Household Income, by number of WHMATA TOD Projects

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	PRJ_N[b]	.	Enter

a. Dependent Variable: CHG_HINC

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.306[a]	.094	.061	57541.85509

a. Predictors: (Constant), PRJ_N

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9594870064	1	9594870064	2.898	.100[b]
	Residual	9.271E+10	28	3311065087		
	Total	1.023E+11	29			

a. Dependent Variable: CHG_HINC

b. Predictors: (Constant), PRJ_N

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	40213.777	12176.069		3.303	.003
	PRJ_N	13667.178	8028.662	.306	1.702	.100

a. Dependent Variable: CHG_HINC

D. Change in % poverty by number of WMATA TOD Projects

Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	PRJ_N[b]	.	Enter

a. Dependent Variable: CHG_P_POV

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.596[a]	.356	.333	.12358

a. Predictors: (Constant), PRJ_N

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.236	1	.236	15.461	<.001[b]
	Residual	.428	28	.015		
	Total	.664	29			

a. Dependent Variable: CHG_P_POV

b. Predictors: (Constant), PRJ_N

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.057	.026		2.168	.039
	PRJ_N	-.068	.017	-.596	-3.932	<.001

a. Dependent Variable: CHG_P_POV

Figure A: Change in percent white, Number of WMATA TOD Projects

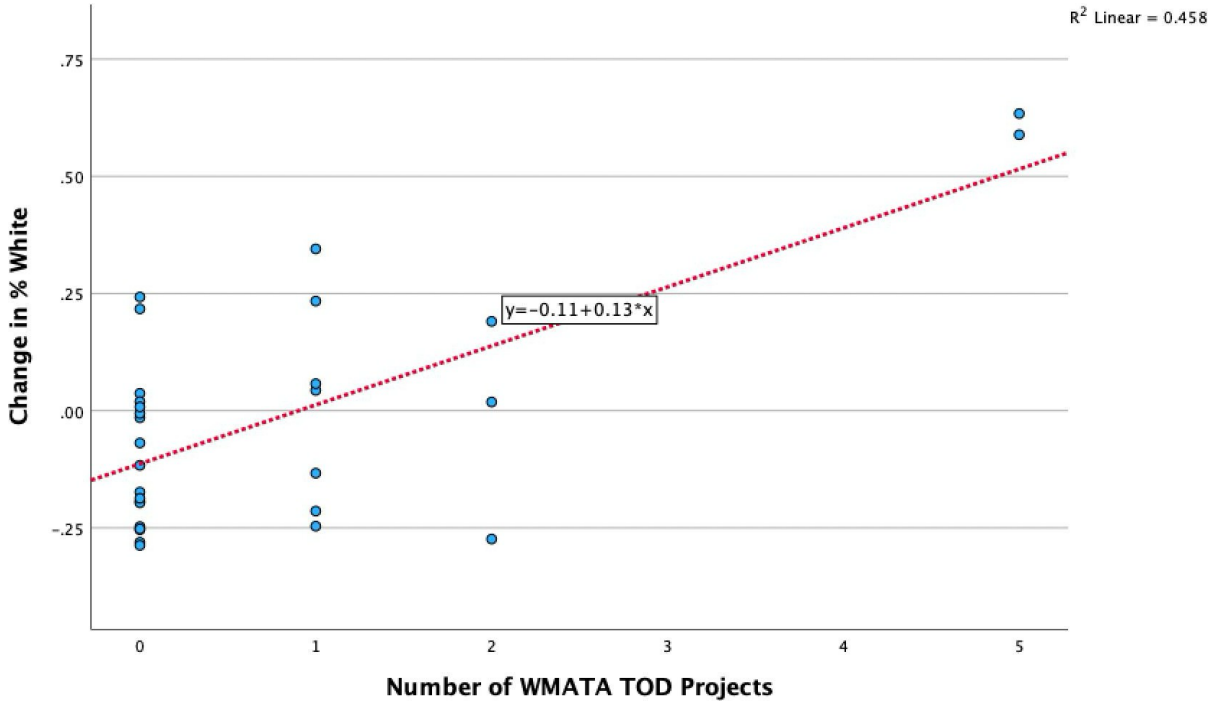

Figure B: Change in % with at least Four Years of College, by Number of WMATA TOD

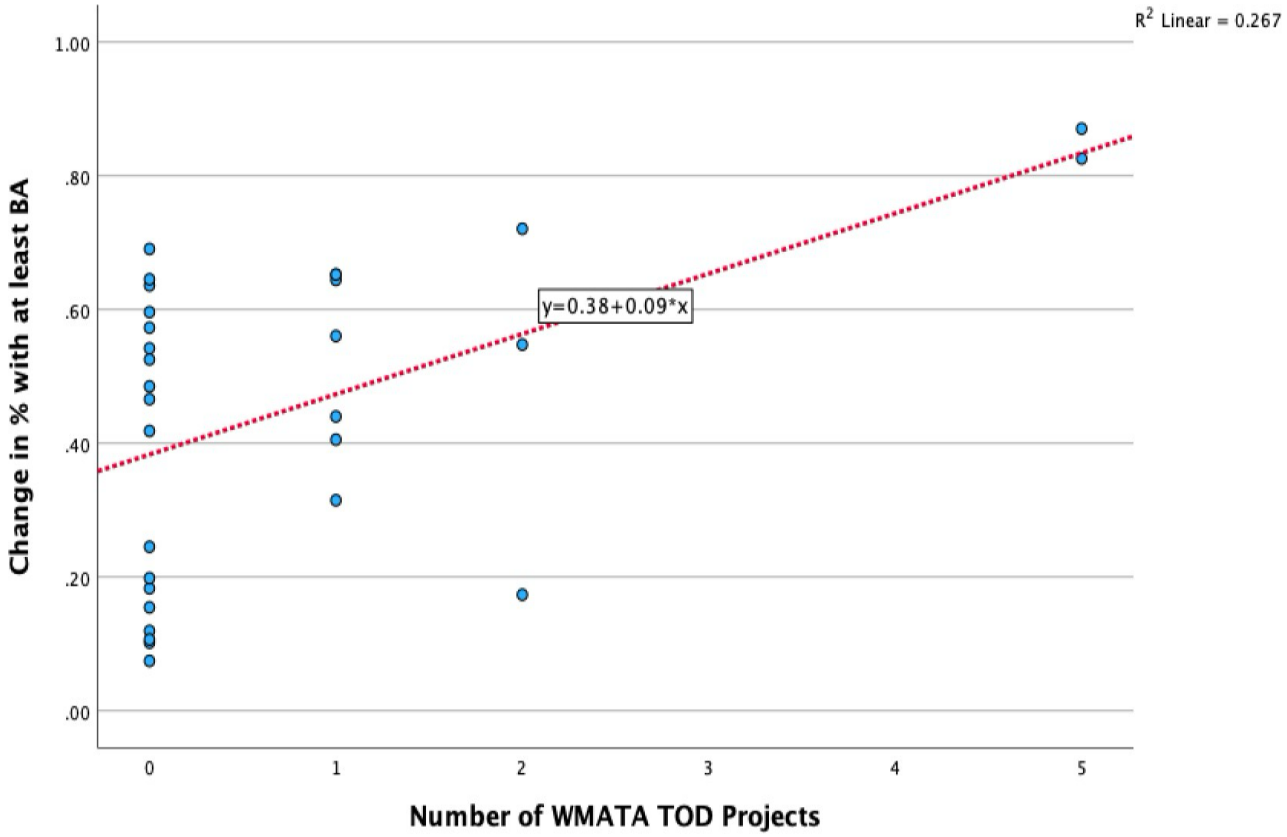

Figure C: Change in median household Income, by number of WMATA TOD projects

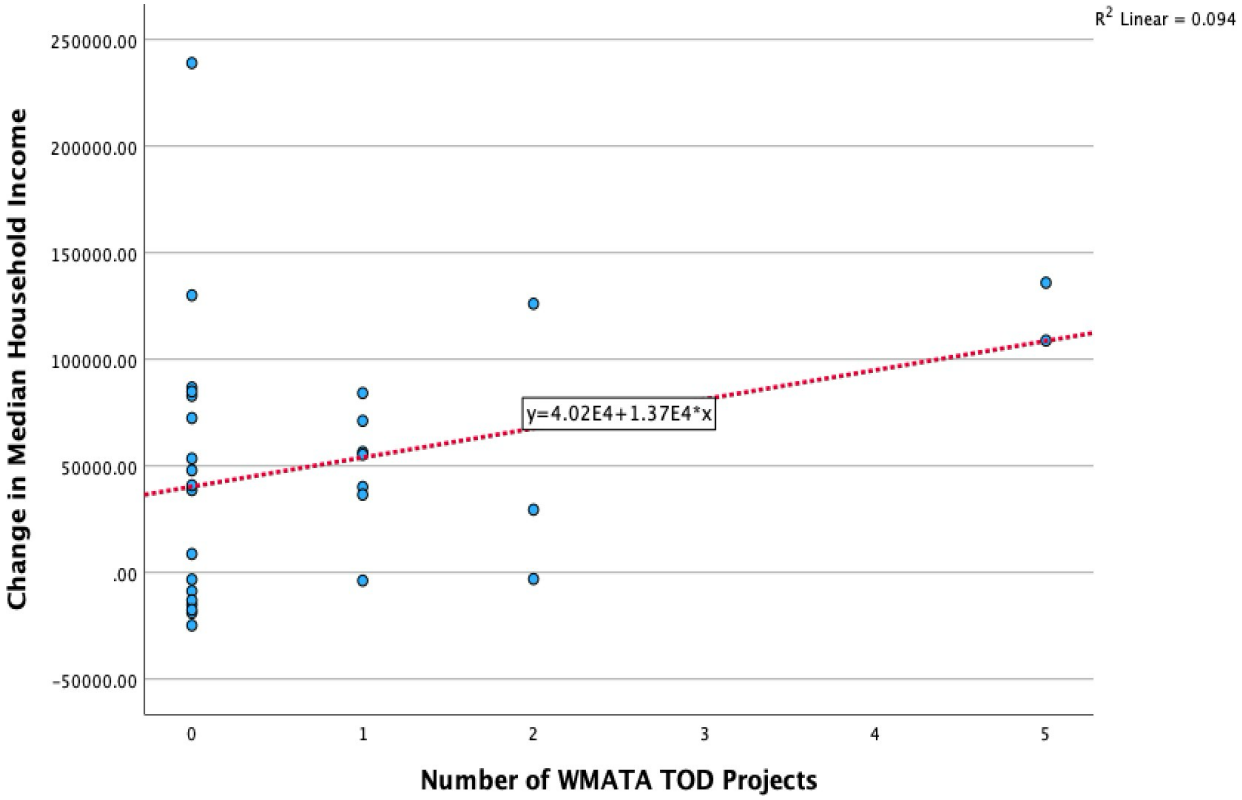

Figure D: Change in % in poverty, by Number of WMATA TOD Projects