Article

Data-Driven Approach to Understanding Complex Urban Phenomena: A Preliminary Study on the Gentrification of H Street NE in Washington, DC

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Abstract: Cities are increasingly recognized as complex systems, emerging through conditional and history-dependent urban processes. To understand a complex urban phenomenon to the point where we can act on it, we need a quantitative yet holistic approach. In this paper, we report on a preliminary study on the gentrification of H Street NE in Washington, DC, USA. Popular accounts claim that this started in 2016, with wealthier new residents displacing poorer old residents. When we examined a cross-section of demographic, income, housing, commercial activity, and social activity data, we found a classic gentrification sweeping over H Street NE starting around 2000. These slow changes drove rapid changes in renter proportions and rents in one of the five census tracts making up the community, a wave of church closures, and a sudden doubling of restaurants and nonclassified businesses. Our results suggest that the gentrification of H Street NE is a small messy piece in a broader picture of urban transformation in Washington, DC.

Keywords: complex systems; cities; gentrification; data-driven approach

1. Introduction

According to Smith and Williams, *gentrification* is the "rehabilitation of working-class and derelict housing and subsequent transformation of an area into a middle-class neighborhood" [1]. One of the most famous examples of gentrified neighborhoods is Notting Hill in West London, UK [2]. Early proponents such as Lowry [3], Smith [4], and Altschuler [5] argued that gentrification will benefit the original residents through trickle-down economics. However, scholars like Glass [6], Abrahamson [7], and Slater [8–10] found that gentrification is detrimental to the original communities, since the reconstruction required these communities to be displaced and dispersed. Only recently, Cameron and Coaffee showed the benefits of gentrification, using Gateshead in New Castle, UK, as a positive example [11].

Ultimately, since urban renewal plans must have been developed with good intentions, we should be able to find more (if not all) positive examples of gentrification. When we implement the same things to similar systems but obtain vastly different outcomes, there is a good chance that these are *complex systems* [12–15], in contrast to *regular systems* (which are systems whose behaviors can be accurately described using simple mathematics; see, for example, [16,17]) or *chaotic systems* (which are systems whose behaviors cannot be predicted because of their extreme sensitivity to initial conditions; see, for example, [18,19]). In a nutshell, complex systems are systems described by many variables that interact strongly, conditionally, and nonlinearly. Consequently, without an overall design or designer, these systems can show unexpected behaviors through *self-organization*. These behaviors are

robust because they do not change over a broad range of environmental conditions. We call these *stable regimes* or *phases*. However, a complex system can switch from one stable regime to another if the control parameters vary across critical values. We call these sudden changes from one stable regime to another *regime shifts* or *critical transitions*. Over short times, a complex system's behavior is easy to predict if we know which stable regime it is in. Through the analysis of early-warning indicators, it is even possible to tell whether a complex system is close to a critical transition. However, over a long time, the sequence of stable regimes that a complex system moves through is hard to predict. In fact, small changes to the early sequences of stable regimes lead to very different sequences of stable regimes later on. We call this *contingency* or *history dependence*.

We believe that urban neighborhoods and their communities make up complex systems whose trajectories are history-dependent. If we try to act on them (for improvements or urban renewal), they are highly resistant to change. This is not to say that we have no control over the outcomes of our interventions or that we must accept that we are always playing dice. Recognizing that we are dealing with complex systems is an essential first step because it prevents us from buying into the set narratives of gentrification being negative (or, for that matter, positive). We observe that, in the gentrification studies community, the set narrative is hardly ever questioned. This is not a simple knowledge gap, because it makes us blind to other possibilities. In principle, a narrative should be based on causes and effects distilled from data. This identification of causes and effects has strict requirements on the data used, and also require a proper understanding of the theory of complex systems. In this preliminary study, we illustrate how we can identify chains of causes and effects so to test some narratives and to eliminate others. To begin, we observe that many gentrification studies rely on census data. These are typically 10 years apart (more recently, 5 years apart) and are, at best, snapshots before and after gentrification. Even when other data are included, and a factor analysis is performed on these snapshots, it is only possible to identify correlations between the factors and the outcome, but not the causality. By combining the analysis of data with interviews and surveys of stakeholders, it is possible to establish causes and effects, or, at the very least, to learn the most important decisions. However, self-reporting is susceptible to priming by investigators, and must therefore be performed carefully.

Finally, let us explain how testing gentrification as a complex process restricts the kind of data we can use. Gentrification is rapid because of feedback loops in the process. This means that, from the complex systems point of view, we must distinguish between slow changes (which can potentially be drivers of the changes, i.e., causes) and fast changes (almost always responses to the changes, i.e., effects). See, for example, the discussions by Bunten et al. in their 2024 paper [20]. To achieve this, we need to work with longitudinal data. For the study of gentrification, Atkinson was the first to recognize the value of longitudinal data by combining data from the England and Wales Longitudinal Study with census cross-sectional data from 1981 and 1991 [21]. However, longitudinal data became more commonly used only within the last decade. For example, Ding et al. used the quarterly Federal Reserve Bank of New York Consumer Credit Panel/Equifax data on more than 50,000 adult residents in Philadelphia [22] to study how residential mobility depends on socioeconomic status. Agbai, on the other hand, combined yearly surveys with census data from 1990, 2000, and 2010 to understand health outcomes in gentrifying neighborhoods [23]. These two studies used only one longitudinal dataset; as such, the signal of gentrification was not strong. More recently, Yee and Dennett applied *k*-means clustering on eight variables from the combined longitudinal data on housing transactions, planning permissions, population churn, and census in 2001 and 2011 to detect the following three clusters: (1) gentrifying, (2) incumbent upgrading, and (3) re-urbanization [24]. Unfortunately, they did not plot the variables against time, and did not distinguish between slow and fast changes. These limitations, as well as others, are explained in the review by Easton et al. [25].

In this paper, we showcase a preliminary study of the gentrification of H Street NE, a neighborhood in Washington, DC, USA, and illustrate how a causal narrative can be obtained by applying a complex systems approach onto multiple longitudinal datasets. In Section 2, we start with a survey of the literature relevant to gentrification in Washington, DC before explaining how to think of an urban neighborhood as a complex system. In particular, how such an approach would force us to examine the gentrification phenomenon from the perspective of various datasets. We explain how the true narrative emerges as consistent and compatible with the findings from these different datasets. Following this, in Section 3, we describe a preliminary case study on H Street NE, a neighborhood in Washington, DC, USA, that has recently undergone gentrification. Analyzing demographic data for the community between 2000 and 2019, we found that this gentrification actually proceeded in three waves, the first starting before 2000, the second starting around 2000, and the third starting shortly before 2010. These slow replacements of old poor Black residents (which are more likely to rent) by new rich White residents (who are more likely to buy) drove the monthly rent up sharply in one area, and a sharp spike in the monthly number of home sales in another area of H Street NE. In response to these demographic changes, we also found the slow decline in many businesses serving old residents, and a sudden doubling of restaurants and nonclassified businesses. Finally, we also identified a wave of church closures in 2006 and 2007 as a result of this gentrification. In Section 4, we discuss how these findings compare against the narrative of affluent new residents displacing poor old residents, and suggest how the gentrification of H Street NE is part of a broader urban transformation sweeping over Washington, DC. We then conclude in Section 5.

2. Literature Survey

2.1. Gentrification of Washington, DC

To frame our findings in Section 3, let us examine the literature on gentrification in Washington, DC, which started in the northwestern part (see Figure 1.1 in Baqai's Master's thesis [26]). In this literature, the dominant narrative is wealthy new residents (usually White) displacing poor old residents (usually Black) [27–31]. Many studies document such displacements' human and cultural costs [32–36]. Given that many urban renewal projects were carried out under the HOPE VI program, which encourages the demolition of existing housing stock for re-development [37], it is entirely possible that this narrative is correct in some neighborhoods. Indeed, many scholars have called for equitable development to combat the undesirable outcomes of gentrification [38–41]. However, it is also conceivable that the gentrification of other neighborhoods proceeded differently.

In a recent study by Richardson et al. [42], they first identified neighborhoods eligible for gentrification. These were the neighborhoods where the home values and family incomes in 2000 comprised the lowest 40th percentile in their metropolitan area. Next, they checked if education levels, home values, and incomes had increased from 2000 to 2013 to decide if gentrification had occurred. Finally, in gentrified neighborhoods, they checked whether racial and ethnic displacement had occurred over the same period. Based on their findings, New York City was the most gentrified by sheer volume. Still, Washington, DC had the most significant proportion of eligible neighborhoods gentrified. Citing the dissolution of the Lincoln Temple United Church of Christ due to the rapid decline in their congregation as an example of "extreme and unnecessary cultural displacement", Richardson et al. avoided discussing the elephant in the room: out of 11,196 neighborhoods across the USA eligible for gentrification in 2000, 1049 were gentrified in 2013, but the racial displacement was seen in only 232 of them. What happened to the remaining 817 gentrified neighborhoods? Were there no displacements in these? Or was the incoming racial mix like the outgoing one? Indeed, it is not clear that the Black population loss was due entirely to displacement rather than a combination of death and displacement.

This suggests that gentrification is a complex process [43]. Indeed, in a case study on the Mount Pleasant district in Washington, DC, Riely found that, while the gentrification

there led to a displacement of the Black population, the commercial landscape remained unchanged [44]. Through surveying 87 respondents and selecting 8 to follow up with in-depth interviews, Riely found that the new residents were just as keen as the old residents to preserve the retail culture in the district. In this paper, we are not the first to suggest that the gentrification of urban neighborhoods is a complex process. Beauregard did so in his 1986 book chapter [45]. Writing at a time when the Santa Fe Institute was two years old and complex systems science was still not well understood, Beauregard identified the essence of self-organization, emergence, and contingency brought about by the conditional interactions between different stakeholders.

2.2. Cities as Complex Urban Systems

When a complex system is in a stable regime, the values of some of its variables would be large (and changing slowly), while the values of its other variables would be small (and changing rapidly). It is also possible for some of these significant and slow variables to exhibit cyclical variations, in which case the relevant quantities would be the amplitudes of these cyclical variations and their periods. If the complex system in question undergoes a critical transition to another stable regime, some large and slow variables would become small and fast. In contrast, some small and fast variables would become large and slow. These changes are individually sudden, but over the whole cross-section of variables, the switching might be earlier in some variables and later in other variables. We call this spread in switching times a *cascade*. The sequence of variables from the earliest to the latest in the cascade tells us how different variables are causally connected. We can develop a consistent action plan for this complex system only after we understand the causal relations between the variables.

In his widely read book, *Scale*, on cities as complex systems [46], West introduced readers to the concept of scaling, which is a characteristic signature of diverse, complex systems, such as financial markets, ecological systems, biological systems, social systems, and, naturally, urban systems. For urban systems, we can quantify this scaling behavior in terms of a scaling exponent $\beta = 0.15$. In general, when we double the population of a city (from N to $2N$), we also double the number of residential units (from H to $2H$). West calls this *linear urban scaling*. However, the number of gasoline stations, the total length of roads, electricity transmission lines, water pipelines, and the energy consumed do not double when we double the size of a city. Instead, when the population of the city is doubled (from N to $2N$), these quantities increase only $2 - \beta = 1.85$ times. West calls this *sublinear urban scaling*. West and co-workers also discovered *superlinear urban scaling* in cities, whereby quantities such as economic productivity, the number of patents, cases of AIDS, the number of educational facilities, and the crime rate increase by a factor of $2 + \beta = 2.15$ when we double the size of the city. The reason behind this scaling is the self-organization of urban systems into hierarchies of places. This was recognized as early as 1933, when Christaller proposed his *central place theory* to explain the economic network of towns and villages surrounding large cities [47]. This theory later became the first scaling law established in urban economics [48], even though it assumes a scaling exponent different from what West and co-workers measured in the real world. This discrepancy prompted Bettencourt to develop a modern theory on the network origin of urban scaling [49–51]. Subsequent studies on many regions worldwide over the last 10,000 years suggest that urban scaling existed even for very early cities [52–54], implying it is not just a modern phenomenon.

Bettencourt's theory of urban scaling tells us how cities self-organize and how this self-organization evolves as cities grow. Unfortunately, it is difficult to use the theory to predict what happens when we intervene in developing specific neighborhoods. For this, we need to turn to the theory of critical transitions in complex systems, which is convincingly demonstrated by Scheffer's experiments on shallow lakes in the Netherlands [55–62]. These became murky because of *phytoplankton* blooms (human-induced eutrophication), which led to the decrease in submerged vegetation, leading further to phytoplankton grazers such as *Daphnia* becoming vulnerable to predation by fishes. Once a lake reaches this

state, it is difficult to make it clear again because the fish keep the *Daphnia* population low. Understanding that the fishes were in their way, Scheffer and co-workers moved them to a separate location to allow *Daphnia* to proliferate and keep the phytoplankton population under control [57]. Eventually, the lake cleared up and the fish could be reintroduced. The moral behind this story is that a significant 'energy' barrier separates the lake's murky and clear states, making it extremely difficult to reverse the eutrophication. On the other hand, it is easier to first bring the system to a fishless state, within which the lake becomes clear, before reintroducing the fish. Similar examples can be found in coral reefs, woodlands, deserts, and oceans. Therefore, we suspect that urban processes and states can be similarly manipulated.

In fish-filled lakes, interventions can produce puzzling outcomes because positive and negative feedback loops juxtapose causes and effects. This is even more so for urban systems, where we find feedback loops between the network of networks or multilayer networks that they self-organize into. Fortunately, we now understand a great deal about how a disturbance can grow quickly in a single network layer [63,64] and spread to other network layers in the form of cascades [65–71]. If we can time the cascades from the earliest to the latest, we can identify the cause of the whole cascade and the most accessible paths to propagate along. We attempted this in Section 3, where we describe the datasets used and how we analyzed them.

2.3. Main Knowledge Gap and Research Questions

The standard narrative of negative gentrification is the displacement of poor old residents by rich new residents, who reshape the community culturally, economically, and socially. Accepting this set narrative (or the narrative of positive gentrification) unquestionably blinds us to other possibilities and prevents us from identifying the causes and effects, as well as testing them in our data.

After collecting a reasonable cross-section of longitudinal data, we apply our understanding of the theory of complex systems to identify slowly changing variables as potential causes and rapidly changing variables as effects. Then, if possible, we construct a narrative based on the sequence of causes and effects distilled from the data.

3. Materials and Methods

3.1. History and Gentrification of H Street NE

According to Vincent S. Morris, who wrote for the *Washington Times* [72], H Street NE used to be the second largest commercial district after downtown Washington, DC. It was burnt down during the Racial Riots of 1968, triggering an exodus of a significant proportion of its resident population (78,400 in 1980 to 72,100 in 1990). In the long period of neglect that followed, criminal activities increased, creating a negative feedback loop that further exacerbated the state of the neighborhood. Many of the remaining residents relied on public assistance to survive from month to month.

Since then, there have been many attempts to revitalize the neighborhood, including the organization of an H Street NE Festival, which started in 1987, with only 500 residents attending. In 2013, more than 100,000 residents attended the event, and the 2014 edition was expected to have 125,000 attendees [73]. In 2003, a USD 200M project to bring back the street cars between Union Station and Benning Street NE was also announced [74]. Streetcars started running along H Street NE in 1862 [75] and ended operations in 1962 [76]. Construction started in 2006, and the line became operational in 2016 [77]. Unfortunately, it is difficult to measure how much these attempts have contributed to the present vitality of the H Street NE neighborhood.

Starting in 2016, reports emerged in the media and social media on the gentrification of H Street NE. In [78], the unnamed author started his blog by complaining about the many emails he had received about gentrification in Washington, DC. Noting the defiant mood of residents with their hashtag #iwillnotbemoveddc, the author remembered an earlier series of conversations on 14th Street and wondered whether it was already too late

to talk about the gentrification of H Street NE. In an article published in *The Guardian* [79], the author Uzodinma Iweala recounted his childhood experiences after being born in 1982 into a Washington, DC that was 70% Black, nicknamed "Chocolate City". He then painted a picture of how the racial mix changed (a decrease in the Black population by 7.3%, an increase in the White population by 17.8%, and an undisclosed increase in the Hispanic population) under Anthony Williams, who, as mayor of Washington, DC from 1999 to 2007, attracted investment and new residents to the city. While visiting H Street NE, Iweala spoke to residents who assumed that he was there to buy a house, because the only visitors they have seen are those interested in the cheaper real estate of fringe communities. Ending his article in a strong sense of resignation, Iweala declared the changes he saw along H Street NE as 'cultural erasure'.

Finally, through a mixed text and photographic essay [80], Joseph Young told the story of H Street NE before and after gentrification. When he first moved into H Street NE in 1994, it was a terrible place to live. Crime was rampant and drug addicts frequently broke into homes to steal. If an apartment was unoccupied, drug dealers would frequently use it as a base for their drug transactions and parties. As such, many homes along H Street NE have steel bars in front of their doors and windows, making them look more like prisons than abodes. Wanting to protect his family and neighborhood, the author had a run-in with drug dealers, who harassed and threatened him daily. Fortunately, the police acted after that, and the drug dealers were arrested and jailed. However, Young feared he would not survive the gentrification, as upwardly mobile families started moving into his neighborhood, causing the rent to skyrocket and forcing his neighbors to relocate. In all of these accounts (amongst many others), the dominant narrative is the arrival of wealthy new Millennial families displacing the poorer old Baby Boomer residents.

3.2. Analyses of Datasets Relevant to the Gentrification of H Street NE

If the above narrative is correct, and there was indeed a displacement of old residents by new residents, we would expect to see changes in the following five data types: (1) demographics; (2) income; (3) home sales, home price, and rent; (4) commercial activities; and (5) social and cultural activities. In the first data type (demographics), as the old residents were mostly Black, the new residents would be Whites and Hispanics. If the new residents hold better jobs, the gentrification will also appear in the wealth and income data (the second data type). If the demographic change is sudden, we will observe a jump in home sales, home prices, and rents (the third data type). Moreover, there is frequently also a difference between the new and the old residents in how they spend their money (the fourth data type) and free time (the fifth data type).

If all of these changes are slow, it would be difficult to identify the causes and effects. Fortunately, the theory of critical transitions in complex systems tells us that a *response variable y* can change suddenly when it is coupled to a slowly changing *control variable x*. We can think of the slow change in x (*some* of which can be thought of as *causes*) as the result of a slow change in the broader environment. For it to experience a sudden change, the response variable y (*all* of which can be understood as *effects*) must, in general, be a nonlinear function of x. This nonlinear dependence on x can arise because of the existence of feedback loops, which keeps y more or less constant under small changes to x. A sudden change in y then occurs when x attains a critical value x_c. Furthermore, a response variable y_1 that undergoes a sudden change earlier than another response variable y_2 can potentially be a cause for the latter. Therefore, by accurately timing the sudden changes in the response variables, we can obtain a *chain of causes and effects* in response to an ultimate cause. From the theory described above, we see that sudden changes do not occur in simple systems.

First, let us look at the demographic data (with a breakdown into races) extracted from the censuses of 1990, 2000, 2010, and 2020. As we can see from Table 1, the Black population along H Street NE has been decreasing over the years. This decrease was the most rapid between 2000 and 2010. We also see that, between 2000 and 2020, the Black population that was lost was primarily replaced by the White population, although there was also

a slight loss in the White population between 1990 and 2000. On the surface, these data are consistent with a picture of racial replacement accompanying gentrification. However, we must be very careful with snapshots taken 10 years apart. It would also be important to confirm that the old Black residents are older in age, while the new White residents replacing them are younger in age.

Table 1. Breakdown of the population into races, obtained by combining the census tracts making up H Street NE, from the census years 1990, 2000, 2010, and 2020.

Year	Black		White		Asian		Hispanic	
	Population	Change	Population	Change	Population	Change	Population	Change
1990	9009	-	3218	-	104	-	264	-
2000	7337	−1672	2980	−238	157	+53	333	+69
2010	4669	−2668	6527	+3547	334	+177	521	+188
2020	3720	−949	10594	+4067	931	+597	1235	+714

Fortunately, we found higher resolution data at https://data.census.gov. Here, we find yearly data starting in 2010 (accessed on 1 September 2024), in addition to the censuses every 10 years. More importantly, these data exist at the level of census tracts, which comprise several city blocks. In Washington, DC, five census tracts (83.01, 83.02, 84.02, 84.10, and 106.02) have H Street NE as one of the boundaries. In Figure 1, we show how the populations (by race) of the five census tracts change from 2010 to 2019, and also how they compare against the populations (by race) in 2000. As we can see, census tracts 83.01 and 83.02 had White majorities in 2000, and these majorities became larger over 2010 to 2019. In contrast, census tracts 84.02, 84.10, and 106.02 had Black majorities in 2000, and we can see the proportions of the White population increasing over 2010 to 2019. This change was most pronounced in census tract 106.02, as its total population tripled between 2000 and 2019. The total populations of the other four census tracts remained more or less constant (or grew slightly in the case of census tract 83.02).
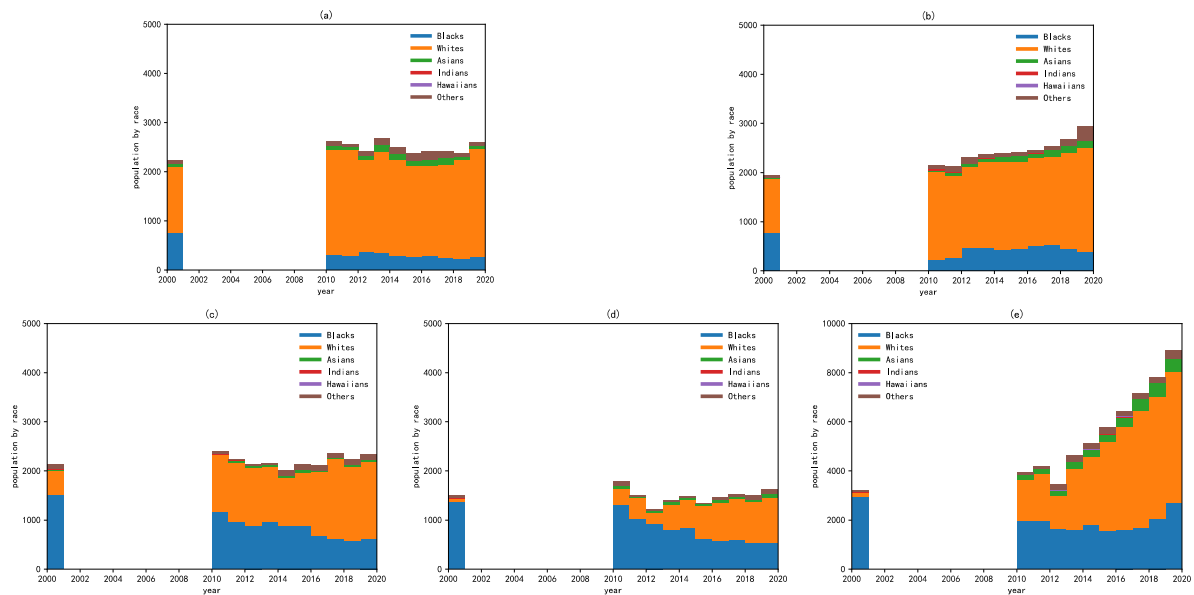

Figure 1. Breakdowns of the population by race for census tracts (**a**) 83.01, (**b**) 83.02, (**c**) 84.02, (**d**) 84.10, and (**e**) 106.02 over the years 2010 to 2019 compared against these breakdowns in 2000. In these stacked bar charts over the years, the numbers of Black people are shown in blue, the numbers of White people are shown in orange, the numbers of Asian people are shown in green, the numbers of Indian people are shown in red, the numbers of Hawaiian people are shown in purple, and the numbers of Others are shown in brown.

Besides the breakdown into races, the census data from https://data.census.gov can be further broken down into sex and age groups (accessed 31 August 2024). In Figure 2, we show the age structures of the populations of the five census tracts as they evolve over 2010 to 2019 benchmarked against the age structures in 2000. In 2000, the most populous age group was 35 to 44 years for all five census tracts. If we take into consideration the sizes of the age groups (5 years for 20 to 24 years, 25 to 29 years, and 30 to 34 years, and 10 years for 35 to 44 years, 45 to 54 years, 55 to 64 years, 65 to 74 years, and 75 to 84 years), we see that the populations of all five census tracts were predominantly middle-aged (30 to 44 years). More importantly, for all five census tracts, the population pyramids are clearly separated into adults and juveniles by the dips seen in the college-going age group. Between 2010 and 2019, census tracts 83.01 and 83.02 started out without the juvenile sub-distribution, but recovered it at the end of the period. By 2019, these two census tracts became overwhelmingly White. On the other hand, census tract 84.10 started out with a Black juvenile sub-distribution, but gradually lost it over time. The 84.02 and 106.02 census tracts had no juvenile sub-distributions over this period.

In 2000, the 84.02, 84.10, and 106.02 census tracts had Black majorities. By 2019, these census tracts also had White majorities. We can see this transition from Black-dominated to White-dominated over the years 2010 to 2019. For the 84.02 and 106.02 census tracts, the White populations not only do not reproduce (no growth in the juvenile sub-distribution), they also do not appear to age in place (increasing numbers of White populations in older age groups). In contrast, for the 84.10 census tract, the transformation began in 2010 (or shortly before) with the arrival of White populations between 25 and 44 years of age. These are likely to be young or middle-aged White families, because they were accompanied by a sizeable group of White people below 5 years of age. Over time, more of such families arrived, adding to the juvenile sub-distribution. More importantly, we see the signs of those who arrived earlier aging in place.

Technically, there is no gentrification if old residents are replaced by new residents with a similar wealth and income, even if there is racial displacement. Therefore, it is important to next check for any change in income level as the old Black residents are replaced by the new White residents. Income data are also available at https://data.census.gov (accessed on 1 September 2024), but only for Black and White populations. As we can see in Figure 3, there is a significant dispersion between the mean and median incomes over the five census tracts. Averaging over the five census tracts, we see that the mean and median incomes of Black households remained more or less constant at the levels of USD 30,000 and USD 60,000 per annum, respectively. This tells us that there are many Black household incomes that are far below USD 30,000 per annum. When the same averaging is performed over the five census tracts for the mean and median incomes of White households, we see that they increased from USD 60,000 per annum to USD 85,000 per annum, and from USD 110,000 per annum to USD 160,000 per annum. Whether we use the mean or the median, the income of White households was two times that of Black households in 2010, to almost three times in 2019. Even in 2000, the median income of White households was already twice that of Black households.

Figure 2. Breakdowns of the population by race and age for census tracts (**f**) 83.01, (**g**) 83.02, (**h**) 84.02, (**i**) 84.10, and (**j**) 106.02 over the years 2010 to 2019 compared against (**a–e**) in 2000. In these stacked bar charts over the years, the numbers of Black people are shown in blue, the numbers of White people are shown in orange, the numbers of Asian people are shown in green, the numbers of Indian people are shown in red, the numbers of Hawaiian people are shown in purple, and the numbers of Others are shown in brown. In this figure, axes labels have been omitted for clarity. In Appendix B, we show the breakdowns of the population by race and age for the five census tracts, with detailed labels, from 2010 to 2019.
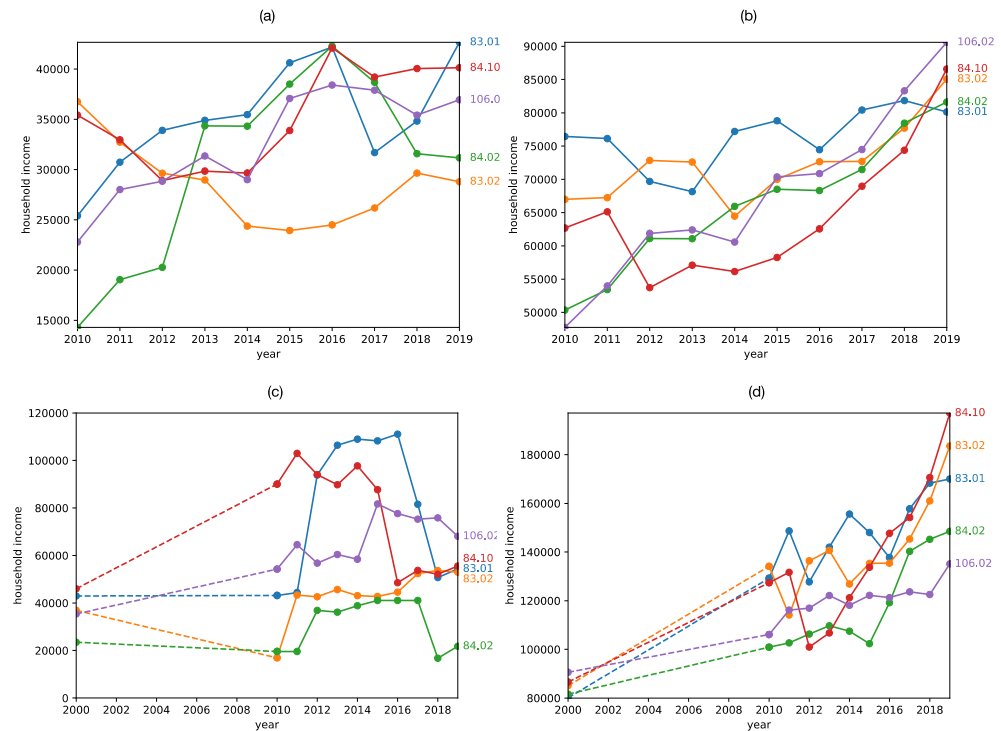
Figure 3. Mean household incomes for (**a**) Black and (**b**) White populations, and the median household incomes for (**c**) Black and (**d**) White populations in the five census tracts between 2010 and 2019. Median incomes are available in 2000. In this figure, the household incomes are shown in blue for census tract 83.01, in orange for census tract 83.02, in green for census tract 84.02, in red for census tract 84.10, and in purple for census tract 106.02 over the years.

So far, we have seen slow changes in the demographics and household incomes. In many different accounts, gentrification is surprising because of its speed. This means that, in addition to the slowly changing variables, we should also see rapid changes in other variables. One sector where we might see this would be in home sales, home prices, and rents. We therefore downloaded home sales data from https://opendata.dc.gov. Because of the way the data are organized in this database, we needed to combine information from the following two datasets: (1) Integrated_Tax_System_Public_Extract_Property_Sales (accessed 19 October 2017), which contains addresses and property types, but only for the last transaction date and price of each property; (2) Tax_System_Property_Sales_(CAMA) (accessed 28 August 2024), which contains the dates and prices of all sales, but not the addresses and property types. The first dataset contains 105,594 properties over the whole of Washington, DC, while the second dataset contains 406,567 transaction records. To extract home sales and home prices in a given neighborhood, we filtered out residential properties in the neighborhood in the Integrated_Tax_System_Public_Extract_Property_Sales dataset and saved their Square Suffix Lot (SSL). The SSL uniquely identifies a given property in Washington, DC. We then extracted transaction dates and prices associated with the list of SSLs from the Tax_System_Property_Sales_(CAMA) dataset. In Figure 4, we compare the monthly sales of homes between 1993 and 2024 along H Street NE and three other streets.

In Figure 1a, we see that the monthly home sales along G Street NE remained more or less constant from 1993 to 2024. In contrast, we see from Figure 1b that there were two peaks in the monthly sales of homes along H Street NE, with the first in 2001 and the second in 2016 (the year that media reports started to highlight the gentrification along H Street NE). Outside of these two periods, the monthly sales of homes along H Street NE were also more or less constant. Figure 1c shows that the monthly home sales along I Street NE were also more or less constant, except for four peaks in 2002, 2010, 2014, and 2018. In particular, the spike in June 2010 consisted of 434 transactions. This is not an error in

the data but is due to the sales of single-family units in the Senate Square condominium (straddling 201 to 225 I Street NE, Washington, DC, 20002, USA) that was completed in 2009. We compared H Street NE to these two streets because they are one block away, one to the north and the other to the south. In Figure 1d, we also show the monthly sales of homes along W Street NW, which is about 4 km northwest of H Street NE. This also shows a peak in the number of monthly sales in 2016. As mentioned in the accounts at the end of Section 3.1, the gentrification of Washington, DC, attributed to the policies of former mayor Anthony Williams, is a broader phenomenon not limited to H Street NE but starting earlier in multiple locations elsewhere.
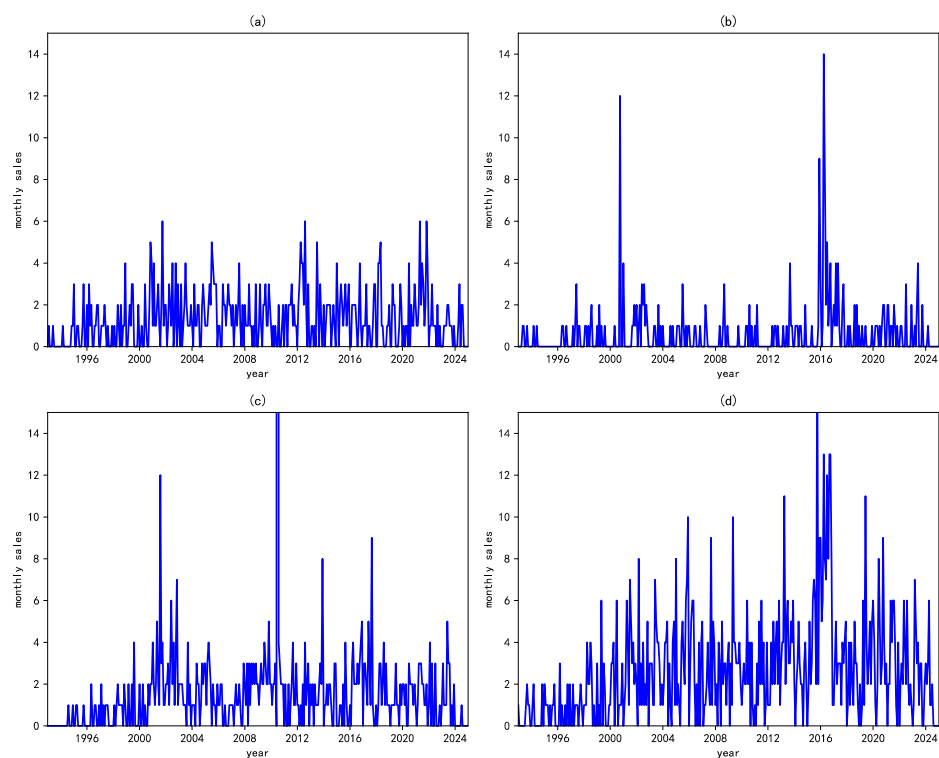

Figure 4. Monthly sales of homes along (**a**) G Street NE (179 residential properties and 507 transactions), (**b**) H Street NE (105 residential properties and 239 transactions), (**c**) I Street NE (624 residential properties and 962 transactions), and (**d**) W Street NW (417 residential properties and 1028 transactions) between 1993 and 2024.

In Figure 5, we show the median home prices along G Street NE (Figure 5a), H Street NE (Figure 5b), I Street NE (Figure 5c), and W Street NW (Figure 5d). On rare occasions, we find home prices exceeding USD 1 million, when the typical home prices were significantly lower. If we ignore these rare USD 1 million transactions and fluctuations in the home price, we see that home prices were increasing over the years along G Street NE, H Street NE, and I Street NE. In fact, the average rates of increase in the home prices were similar in these proximal locations. More importantly, there appears to be no sudden changes in the rates of increase in home prices in these locations, apart from the bump between 2004 and 2008, when home prices came close to or pass USD 0.5 million. Judging from the timing, it is plausible that this bump is a reaction to subprime lending, where homeowners with poor credit ratings could buy homes and finance their mortgages at a subprime rate for two to three years before the prime rate kicked in. Not surprisingly, subprime homeowners who could not pay their mortgages at the prime rate defaulted en masse in 2006 and 2007 [81], leading first to the Subprime Crisis and then the Global Financial Crisis.
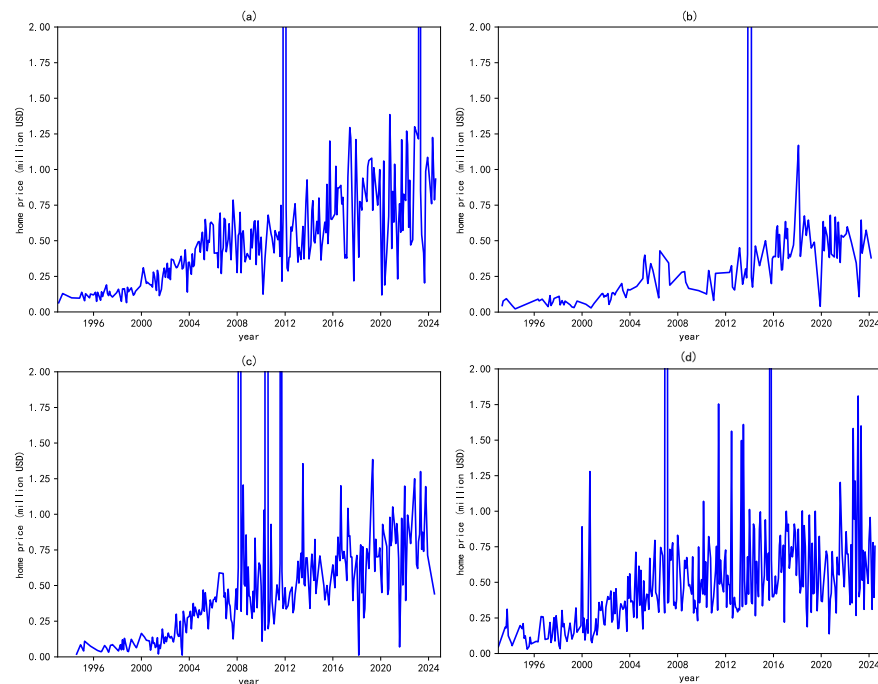
Figure 5. Home prices along (**a**) G Street NE (179 residential properties and 507 transactions), (**b**) H Street NE (105 residential properties and 239 transactions), (**c**) I Street NE (624 residential properties and 962 transactions), and (**d**) W Street NW (417 residential properties and 1028 transactions) between 1993 and 2024.

Next, we examine the rental data for H Street NE. Unlike buying a home, which is a hard decision to make because of high home prices, renting is a cheaper alternative. Therefore, we might expect rents to be more responsive to structural changes in the housing market if there is not a huge supply of vacant homes waiting to be rented. In Figure 6a, we show the rental vacancy rate for the whole of Washington, DC. As we can see, between 6% and 8% of rental units were vacant between 2010 and 2020. When we checked the data downloaded from https://data.census.gov for the five census tracts (accessed on 1 November 2024), we found that, locally along H Street NE, the rental vacancy rate was higher, between 5% and 20%, as shown in Figure 6b. After checking the untapped supply of rental homes, we next checked the renter proportion for the five census tracts, as shown in Figure 6c. This tells us that a new household arriving in H Street NE is more likely to rent a home instead of buying one, except in the 106.02 census tract, where less than 20% of households were renting. Strangely, we see from Figure 6d that the rents in the 106.02 census tract were skyrocketing, while the rents in the other census tracts remained more or less constant.

A neighborhood that has undergone gentrification is also easy to identify if the gentrification is accompanied by a sudden change in its commercial landscape. We should be able to see this using business registration data. Indeed, when we downloaded business registration data from the U.S. Historical Businesses Database in Reference USA (https://www.dclibrary.org/referenceusa, last accessed on 8 August 2024) and compared the number of registered businesses along H Street NE for the year 2003 (long before the 2016 gentrification) and 2016 (during the gentrification), we saw stark differences. Before the gentrification, H Street NE was known as the hair and nail capital of Washington, DC, and was lined with many beauty salons [46]. This fell dramatically during the gentrification. After the gentrification, the number of dine-in restaurants increased dramatically. These facilities eliminated the carry-out food establishments that existed before the gentrification. There was also a significant increase in the number of nonclassified establishments. Some of these were law firms; others had names like 'Touche' and 'Escape the Classroom', 'New Cup City', 'Washington Winter Show', 'Phase II Academy', and 'Fresca'. They were probably

establishments offering entertainment or child-enrichment classes. All in all, the change in the commercial landscape was dramatic when we compared what existed in 2003 with what was found in 2016.
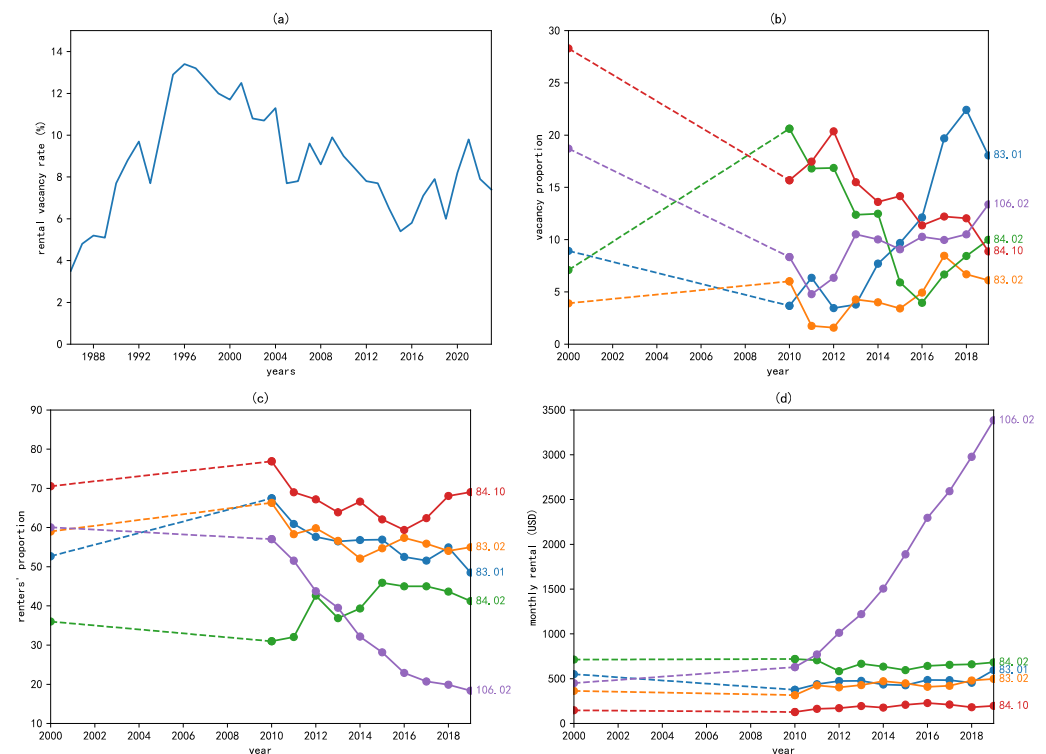

Figure 6. (**a**) The rental vacancy rates in Washington, DC over the period from 1986 to 2023 using data downloaded from the Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org/series/DCRVAC, accessed on 2 August 2024). (**b**) The rental vacancy rates along H Street NE over the period from 2000 to 2019, shown separately for the five census tracts that H Street NE is part of. (**c**) The renters proportions for the five census tracts, between 2000 and 2019. (**d**) The monthly rental in USD for the five census tracts between 2000 and 2019. In this figure, the rental vacancy rates (**b**), the renter proportion (**c**), and the monthly rental incomes (**d**) are shown in blue for census tract 83.01, in orange for census tract 83.02, in green for census tract 84.02, in red for census tract 84.10, and in purple for census tract 106.02 over the years.

However, changes in the commercial landscape are, in general, lagging indicators of gentrification, meaning they are the effects of gentrification and not the cause. Also, not all of the businesses showed sudden changes. To illustrate this, we downloaded business registration data for all years between 2003 and 2019, and selected five business types that changed slowly, to contrast against two business types where we found rapid changes. In Table 2, the slowly changing business types are beauty salons, carry-out foods, liquor retail, men's clothing, and women's apparel. The numbers of these businesses decreased more or less steadily from 2003 to 2019. In contrast, the numbers of restaurants and nonclassifieds increased suddenly in 2012 and 2013, respectively.

When we tracked the registrations from 2003 to 2019, we found the beauty salons telling a sad story of irreversible decline. In 2003, there were 26 beauty salons. Some of them closed within a year, others within two years. Those that failed were replaced by a succession of 15 beauty salons, most of which also closed after a year or two. By 2019, only two beauty salons that were in business in 2003 remained, along with one that started in 2006. Over the 17 years that we tracked, only nine beauty salons were in business for 10 years or longer, serving the old residents. Starting in 2013, six new beauty salons started, presumably serving the new residents. Two of these were still in business in 2019. Three other business categories disappeared completely at the end of the 17 years we

tracked. These were carry-out foods, men's clothing, and women's apparel. There were few of them to begin with in 2003, with three carry-out food, four men's clothing, and four women's apparel establishments. Carry-out food and men's clothing establishments closed down one by one over the years, and appeared to be completely gone by 2011 and 2013, respectively. There was a short revival of women's apparel establishments between 2010 and 2013 because of the arrival of two new stores owned by Asian Americans, but even these stores shuttered in 2017.

Table 2. Numbers of registered businesses along H Street NE over the years from 2003 to 2019. For the sake of contrast, we included beauty salons, carry-out foods, liquor retail, men's clothing, women's apparel, whose numbers changed slowly, nonclassifieds, and restaurants whose numbers showed a sudden jump over this period.

Business Types	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beauty Salons	26	26	24	18	17	12	11	10	9	9	11	13	9	8	7	8	5
Carry-Out Foods	3	3	3	2	2	2	2	1	0	0	0	0	0	0	0	0	0
Liquor Retail	6	6	5	5	6	5	4	4	3	3	3	3	2	2	2	2	2
Men's Clothing	4	4	4	2	2	2	2	1	1	1	0	0	0	0	0	0	0
Nonclassifieds	3	4	6	5	8	8	7	4	6	4	16	14	18	12	16	20	14
Restaurants	13	13	14	17	17	15	19	20	25	31	45	45	47	53	50	52	54
Women's Apparel	4	2	2	2	1	2	2	3	3	3	3	2	2	1	0	0	0

The natural contrast to carry-out food establishments is restaurants. When we tracked the restaurants over the 17 years, we found that the carry-out food establishments did not disappear but instead registered themselves as restaurants, presumably to capture the increasing number of dine-in customers. There are also six pre-gentrification restaurants that are still in business in 2019. Not surprisingly, most of these are low-end restaurants selling sandwiches and fried chicken. The remaining two are higher-end restaurants that had somehow established themselves before the gentrification. To see how strongly gentrification modified the commercial landscape, consider the fact that, between 2003 and 2010, there were on average 16 restaurants in business. This average more than doubled after 2013. This is one of the strongest indicators of gentrification that we have seen so far. More importantly, in this competitive business, most of the new restaurants do not last very long. In Table 3, we show the number of new restaurants identified from the historical business registry. Between 2004 and 2011, there were between three and five new restaurants every year. Of these, typically only one will last beyond three years in business. Between 2012 and 2016, there was a peak in the number of new restaurants per year. There was also a dramatic increase in the success rate of new restaurants, from less than 20% before 2012 to more than 70% after 2012. Successful restaurants after 2012 were higher-end, and also more diverse, offering a range of cuisines from French to Japanese, Mexican, Lebanese, and Ethiopian.

Finally, the social activities before and after gentrification would also be distinct. However, the only data we could obtain on this was church activities because, in Washington, DC, churches must also be registered annually in the business registry. Although these data offer a limited perspective into the social lives of H Street NE residents, we can see from Table 4 an exciting story about the churches themselves. Aside from Adonai Ministry International and the United House of Prayer, which were registered continuously from 2003 to 2016, many churches stopped registering themselves after 2006 and 2007. This suggests a sudden wave of church closures in these two years. In 2012, only two churches remained (Adonai Ministry International and St. John's Church of God), but, in 2013, this number

jumped to five. In addition to Adonai Ministry International and United House of Prayer for All (registered in 2011 and 2013, but not in 2012), and the first registration by Table Church H Street Parish, we also found St. John's Church of God opening a kindergarten. These represented the last struggles by the United House of Prayer for All and St. John's Church of God. Both closed in 2014, even though the kindergarten stayed open until 2016.

Table 3. The number of new restaurants starting along H Street NE in each of the 17 years, and the number of long-lived restaurants starting in each year along H Street NE.

Restaurants	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
New in year	-	4	5	4	3	4	5	5	5	9	15	9	9	8	6	5	6
Surviving $\geq$ 3 years	-	1	1	3	1	1	4	4	5	7	8	7	8	7	5	-	-

Table 4. Churches along H Street NE and the years they were registered in the Washington, DC business registry.

S/No.	Name of Church	Address	Census Tract	Registered
1	Adonai Ministry International	514 H St NE	106.02	2003–2019
2	Born Again Community Baptist	1007 H St NE	84.02	2003–2007
3	Freedom Fellowship Christian	400 H St NE	106.02	2006–2007
4	Greater Light Baptist Mission	326 H St NE	106.02	2003, 2005–2006
5	Newborn Pentecostal Church	1222 H St NE	84.10	2003–2009
6	Spirit of the Living God Christ	1419 H St NE	84.02	2003–2006
7	St. John's Church of God	1301 H St NE	84.02	2003–2014
8	Table Church-H St Parish	1020 H St NE	84.10	2013–2019
9	Third Sun Spiritual Church Inc	1012 H St NE	84.10	2003, 2005
10	United House of Prayer	1314 H St NE	84.10	2003–2011, 2013, 2014

3.3. Timing the Cascading Events

As explained in Section 2, a sudden change in one network layer will propagate as sudden changes in other network layers. Based on the data we collected on H Street NE, we can look for these sudden changes and roughly time them. Sudden changes were found in the total population in census tract 106.02 (contributed mostly by the White population), the annual income of White households, home sales along H Street NE, renter proportions and rents in census tract 106.02, the numbers of restaurants and nonclassifieds, and the number of churches. In chronological order, these were as follows: (1) an increase in the number of home sales along H Street NE in 2001 (in contrast to the steady increase in home prices since the mid-1990s), (2) sharply decreasing rental vacancy and increasing monthly rent in census tract 106.02 before 2010, (3) a wave of church closures in 2006 and 2007, (4) the doubling of the numbers of restaurants and nonclassifieds in 2013 and 2012, respectively, (5) a change from decreasing to increasing renter proportions in census tract 83.01 in 2013, (6) a change in the rate of increase in the White population in census tract 106.02 in 2013, (7) a consistent increase in the incomes of White households starting in 2014, (8) an increase in the number of home sales along H Street NE in 2016, and (9) a change from decreasing to increasing renter proportions in census tract 84.02 in 2016. While there are still gaps in this chronological sequence of events, we can now construct alternative narratives that are different from the 'rich new residents displacing poor old residents' one, as we shall discuss in Section 4.

4. Discussion

Today, we understand a lot more about complex systems, including complex urban systems. Thus, we no longer need to be wedded to only two competing narratives (good gentrification versus evil gentrification). Instead, we can allow objective datasets on a

gentrified or gentrifying neighborhoods to tell the story. Indeed, the chronology of events discovered in Section 3 is more complex than a simple story of wealthy new residents displacing poor old residents. First, we had judged from the demographics shown in Figure 2 that there were three waves of gentrification. Based on the proportions of White people in 2000, we suggested that the first wave of gentrification in census tracts 83.01 and 83.02 started well before 2000, and was more or less complete by 2019. Similarly, we judged that the second wave of gentrification started in census tracts 84.02 and 106.02 started around 2000, and is ongoing. The third wave of gentrification in census tract 84.10 also started around 2000 but progressed slowly compared to the second wave. These changes clearly fit the definition of gentrification as the replacement of poor old residents by rich new ones (Figure 3), and also involved racial displacement.

However, we suggested a pre-2000 start of the first wave of gentrification because we had implicitly assumed that the initial demographics of census tracts 83.01 and 83.02 (and also census tracts 84.02 and 106.02) to be Black-dominated. After comparing the 1990 demographics against the 2000 demographics in Figure 7, we realized this is not the case: the breakdown of population by race and by age was stable over the 1990–2000 decade. This tells us that there was no gentrification before 2000, and only a single wave of gentrification starting around 2000 from different initial race distributions in different census tracts. If this is the case, why did the old residents wait until 2016 to bemoan the gentrification along H Street NE?
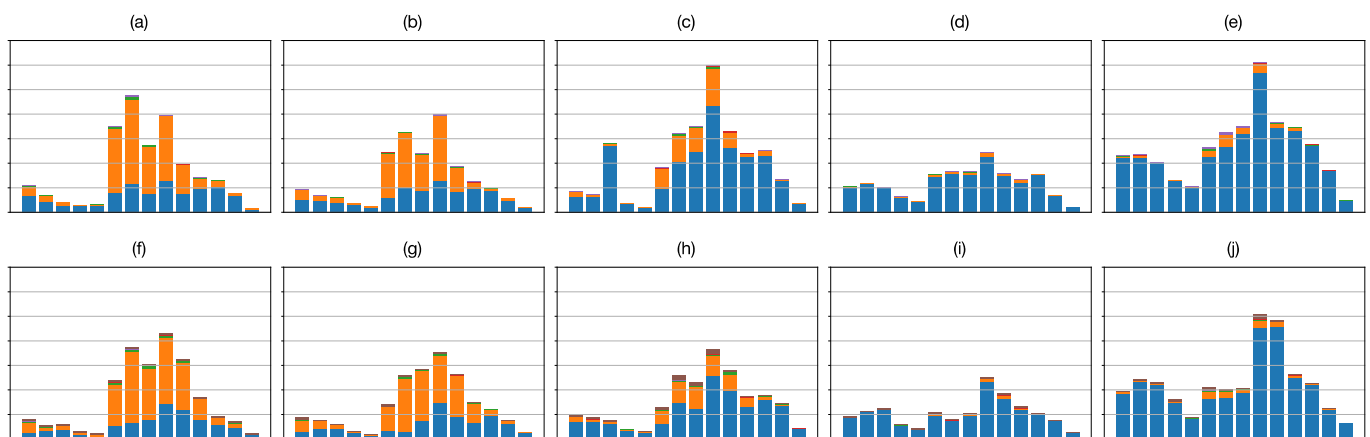

Figure 7. Breakdowns of the population by race and age for census tracts (**a**) 83.01, (**b**) 83.02, (**c**) 84.02, (**d**) 84.10, and (**e**) 106.02 in 1990 compared against (**f–j**) in 2000. In these stacked bar charts over the years, the numbers of Black people are shown in blue, the numbers of White people are shown in orange, the numbers of Asian people are shown in green, the numbers of Indian people are shown in red, the numbers of Hawaiian people are shown in purple, and the numbers of Others are shown in brown. The grid lines are spaced 100 apart, so that the maximum population in each age group can be shown up to 700. In this figure, axes labels have been omitted for clarity. In Appendix A, we show the breakdowns of the population by race and age for the five census tracts, with detailed labels, for 1990 and 2000.

We believe the response to the gentrification of H Street NE is less puzzling if we see it from the lens of complexity science. To begin, the proportion of White to Black populations, and other slowly changing variables, are potential causes. As inputs to gentrification, they are difficult to recognize precisely because they change slowly. On the other hand, we also find variables that exhibit sudden changes at different times in response to the slow changes in the potential causes. As outputs to the gentrification process, these effects are difficult to miss because they are sudden, and because they separate the initial and final states that are very different qualitatively. From this perspective, it is likely that the sudden church closures in 2006 and 2007 was due to the cumulative losses in their congregations in the five census tracts, but specifically in census tracts 83.01 and 83.02. In other words, the

sudden church closures in 2006 and 2007 was in response to gentrification starting around 2000, in addition to other reasons. Another effect of this gentrification was the change from decreasing to increasing renter proportions in census tract 83.01 in 2013.

We also believe that the sharply decreasing rental vacancy and increasing monthly rent in census tract 106.02 before 2010 to be the effects of this gentrification. Other effects include a change in the rate of the increase in the White population in census tract 106.02 in 2013, and a change from decreasing to increasing renter proportions in census tract 84.02 in 2016. Finally, it is tempting to attribute the doubling of the numbers of restaurants and nonclassifieds in 2013 and 2012, respectively, a consistent increase in the incomes of White households starting 2014, and an increase in the number of home sales along H Street NE in 2016 also as effects of the gentrification. Indeed, when we examined the home transaction data for 2016, we found that 26 of these were apartment units in 301 H Street NE (in census tract 83.01), while 8 were apartment units in 1115 H Street NE (in census tract 84.02). Both developments were completed in 2015, with initial apartment sales in 301 H Street NE going for between USD 220,000 and USD 800,000, and those in 1115 H Street NE going for between USD 140,000 and USD 400,000. We cannot find what sat on 301 H Street NE previously, but 1115 H Street NE was previously the site of a Woolworth nickel-and-dime store.

We do not know when developers in Washington, DC became aware of the gentrification sweeping through the H Street Corridor, although it is reasonable to assume that the developments of 301 H Street NE and 1115 H Street NE were their responses to what they perceived as an ongoing demographic change generating demands for their products. In fact, the developers might have the correct picture, since census tracts are artificial divisions created for the purpose of collecting data. The gentrification of Washington, DC did not sweep through the census tracts making up H Street NE in a temporally and spatially uniform manner. We suspect the price levels and housing stocks initially available over the census tracts are the reasons, but verifying this would take another paper of its own.

At this point, let us scrutinize the sudden commercial and social changes associated with the gentrification of H Street NE. As we have noted in Sections 3.2 and 3.3, the numbers of nonclassifieds and restaurants are commercial responses because of their sudden increases in 2013 and 2012, respectively. Here, let us focus on the restaurants. As mentioned in Section 3.2, five of the seven restaurants starting in the early 2000s and remaining in business in 2019 are low-end restaurants offering sandwiches and fried chicken, and Asian take-outs. Not surprisingly, given the depth of the gentrification of the western end (census tracts 83.01 and 83.02) of the H Street Corridor, these surviving restaurants are all found in the eastern, less-gentrified end (census tracts 84.02 and 84.10) of the H Street Corridor. The two high-end restaurants that started in the 2000s are also found in census tract 84.10. In contrast, successful high-end restaurants that started in or after 2013 are more uniformly distributed along the H Street Corridor. This is easy to understand: the richer customers they cater to have greater mobility, so it is less important where the restaurants are situated. More importantly, for the number of restaurants to double after 2013, some commercial locations must be re-purposed. We would expect some of these new restaurants to occupy the space left by the old restaurants that went out of business. This was indeed true for some, using the space left vacant before and after 2003. Others re-purposed the space left vacant by beauty salons, grocers, clinics, automobile repair shops, computer stores, as well as stores left vacant for a long time. There were a number of these long-vacant stores in the eastern half of the H Street Corridor. At least one new restaurant was re-purposed a residential unit, but none occupied any of the closed churches, whose spaces were probably too big. As we can see, gentrification is a messy and erratic phenomenon.

Finally, let us discuss the causes and effects of the 2006–2007 church closures. Unlike their more or less linear interactions with businesses, church congregations involve parishioners interacting with each other, providing strong feedbacks within these congregations. Therefore, instead of the number of businesses decreasing proportionally as the number of

old residents decreases, the nonlinear interactions with feedback prevent churches from closing down just because a few parishioners stop coming. Unfortunately, this also means that the churches close simultaneously as the number of old residents falls below the critical value. From the demographic changes shown in Figures 1 and 2, it is probable that the church closures were due to the effect of demographic changes in census tracts 83.01 and 83.02. Searching through the ProQuest database, we stumbled across the obituaries of a few residents of H Street NE. We even found the obituary of the pastor of one of the closed churches. Unfortunately, most of these obituaries were published in local newspapers that may have been discontinued. They exist as raw scan files, making them difficult to find through automated and systematic searches. We suspected initially that the demographic change was due to the old residents dying, leading to the wave of church closures. Later, we realized that there is no way to distinguish between old residents dying and old residents simply moving away. However, we can be sure that the declining Black population and church closures did not cause the gentrification of H Street NE, because, by 2006/2007, this gentrification had been raging on in census tracts 83.01 and 83.02 for half a decade, and had started in census tracts 84.02 and 106.02.

While it is clear that most of the churches that closed were Baptist or Evangelical with predominantly Black congregations, we were also curious about where the White population who replaced them go to church, or if they attend church at all. This is because Table Church, which is a multiracial, LGBTQI+-affirming church that is likely to cater to the newly arrived Millennial families, was first registered only in 2013. Another important question that is implied by the gentrification starting in the early 2000s is why it takes so long to be noticed. Or, if old residents had noticed it earlier, why did they wait until 2016 to voice themselves? Unfortunately, questions like these cannot be answered using the cross-section of longitudinal hard data analyzed in this paper, even with their high spatial and temporal resolutions. Instead, we need soft data generated by asking current and former community members directly in interviews, focus groups, or surveys. For the decisions that old and new residents have made (to stay, to leave, or to move in), it is important to know what the key influences were so to establish the agency of 'gentrifiers' or the lack of agency on the part of the 'gentrified'. Unfortunately, most of the members of this team are based in Asia and are thus unable to justify using additional resources to study a phenomenon so far away.

Ultimately, the gentrification of H Street NE is part of the broader gentrification of Washington, DC, which started in the northwestern parts of the city and is spreading eastwards and southwards. Instead of studying isolated neighborhoods that have become gentrified or are currently gentrifying, it is important to understand these as parts of a larger whole and to track the spatio-temporal progression of gentrification over the entire city.

5. Conclusions

In this paper, we argued that gentrification is a complex process where causes and effects are linked through cascades. To unravel this causal chain, it is necessary to analyze various datasets, such as demographics, income, home sales, home price, rent, commercial activities, and social and cultural activities. In this preliminary study on the gentrification of H Street NE in Washington, DC, USA, we analyzed a cross-section of the abovementioned datasets to pin the start of the gentrification through H Street NE to shortly after 2000. These slow changes conform to the standard definition of gentrification as the replacement of poor old residents by rich new residents, and was accompanied by racial displacement of Black people by White people. As the demographic change progressed, we identified a sudden wave of church closures in 2006 and 2007, a rapid change in renter proportions and rents in census tract 106.02, a sudden doubling of the numbers of restaurants and nonclassifieds in 2013 and 2012, respectively, and a sudden spike in home sales in 2016. Out of these, we feel that the timing of home sales should be revised to 2011, since the two apartment blocks that contributed to the 2016 sales spike took five years to build. With this revision, the height of the ongoing gentrification of H Street NE becomes consistent around 2010 to

2012, with further gentrification only in the remaining census tract 84.10. Through such a complex systems-inspired approach, we have answered some of the questions about the gentrification of H Street NE, but raised many more questions on the gentrification over the broader Washington, DC area.

Author Contributions: Conceptualization, M.C., A.N. and S.A.C.; methodology, T.-W.Y. and S.A.C.; software, S.A.C.; formal analysis, M.C., A.N. and S.A.C.; writing—original draft preparation, T.-W.Y. and S.A.C.; writing—review and editing, M.C., T.-W.Y., A.N. and S.A.C. All authors have read and agreed to the published version of the manuscript.

Appendix A. Breakdowns of Race and Age in 1990 and 2000
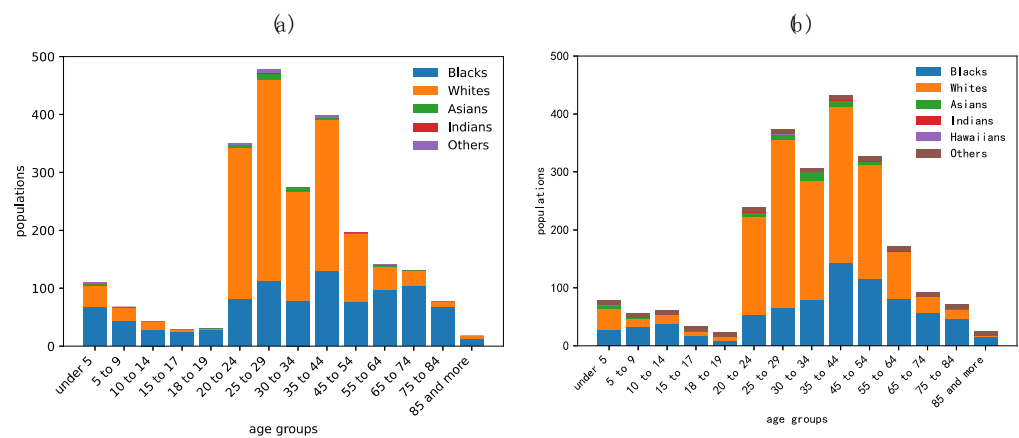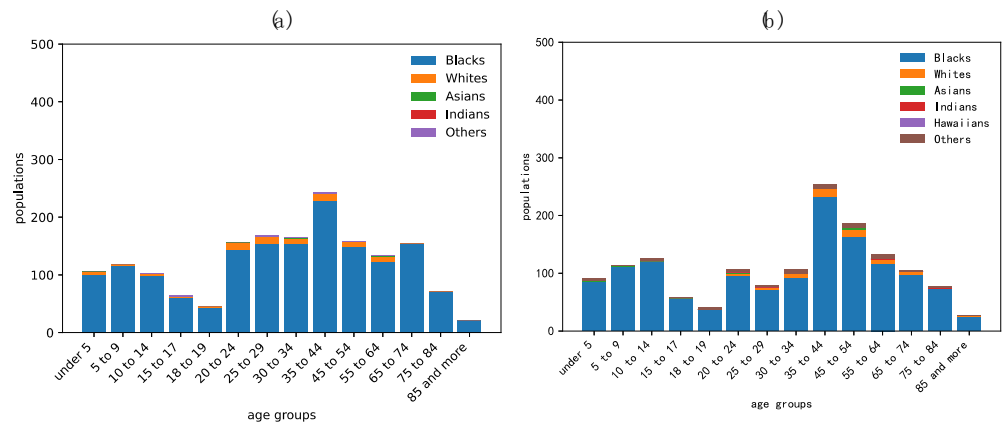

Figure A1. Breakdowns of the population by race and age for census tract 83.01 in (**a**) 1990, and (**b**) 2000.
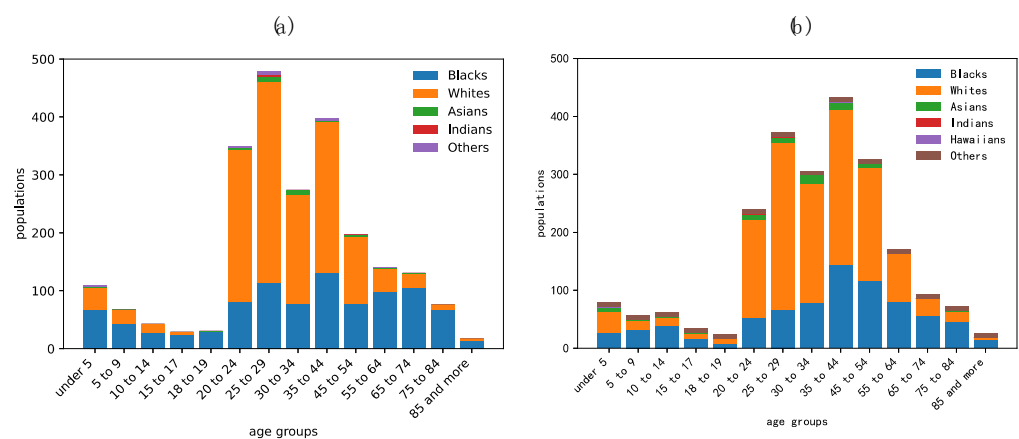
Figure A2. Breakdowns of the population by race and age for census tract 83.02 in (**a**) 1990, and (**b**) 2000.
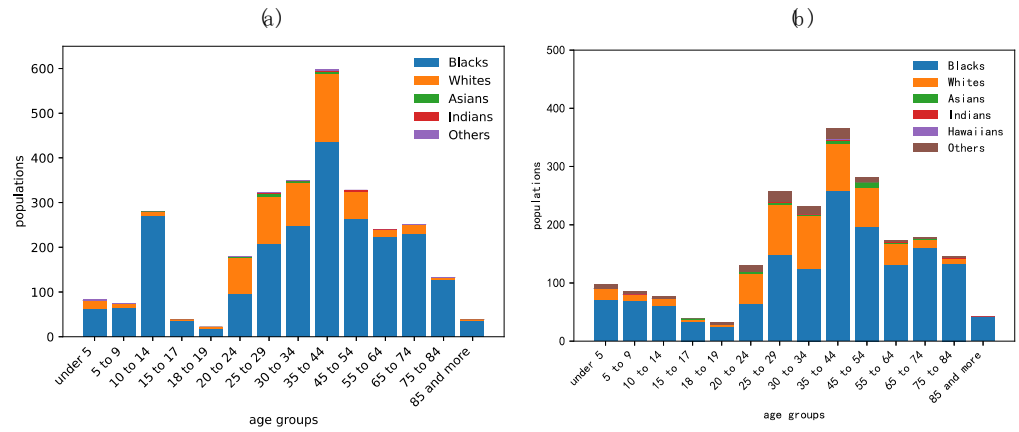
Figure A3. Breakdowns of the population by race and age for census tract 84.02 in (**a**) 1990, and (**b**) 2000.

Figure A4. Breakdowns of the population by race and age for census tract 84.10 in (**a**) 1990, and (**b**) 2000.
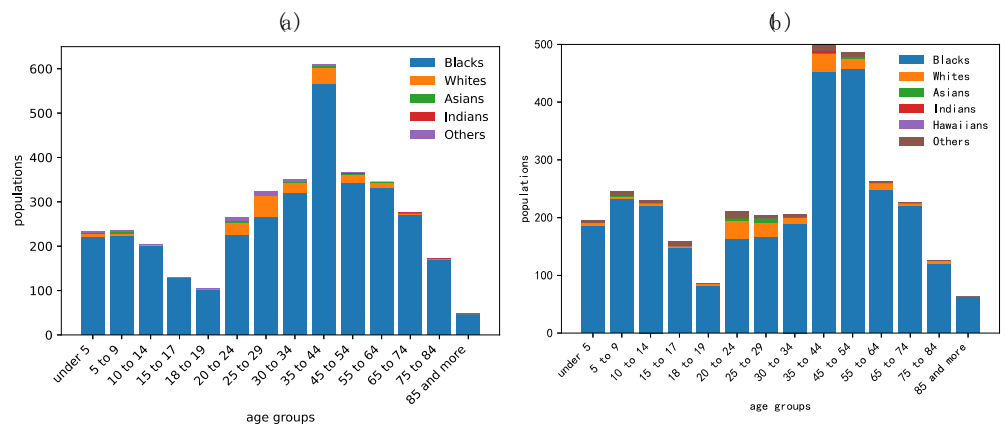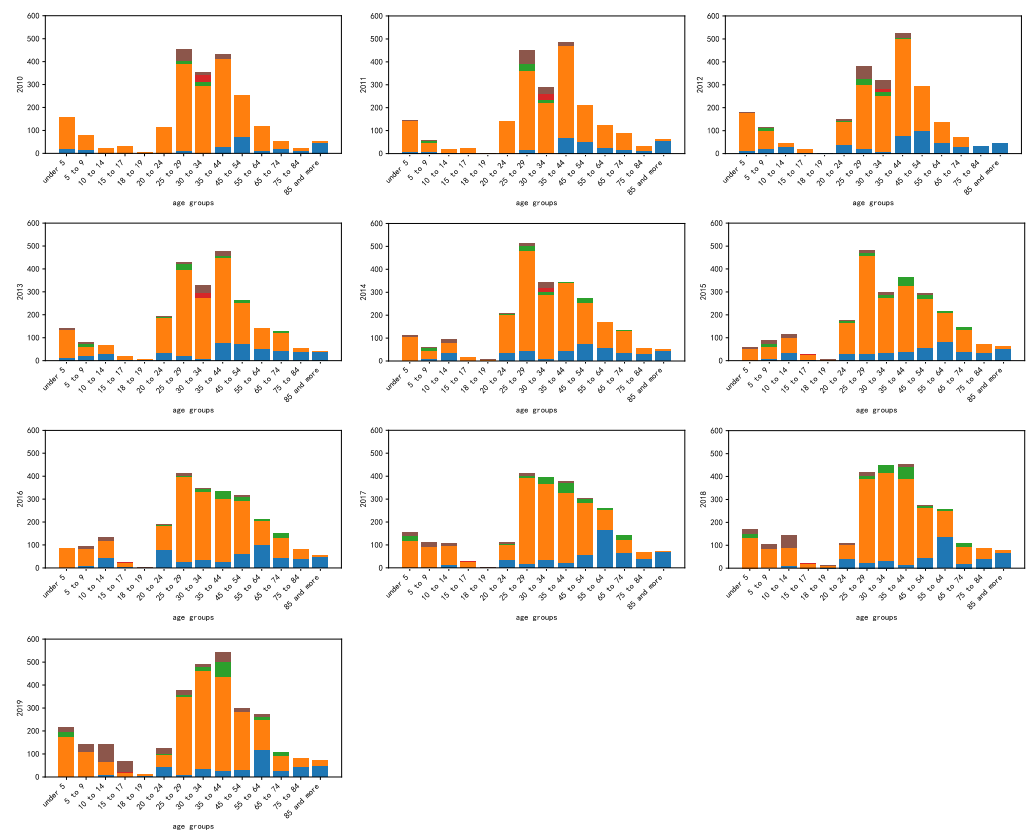

Figure A5. Breakdowns of the population by race and age for census tract 106.02 in (**a**) 1990, and (**b**) 2000.

Appendix B. Breakdowns of Race and Age from 2010 and 2019

Figure A6. Breakdowns of the population by race and age for census tract 83.01 from 2010 to 2019.

Figure A7. Breakdowns of the population by race and age for census tract 83.02 from 2010 to 2019.
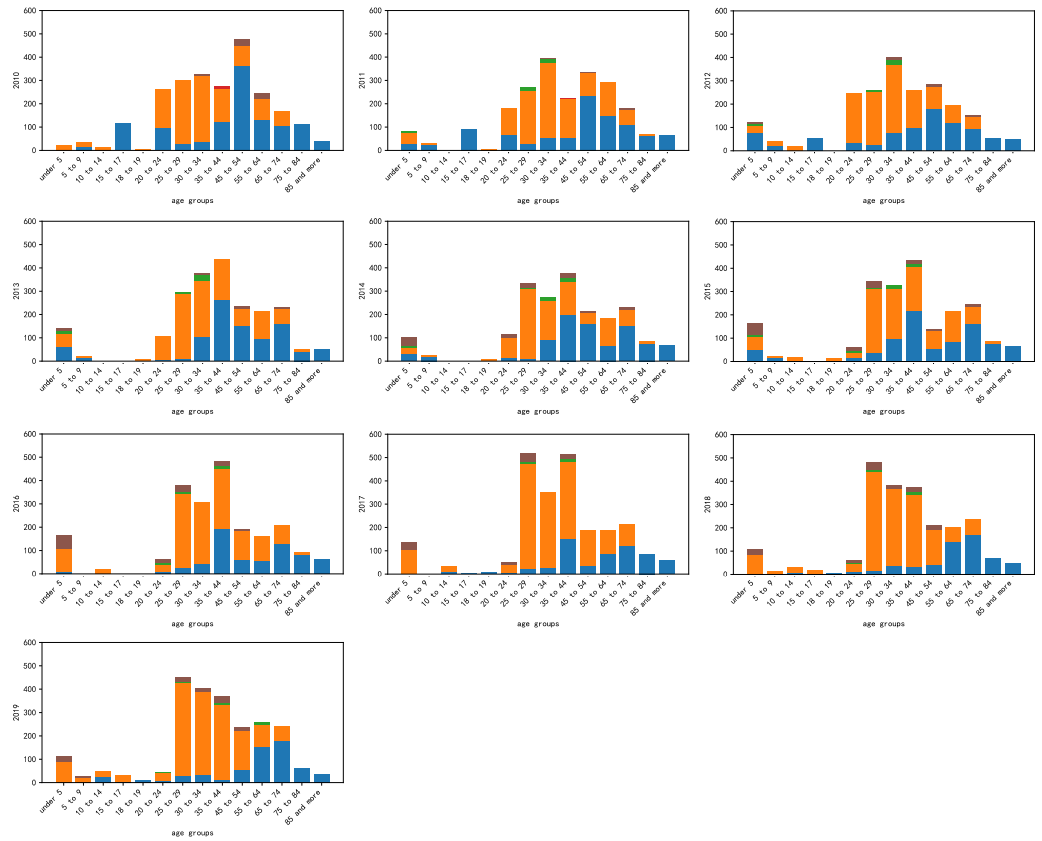
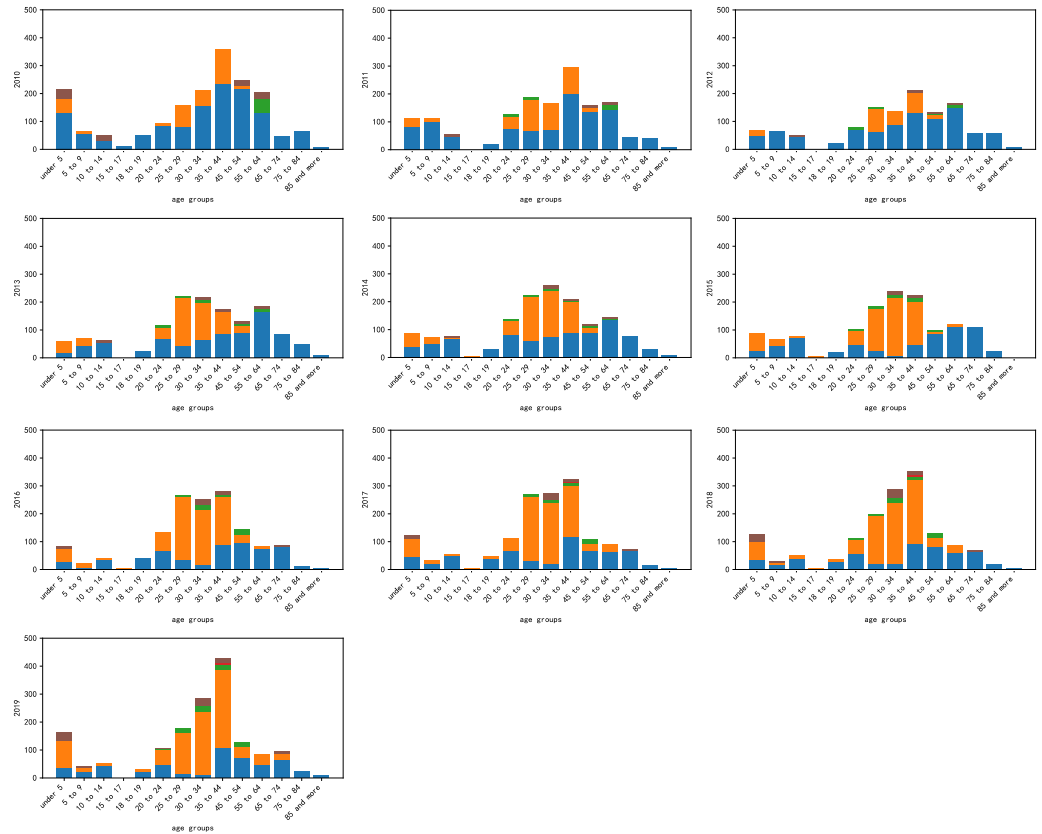**Figure A8.** Breakdowns of the population by race and age for census tract 84.02 from 2010 to 2019.

Figure A9. Breakdowns of the population by race and age for census tract 84.10 from 2010 to 2019.
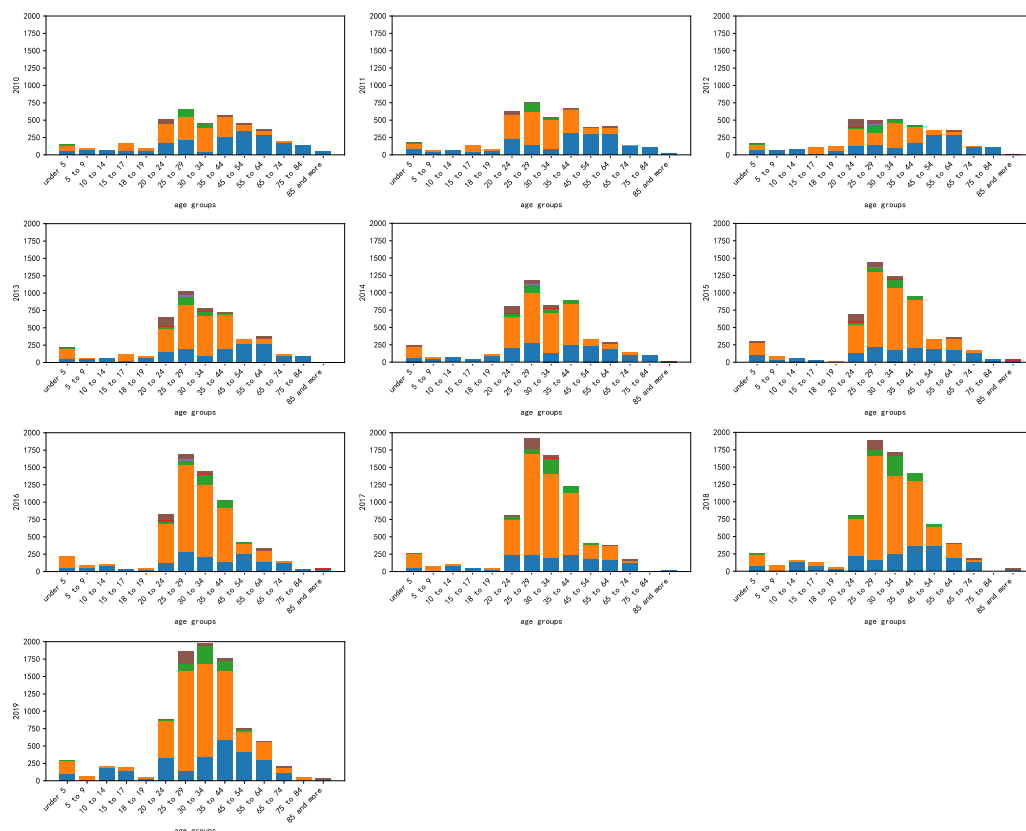
Figure A10. Breakdowns of the population by race and age for census tract 106.02 from 2010 to 2019.

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