Climate Gentrification: From Theory to Empiricism in Miami-Dade County, Florida

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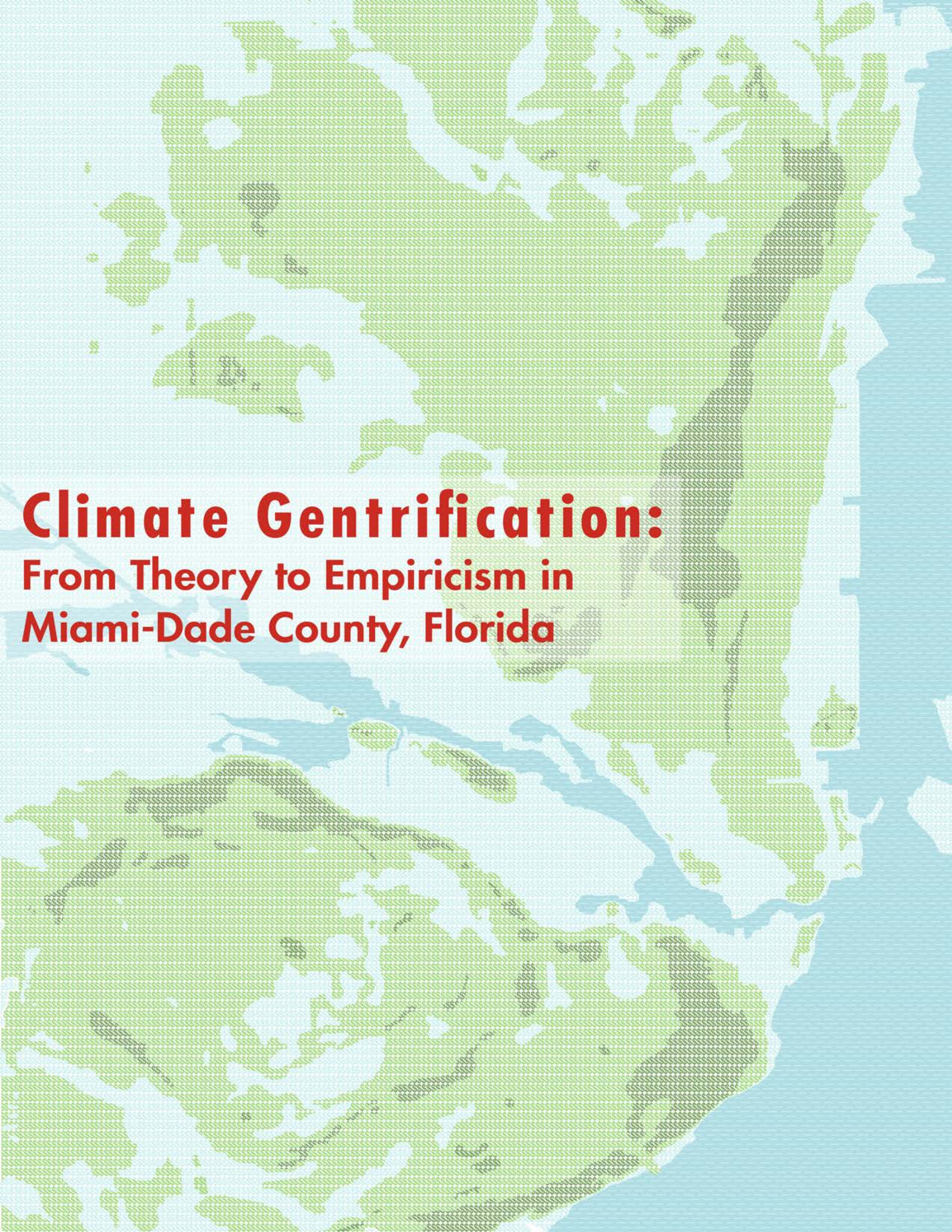

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Cover: Modified representation (not to scale) of relative elevation in the vicinity of the Miami River in Miami, Florida (USA).

Abstract

This article provides a conceptual model for the pathways by which climate change impacts could operate to destabilize geographies and real estate markets whose inferior or superior qualities for supporting human settlement are subject to a descriptive theory known as ‘Climate Gentrification.’ The article utilizes Miami-Dade County, Florida (MDC) as a case study to explore the market mechanisms that speak to the operations and processes inherent in the theory. This article tests the hypothesis that the rate of price appreciation of single-family properties in MDC is positively related to and correlated with incremental measures of higher elevation (the “Elevation Hypothesis”). As a reflection of an increase in observed nuisance flooding and relative SLR, the second hypothesis is that the rates of price appreciation in lowest elevation cohorts have not kept up with the rates of appreciation of higher elevation cohorts since 2000 (the “Nuisance Hypothesis”). The findings support a validation of both hypotheses. Climate Gentrification reinforces the proposition that climate change impacts will effect environmental and physical qualities of property in a manner that is likely destabilizing for some communities and markets. Uncovering these relationships is a critical first step for understanding the occurrence and parameters of Climate Gentrification.

Keywords

Climate Change; Climate Gentrification; Economics; Housing; Resilience; Adaptation

Table of Contents

Introduction

This article provides a conceptual model for the pathways by which climate change impacts, and the responsive social economic behaviors to those impacts, operate to destabilize geographies and real estate markets whose inferior or superior qualities for supporting human settlement are subject to a descriptive theory known as 'Climate Gentrification' (hereinafter, "CG"). CG is theorized to manifest in the displacement and entrenchment of existing populations in both high- and low-risk geographies through the mechanisms of three potential pathways: (i) the Superior Investment pathway; (ii) the Cost-Burden pathway; and, (iii) the Resilience Investments pathway. To provide empirical resolution to a theory of CG, the article utilizes Miami-Dade County, Florida ("MDC") as a case study to explore the potential behaviors of urban housing markets that speak to the operations and processes inherent within the pathways of CG.

Consistent with this theory, it is speculated that comparatively high and low elevation properties in MDC will be more or less valuable overtime by virtue of a property's ability to feasibly support habitation in the face of nuisance flooding and seal level rise ("SLR"). If such relationships are to exist, then historical data may (or may not) already reflect such relationships that would otherwise provide partial evidence for explaining the potential for CG in high and low elevation neighborhoods in MDC. As such, this article tests the hypothesis that the rate of positive price appreciation in MDC from 1971 to 2017 is positively related to and correlated with incremental measures of higher elevation of the underlying properties (the "Elevation Hypothesis"). As a reflection of an increase in observed nuisance flooding and relative SLR since 2000 (Southeast Florida Regional Compact, 2015), the second hypothesis is that the rates of price appreciation in the lowest elevation cohorts are below the rates of appreciation of higher elevation cohorts since at least 2000 (the "Nuisance Hypothesis").

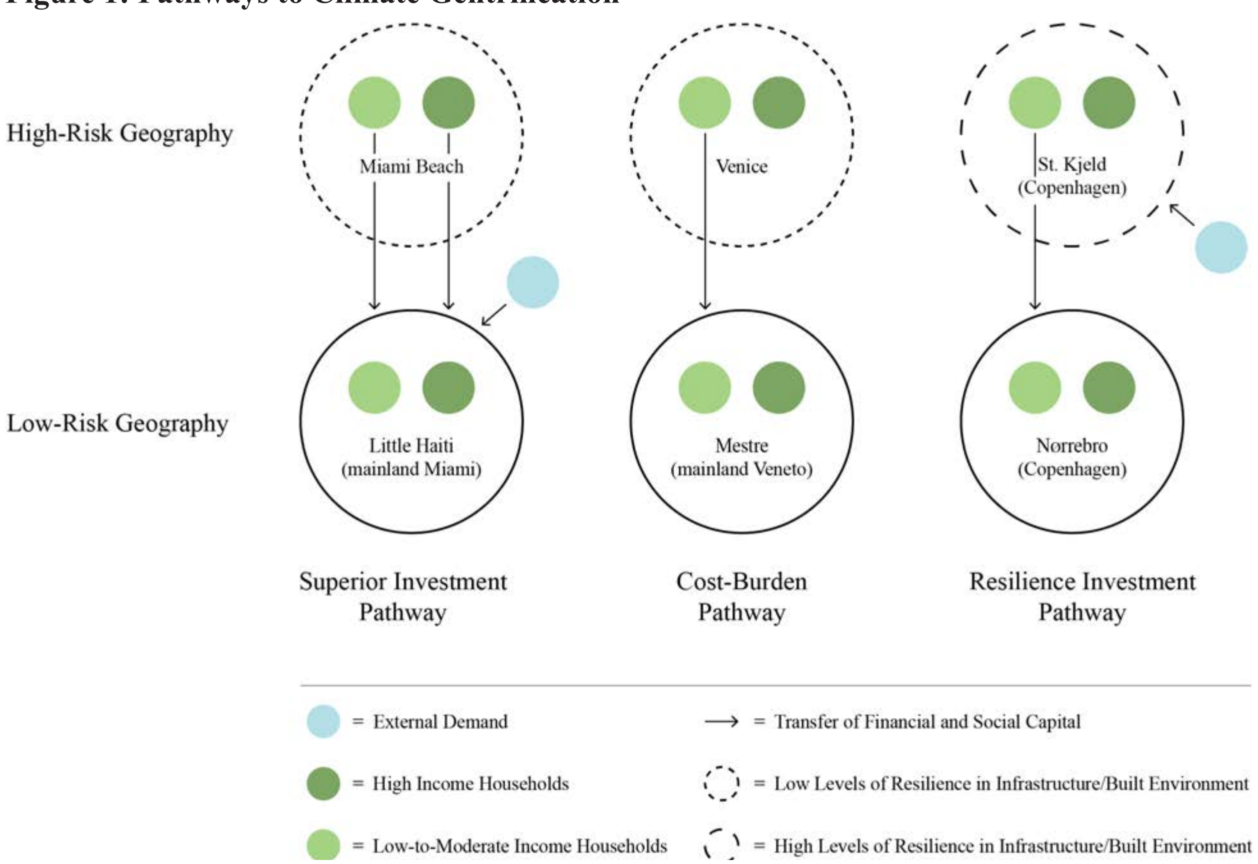
Both hypotheses are evaluated across MDC, as well as within various jurisdictions (i.e., municipalities plus incorporated portions of the county) within MDC. If validated, these hypotheses would provide partial evidence that market mechanisms reward and penalize properties with a higher and lower elevations, respectively. While a validation of these hypotheses is by no means definitive in explaining economic behaviors driving conventional gentrification in Miami, it would highlight one of multiple potential pathways by which CG may manifest in the light of probabilistic increase in the rate and intensity of nuisance flooding and inundation from SLR in the future.

The relevance of a theory of CG is defined by the need to promulgate a broader awareness of the processes shaping socioeconomic vulnerabilities and not just physical environmental exposure (Füssel, 2007; O'Neill, et al., 2014). Likewise, it highlights the dynamic and dependent relationships of elements of the built environment (e.g., housing, transportation, public facilities) that may either exacerbate vulnerabilities associated with climate change impacts or are themselves exacerbated by such impacts (Räsänen, et al., 2016; Walker, et al., 2016). As climate adaptation planning internalizes the implications of resource constraints (North and Longhurst, 2013) and due process (Sovacool and Linnér, 2016) within the context of distributive and procedural justice (Bulkeley, et. al, 2013; Shi, et al., 2016), the onus of the public sector is to contextualize existing institutional parameters that define both vulnerability and exposure of sensitive populations (Anguelovski, et al., 2016; Chu, Anguelovski, and Roberts, 2017). In this case, understanding the institutional and economic mechanisms of real estate markets is arguably critical for long-term planning. Whether it is land use or affordable housing planning, the common denominator is the relative availability and price of property and real estate. If CG proves to be an accurate description of economic processes and behaviors, high-elevation property, shaded or wind-cooled property, fresh water resourced property, geologically stable property, ecologically diverse property, pollution-free property, and resiliently design buildings will all provide attributes of market valuation that complicate the existing capacities of society to house and shelter its most vulnerable populations.

Climate Gentrification

While CG has been popularized in the media (Flavelle, 2016; Bolstad, 2017), there has been limited scholarship defining the broader theoretical application of this emerging theory (Keenan and Weisz, 2017). CG is based on a simple proposition: climate change impacts arguably make some property more or less valuable by virtue of its capacity to accommodate a certain density of human settlement and its associated infrastructure. The implication is that the price volatility associated with rent seeking, speculative investment, or superior purchasing power is either a primary or a partial driver of the patterns of urban development that lead to displacement (and sometimes entrenchment) of existing populations consistent with conventional framings of gentrification of any given geographic area (Slater, 2006; Lees, Slater and Wyly, 2013). While geographic exposure of property is a primary locational and environmental attribute of CG, the relative degree of engineered built environment resilience within buildings and infrastructure systems on such property may also provide a secondary axis of analysis that may explain why two equally exposed property markets of similar constructed attributes may perform differently over the long-term in the face of climate change impacts and extreme weather (Hollnagel, 2013).

Figure 1: Pathways to Climate Gentrification



CG may arguably manifest in one of several ways or pathways, as represented in Figure 1. The first pathway is what primarily frames this article. It relates to the substitution of property and real estate from an inferior location to a superior location. This may also be viewed as a selection of properties with superior locational and environmental attributes among alternative investment options with inferior qualities. For purposes of representational simplification in Figure 1, it is assumed that there are only two local options for settlement and investment, and it is assumed that there are two population wealth cohorts—high-income (i.e., rich) and lower-to-middle income (i.e., not rich). Superiority of one option to another is adjudicated by a property's comparatively lower level of physical environmental exposure or its high level of constructed attributes for engineered resilience and/or mitigating hazards and climate change impacts. In this article, superiority is informally hypothesized to be the relative high elevation of certain geographies (e.g., Little Haiti in Miami) relating to the short and long-term impacts of nuisance flooding and SLR. More fundamental to the theory, it describes a behavior of moving financial and social capital to a geography that offers superior risk-adjusted returns for accommodating real estate and infrastructure. It may also offer superior attributes for accommodating socially organized communities and not just assets. This pathway is collectively referenced as the "Superior Investment Pathway."

As represented in Figure 1, the Superior Investment Pathway is shown within the context of two options. In reality, there may be many options that are not always localized. In this case, it is hypothesized that households—particularly low-to-middle income households—would gradually move from the coastal barrier islands (e.g., Miami Beach, Key Biscayne, North Miami Beach) to the mainland of MDC where elevations are significantly higher by a multiple of 2.0 on average in some areas. However, as economic productivity and jobs may be undermined by flooding and SLR, populations may leave MDC altogether (Hauer, Evans, and Mishra, 2016). As such, CG may operate across multiple scales (i.e., neighborhoods, municipalities, states, regions, countries). For instance, SLR impacts in MDC may lead to CG in central Florida, which is much less physically exposed to such impacts. Likewise, Atlanta may be subject to CG stemming from coastal SLR on the east coast of the U.S. because of its superior opportunities in the labor and/or housing markets (Hauer, 2017). While these networks, transfers and transitions are difficult to model, emerging research in demographics suggests that CG may operate at multiple scales beyond those simplified representations in Figure 1 (Curtis and Schneider, 2011; Neumann, et al., 2015). Interview data suggests that speculative real estate capital is already hedging on south Florida's gradual exodus to central and north Florida.

The second pathway for CG relates to the deterioration of environmental conditions such that the tax burdens and overall cost of living can only be feasibly borne by wealthier and wealthier households as climate change impacts manifest in greater frequency and intensity. In this case, households or investors do not substitute for another location. Gentrification happens inversely by the fact that vulnerable populations are unable to afford to live *in situ* in a particular geography. This would be primarily due to the increased costs of insurance, property taxes, special assessments, transportation and consumer goods, as well as a loss in overall productivity (e.g., sitting in traffic in water clogged streets). For comparatively wealthy households, prior research has suggested that the "risk of coastal flooding seems inconsequential in determining property values due to the substantial premiums that appear to be associated with proximity to coastal water"(Bin and Kruse, 2006, p. 137). For those households who are more sensitive to the carrying costs and rents associated with such hazards, there may be no alternative but to relocate. Thereafter, those that remain are those who have invested speculative capital that they can "afford" to lose. An example of this is in Venice, Italy where environmental conditions, including relative SLR and unabated tourism, have resulted in a total cost-burden that has undermined class diversification in the city (Moretti, 2012). This pathway is collectively referenced as the "Cost-Burden Pathway."

It would be anticipated that over time such a phenomenon would occur in the beach front barrier islands of MDC, such as Miami Beach. However, research models suggest that adaptation investments in risk mitigation likely have a threshold by which even informed (and comparatively wealthy property owners) will eventually abandon their investments (McNamara and Keeler, 2013; Treuer, Broad, and Meyer, 2018). As such, it should be qualified that the pathways to CG are limited in their duration and intensity, as threshold dynamic estimations are highly unpredictable (Haer, et. al., 2017). Eventually, in the face of SLR, it can be argued that even the most-wealthy will likely have to abandon Venice and Miami Beach.

The third pathway relates to the unintended consequences of making investments in physical engineered resilience in buildings and local infrastructure (Ayyub, 2014; Cerè, Rezgui, and Zhao, 2017). As a consequence of these investments, the underlying property and real estate increases in value by virtue of the fact that the positive externalities associated with performance of the proximate resilience infrastructure investments represents a superior outcome to the status quo—even when netted-out by any costs associated with the taxes and fees for building and maintaining the resilience infrastructure (Bunten and Kahn, 2017). Therefore, any tax consequences associated with the investments would be absorbed or internalized by increases in property valuation and/or rent payers. This pathway is a derivative of the well-developed concept of 'Green Gentrification,' wherein investments in sustainability oriented amenities and infrastructure are unevenly distributed or otherwise correlated to or associated with gentrification (Checker, 2011; Curran and Hamilton, 2012; Bryson, 2013; Sandberg, 2014; Anguelovski, et al., 2017; Gould and Lewis, 2017).

Although not widely studied, the exemplar case for this pathway is the St. Kjeld Climate District in Copenhagen where a broader resilience strategy to revitalize a neighborhood led to some measure of displacement from increased rents (Kjaer, 2015) and the marginalization of existing homeowners (Baron and Petersen, 2016). However, there is an alternative potential scenario wherein resilience investments operate to reduce risk and exposure to such an extent that it comparatively reduces long-term tax and insurance liability to such an extent that neighboring geographies are less economically appealing. Whereas in Copenhagen the resilience investment brought the neighborhood real estate up to 'market rate,' in this sub-pathway the overall market value increases above and beyond the mean valuation by and between alternative substitute sub-markets because of the comparatively lower carrying costs (e.g., taxes and insurance). Collectively, these two scenario sub-pathways are referenced as the "Resilience Investment Pathway."

Each of the three pathways represent possible mechanisms and behaviors that may lead to CG. They do not independently represent deterministic conditions, as exogeneity in real estate and property markets often defies current methodologies for pinpointing long-term valuation trends or preferences. As such, CG is referenced as a descriptive theory for understanding and explaining emerging trends otherwise referenced as conventional gentrification. As will

be discussed, climatic and environmental impacts and hazards should be understood within a broader array of influences driving gentrification, including historic racial or religious segregation, income inequality, and the spatial distribution of jobs, transportation, and housing. However, with CG, it can be argued that such climactic and environmental influences will increasingly play, as outlined in the three pathways, an important role in the weighted factors driving investment and locational decisions of households, investors, mortgagors, insurers, and the public sector. The empirical portion of this article seeks to identify potential methodologies and measurements that may validate the underlying mechanisms inherent in several of the pathways defining a theory of CG.

Research Design and Methodology

The research design of this article is based on a mixed-methods approach undertaken in two distinct phases: (i) theory development and (ii) empirical data analysis and hypothesis testing (Creswell, 2013). In the first phase, desk and exploratory research was undertaken in MDC as it relates to vulnerability assessment and the identification of existing disaster, engineering, and community resilience activities and capacities. MDC was selected as a case study based on its popular and scientifically determined vulnerability and exposure to climate change impacts, including increased nuisance flooding, SLR inundation, and increased intensity of tropical cyclones (Yin, 2013). As part of the theory development phase, semi-structured and unstructured interviews were conducted with numerous (n=48) local officials, researchers, real estate developers, real estate investors, real estate financiers, real estate brokers, residents and community activists. The interviews suggested an emerging—often unspoken—consensus that high-elevation property and real estate would increase in value over the long-term, as climate change impacts materialize unevenly across parts of MDC.

Some local community activists and real estate actors even went so far as to speculate that existing comparatively high elevation neighborhoods in MDC were gentrifying, in part, because of long-term speculation being driven by a hedge on SLR. Interviews with various relevant private sector real estate actors and researchers suggested that SLR was a minor consideration and that current gentrification patterns were consistent with infill development stemming from the fact that MDC had largely run out of undeveloped property due to restrictions on further building into the Everglades on the western portions of MDC. However, local community activists in certain high-elevation gentrifying communities have begun to declare that CG was not only long-term existential threat to their communities but also an immediate threat. In either event, the qualitative data helped drive the formulation and development of a theory of CG over the course of nearly three years. During this period, the first author spoke publicly about this emerging theory. In light of the eventual popular usage of CG as rhetoric, the empirical aspects of this article seek to identify whether a validation of the Elevation Hypothesis and the Nuisance Hypothesis could partially and/or potentially explain market phenomena consistent with a Superior Investment Pathway or a Cost-Burden Pathway.

In order to test the hypotheses, the detailed property sales information for MDC was obtained from the Miami-Dade County Property Appraiser's Office. The dataset contained approximately 800,000 properties across MDC and included records for each property, including property type, unit count, lot and building size, property and building values, year built, bed and bath counts, market and property tax assessment values, exemptions, owner name, site address, mailing address, zoning, and the last three transactions for each property (the

"Property Dataset"). Property records with incomplete, miscoded, or extreme values were culled from the Property Dataset. In order to understand how patterns exhibited by this Property Dataset might be conditioned or contextualized by elevation, the analysis involved combining the property record data with elevation data (1/9th arc-second) for Miami-Dade County sourced the United States Geological Survey ("Elevation Dataset")(USGS, 2017).

As will be discussed in more detail in the following section, the economic analysis comprised of two principle steps. First, a price index was constructed to allow a comparison of price appreciations of properties across the entire Property Dataset. This normalization of price appreciation allowed for a more resolute apples-to-apples comparison of price appreciation by and between different property characteristics. Second, a linear mixed effects model was constructed and coded to understand how the relationship between elevation and price appreciation varied across jurisdictions in MDC—holding various other explanatory variables constant. Both the price indexing and the regression analysis were conducted in parallel using open source programming languages R and Python. The duplication in programming language provided an additional measure of quality control over the analysis.

Empirical Modeling and Findings

From the Property Dataset, properties containing single-family homes were isolated. Following the cleaning of the Property Dataset and the isolation of single-family homes, the resulting Property Dataset was reduced to 107,984 properties. Single-family homes were selected to the exclusion of condominium and cooperative properties (i.e., vertical property regimes) for several reasons. First, these vertical property regimes are arguably less sensitive to the nuisance and risk of loss from intermediate flooding because of their varied base floor elevations. Specific to the Nuisance Hypothesis, it was speculated that single-family properties were a superior typology because single-family properties were generally not designed for intermediate flooding—as condominiums often are—and the risk-of-loss is borne by one owner, as opposed to an entire vertical property regime non-profit association. For instance, habitable first floors in condominiums are often well above base floor elevations of single-family properties, and, in some cases, the first floors are not legally habitable at all. These speculations are entirely untested in this article. However, these speculations represent an important potential avenue for future typological, architectural research.

Second, speculative condominium development patterns were highly spatially concentrated and did not offer much insight for patterns across time, space, and elevation. Commercial real estate was also removed because valuation of commercial property is largely dependent on net operating income generated by property and investment cycles (i.e., capital market cycles)(Geltner, 2015). Finally, properties were culled if they were bought and sold in the same year or were entirely transacted before 1971, as there was inadequate data spanning 1911 to 1970 in the MDC property appraiser's database.

The Property Dataset was then geocoded with ESRI's ArcMap software. The resulting dataset was then geocoded with the Elevation Dataset. The latitude and longitude coordinates of each property were then appended to specific elevations for each address in the revised Property Dataset. Figure 2 and Figure 3 represent the range of elevations found in each of the selected municipalities and the unincorporated portions of MDC. Not all municipalities in MDC were selected for analysis because certain municipalities, such as Homestead, did not have

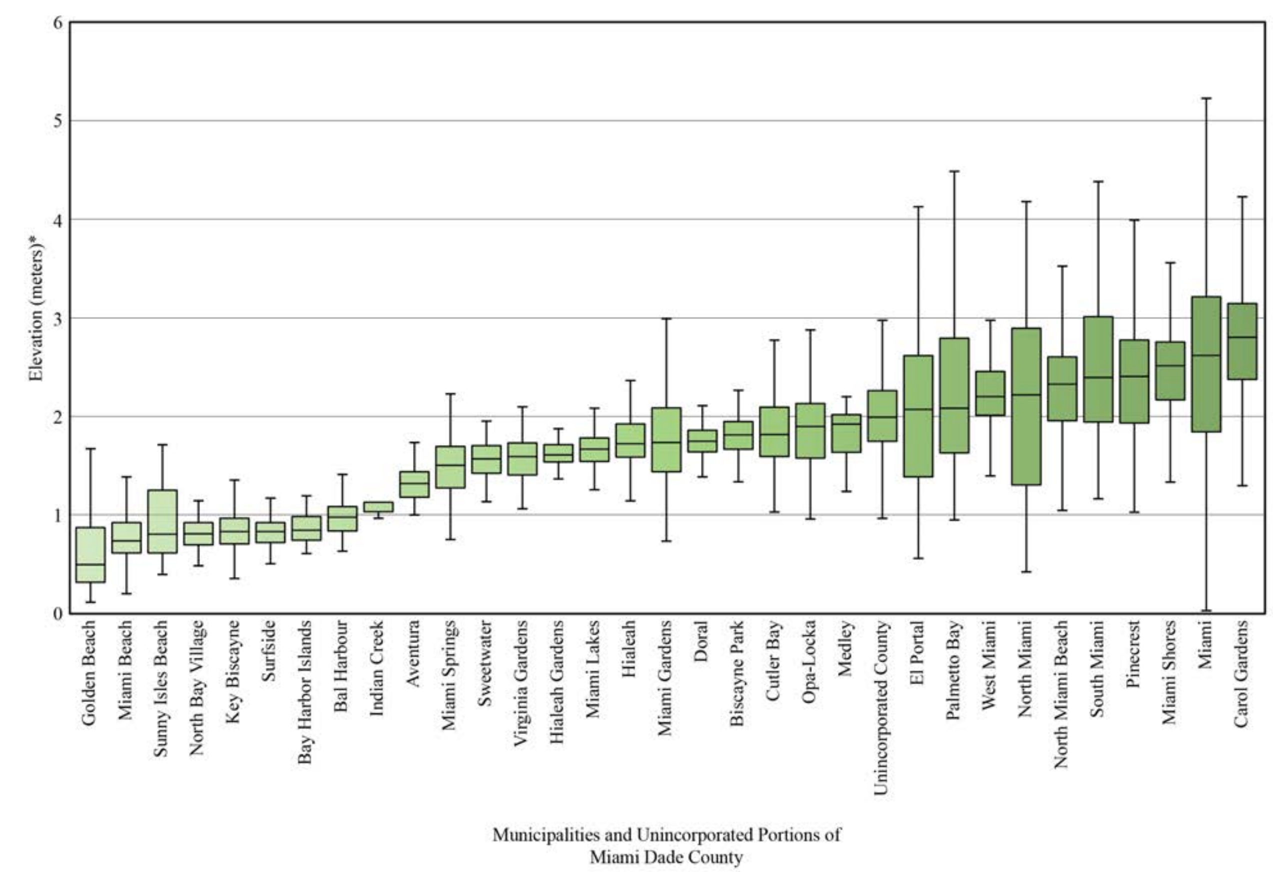
a either a meaningful internal variation in elevation data and/or a robust level of data. With the revised Property Dataset and the Elevation Dataset, two computational strategies were deployed. As will be discussed, the first was to construct a price index and the second was to conduct a statistical regression on modified samples within the subject datasets.

Multiplicative Price Index

A prerequisite to testing the hypotheses was to construct a price index in order to overcome two potential challenges. First, there is arguably a great variation in the quality of properties sold from period to period. Second, it is desirable to eliminate life and capital cycle effects on property prices. The last deficiency was tackled by building the index over a 46.5-year period, from 1971 to the end of the second quarter of 2017. Arguably, this period represents data robust enough to absorb long-term cycling effects of price appreciation in an index (Bailey, Muth, and Nourse, 1963). As previously referenced, condominiums, cooperatives and commercial real estate was removed from the Property Dataset in order reduce the deviations in the quality of properties sold in progressive periods and across market cycles.

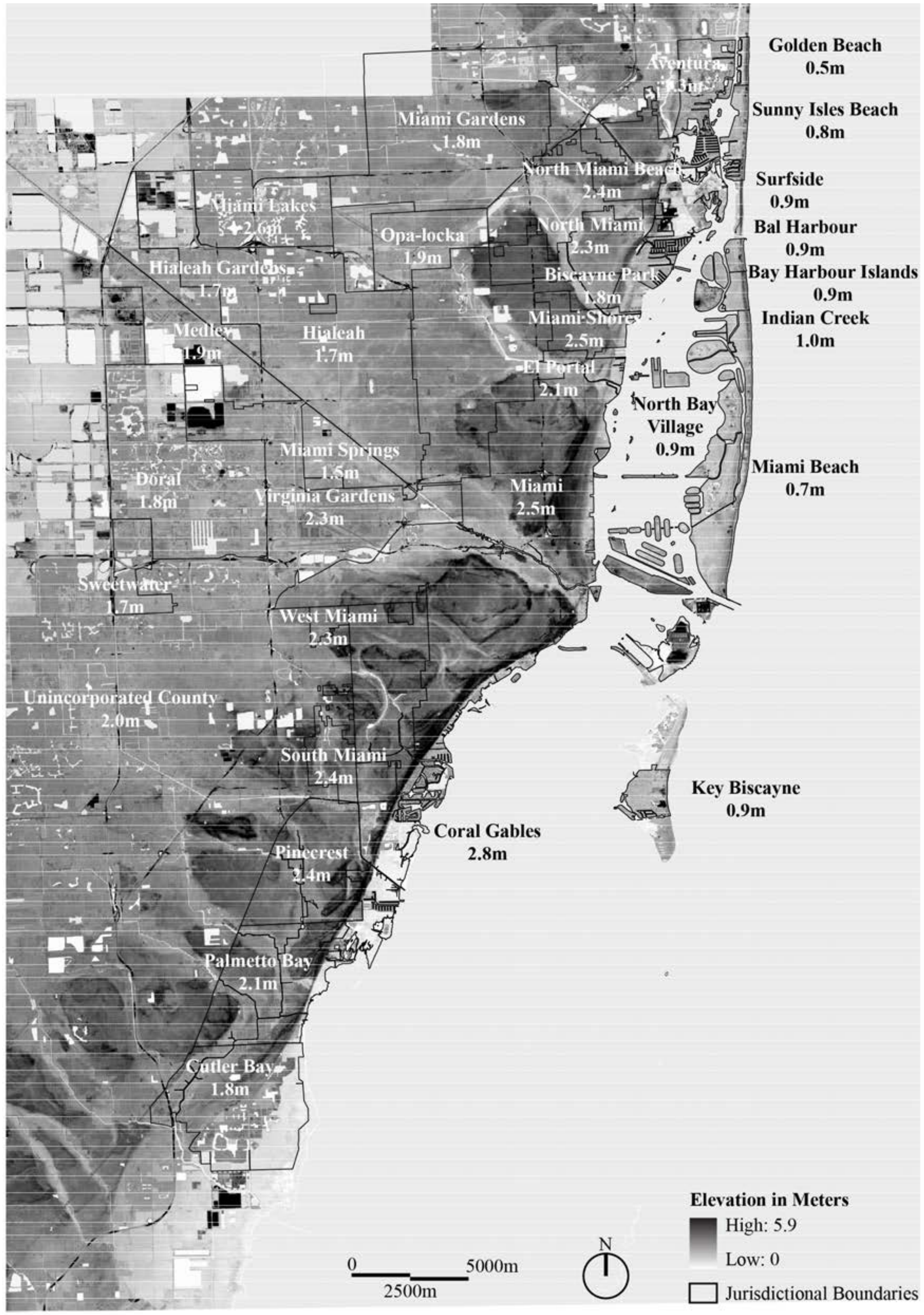
A multiplicative price index was constructed based on data from 107,984 properties from the revised Property Dataset. The first step in indexing properties to the base year (i.e., 1971) was to develop a price multiple for each property. Next, the geometric mean of price multiples of all properties bought and sold in the same

Figure 2: Range of Elevations for Municipalities and Unincorporated Portions of Miami-Dade County



*Note: All observations within the shaded boxes account for 2 standard deviations from the mean.

Figure 3: Map of Elevations for Municipalities and Unincorporated Portions of Miami-Dade County



Note: numbers (meters) correspond to the mean elevation in the respective jurisdictions in accordance with NAD83 U.S. (2011); only the study area of Miami-Dade County is shown.

year were calculated. These means reflect the average price increment of properties in MDC in the last 46.5 years. The means also smooth any observed anomalous increments. The third step was to calculate a price relative for each of these means. The price relative is the calculated mean for that period multiplied by the mean for the period between the base year of 1971 and any given year of purchase. This yielded an indexed data frame of property price relatives sold between different periods indexed to 1971. At this stage, all properties can be thought to be bought in 1971 and then sold anytime between 1972 and the end of the second quarter of 2017. The final step was to calculate the geometric mean of these price relatives with the same final sale year (between 1972 and 2017) in order to get a single multiple for properties sold in the same year. The result is an indexed valuation multiple. To calculate appreciation for any given property, one would take the sum of the multiple minus one times the base acquisition price.

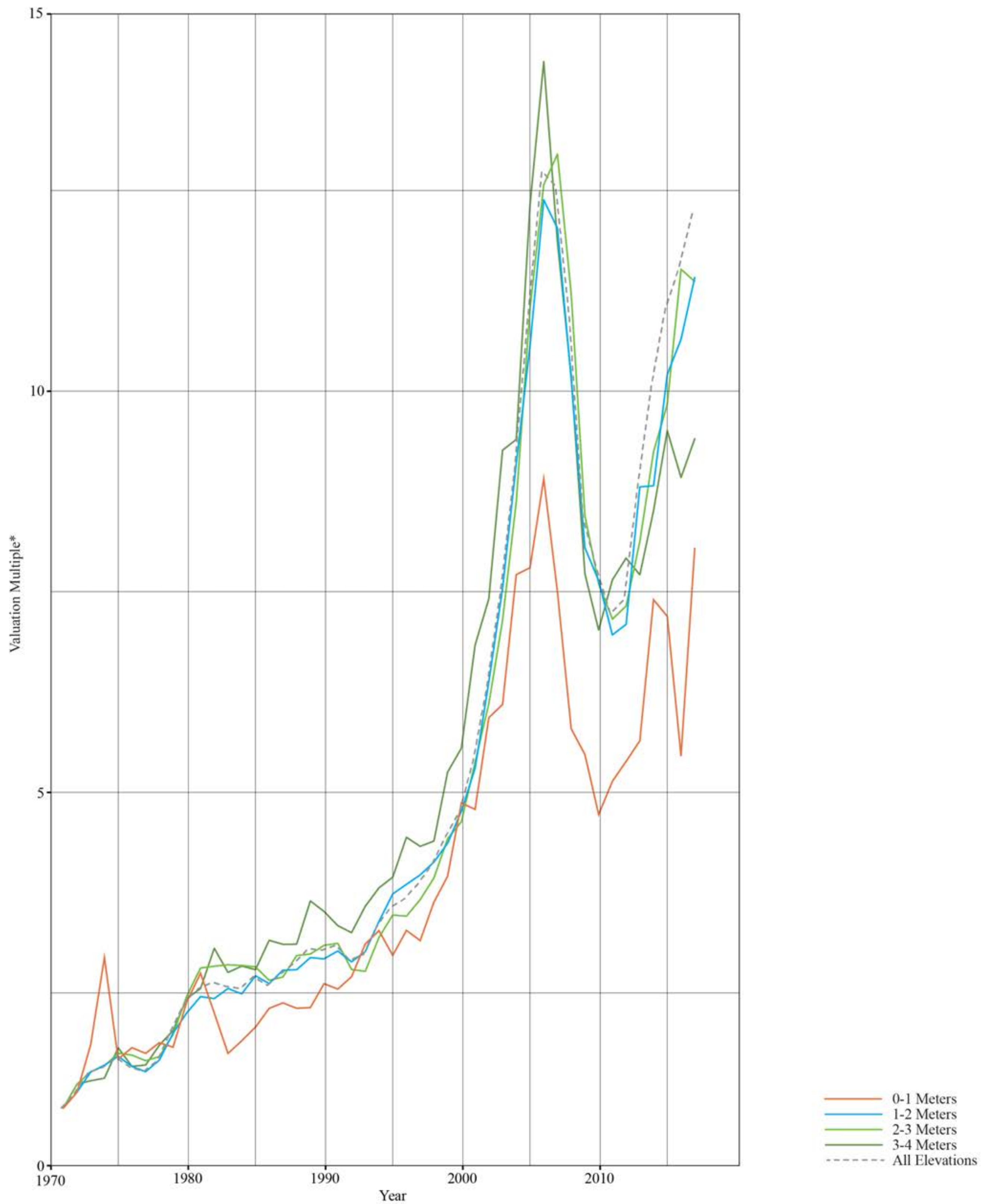
As was observed, the multiplicative price index method is computationally cumbersome. It has also been criticized for its inability to estimate effects of other changes affecting property prices (Hill, 2013). However, we found that the method is quite useful in constructing a general methodology, which can then feed multiple subsets of data frames from the original source to evaluate the effects of property attributes on rates of price appreciation. Nevertheless, as is the case in this article, the approach should be supplemented with regression analysis in order to understand the extent to which each attribute has an effect of property prices. But, first, it is arguably useful to evaluate the unregressed relationship between the index and elevation.

Rate of Appreciation and Elevation Findings

Figures 4, 5, 6, and 7 represent a range of jurisdictions wherein the indexed valuation multiple was decomposed for elevation cohorts measured in 1 meter increments. Measurement anomalies below sea level (< 0 meter) were spot-checked and either culled or grouped into the lowest elevation cohort. The values on the y-axis are multiples indexed to 1971. The total sample size of properties broken down by elevation cohort is found in Appendix Table 1. For all subject properties, Figure 4 demonstrates that properties in the 2-3 meter and 3-4 meter cohorts have had slightly higher rates of price appreciation relative to the 1-2 and 0-1 meter cohorts. This finding would be consistent with a validation of the Elevation Hypothesis. While properties in the 4-5 meter and 5-6 meter elevation cohorts have lagged the group, this finding is less relevant or impactful because these properties represent just 1.41% (n=1,518) of the entire sample. This marginal distribution holds true across all of the evaluated jurisdictions. As such, elevation cohorts above 4 meters can generally be ignored.

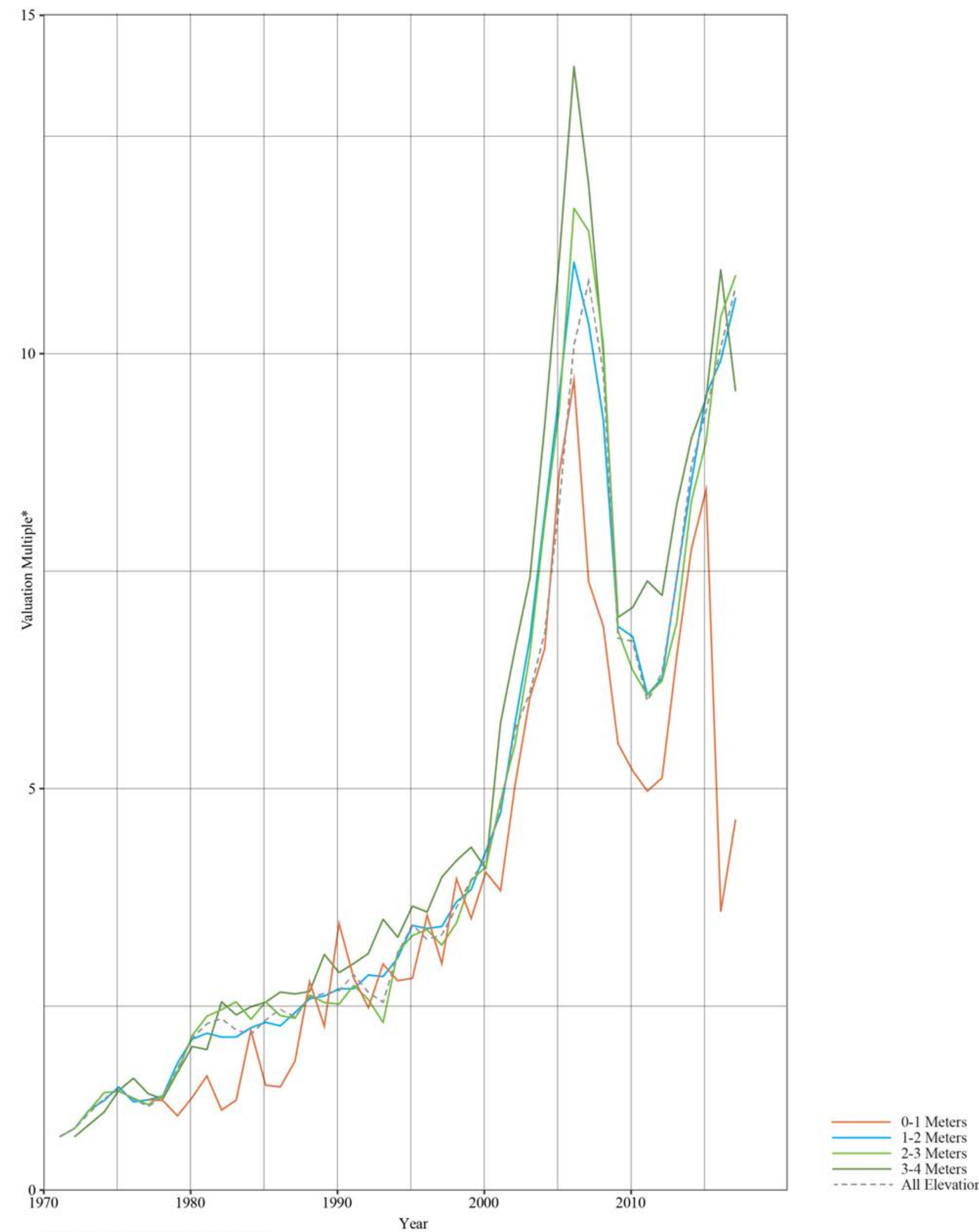
Figure 5 highlights a similar pattern for unincorporated parts of MDC, which accounts for 58% (n=58,804) of the sample. However, unincorporated portions of MDC suggest a slightly stronger relationship to elevation than the entire sample represented in Figure 4. As a general observation, the 3-4 meter cohort has slightly outperformed the 2-3 meter cohort. The 2-3 meter cohort has slightly outperformed the 1-2 meter cohort and the 1-2 meter cohort has outperformed the 0-1 meter cohort. This spread has been particularly pronounced since approximately 2000. Specific to the City of Miami, Figure 6 represents a similar but less conclusive pattern to that of unincorporated MDC and all subject properties within MDC. While the 0-1 meter cohort has lagged the group for most of the time period, the relationships between cohorts are less clear than unincorporated MDC. In particular, there has been a recent increase in rates of appreciate in the 0-1 meter cohort in the last several years. This might be explained by single-family properties benefit-

Figure 4: Indexed Valuation Multiple by Elevation Cohort for All Properties in Miami-Dade County



*Note: Price multiple indexed to 1971.

Figure 5: Indexed Valuation Multiple by Elevation Cohort for Unincorporated Properties in Miami-Dade County



*Note: Price multiple indexed to 1971.

ing from their proximate location to a recent boom in luxury high-rise residential properties located directly on Biscayne Bay and the overall gentrification of areas north of downtown. Overall, the City of Miami accounts for just 6.70% (n=7,234) of the sample.

Consistent with a validation of the Nuisance Hypothesis, the 0-1 meter cohort has significantly lagged the group since approximately 2000 for all properties in MDC in Figure 1. A similar pattern is found among unincorporated properties in Figure 5, with a precipitous drop in price appreciation in approximately 2015 for the 0-1 meter cohort. In addition, 7 of the 12 jurisdictions represented in the Appendix all demonstrated a similar pattern wherein the lowest elevation cohorts (i.e., either 0-1 or 1-2 elevation cohorts) tracked the general group until approximately 2000, or shortly thereafter, at which point they begin to underperform relative to the general track of the group of elevation cohorts. Again, elevation cohorts above 4 meters can generally be ignored.

As represented in Figure 7, properties in the City of Miami Beach have expressed a notably negative relationship between elevation and price appreciation. This is likely explained by the proposition that spatial proximity to the beach or water has a positive impact on both valuation and rate of appreciation, at least as long as those bodies of water are deemed to be amenitized (e.g., sandy beaches)(McNamara, et. al, 2015). The Appendix contains sets of figures for those municipalities that demonstrated varying degrees of positive and negative relationships between price appreciation and elevation. Overall, as memorialized in Appendix Table 1, 11 jurisdictions accounting for 76% (n=82,068) of the overall sample demonstrated some measure of positive relationships. By contrast, 5 jurisdictions accounting for 13% (n=14,014) of the sample were founded to have some negative relationship. While 17 jurisdictions had either inadequate elevation granularity or inconclusive relationships, these jurisdictions accounted for only 11% (n=11,798) of the sample.

Statistical and Spatial Regression Model

Using Python's machine learning package StatsModels, a linear mixed effects model was constructed to understand the relationship between elevation and property price appreciation for single-family properties across the various municipalities and unincorporated portions of MDC. A linear mixed effects model was selected as the appropriate statistical model because it was suspected that elevation had a varying effect among other variables on price appreciation across the arguably heterogeneous urban housing sub-markets in MDC (Peng and Lu, 2012; Reddy, 2015).

From an initial exploratory data analysis, there were several other significant deterministic variables for price appreciation besides elevation: square footage, sale date, and construction year. A linear mixed effects model allowed for an assumption that the effect of each of these factors on appreciation would be fixed across the jurisdictions in our sample, while the effect of elevation alone would vary. It was important to control for these additional factors for a number of reasons. First, larger, more expensive properties were found to experience greater rates of appreciation on average than cheaper, smaller properties. In addition, in MDC, large properties are disproportionately located at or near the coast, and thus tend to be located at elevations close to sea level. In other words, home square footage is positively correlated with appreciation and negatively correlated with elevation. This nexus of factors thus makes it impossible to understand the relationship between elevation and price appreciation without holding other variables constant.

Figure 6: Indexed Valuation Multiple by Elevation Cohort for Miami Properties in Miami-Dade County

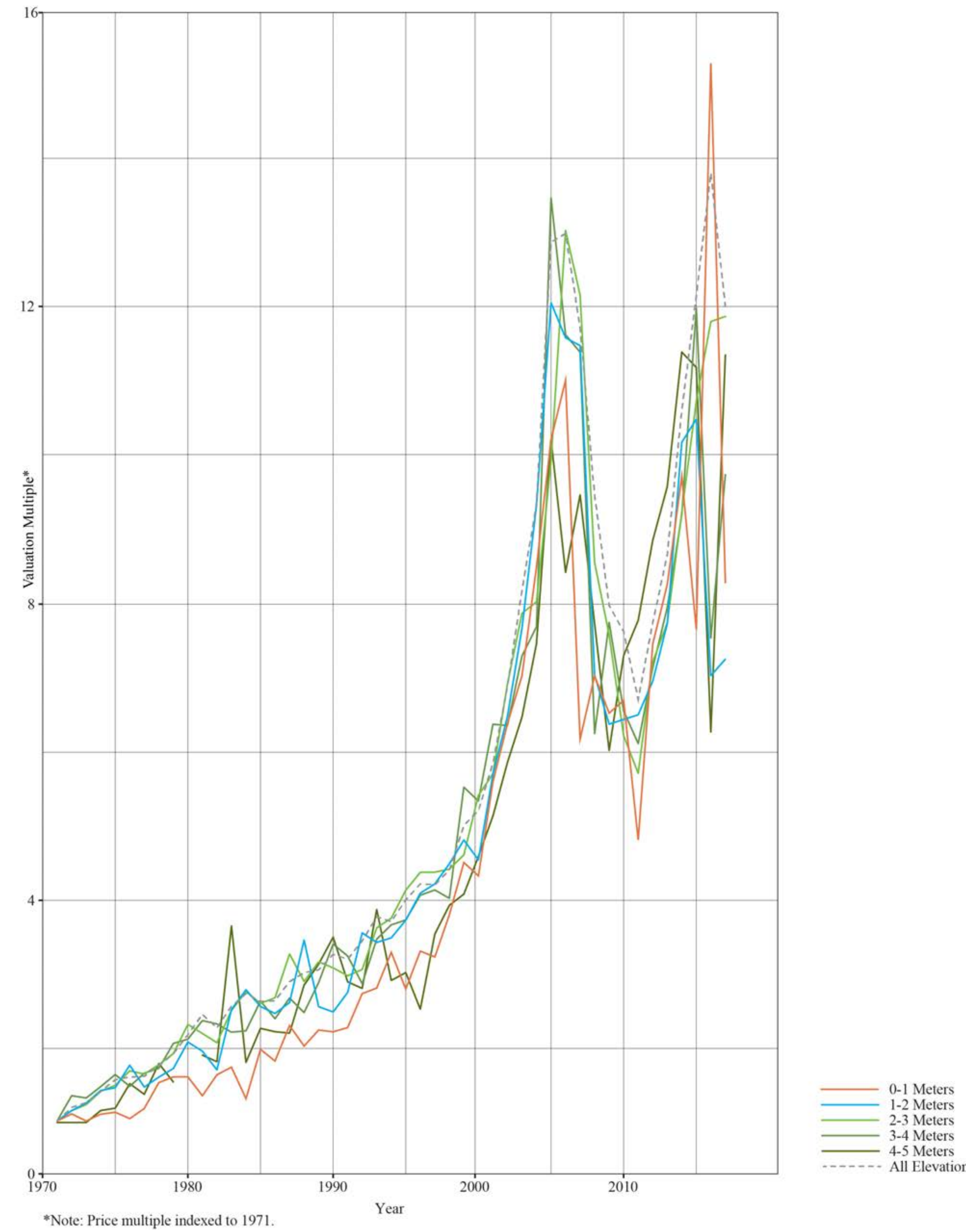
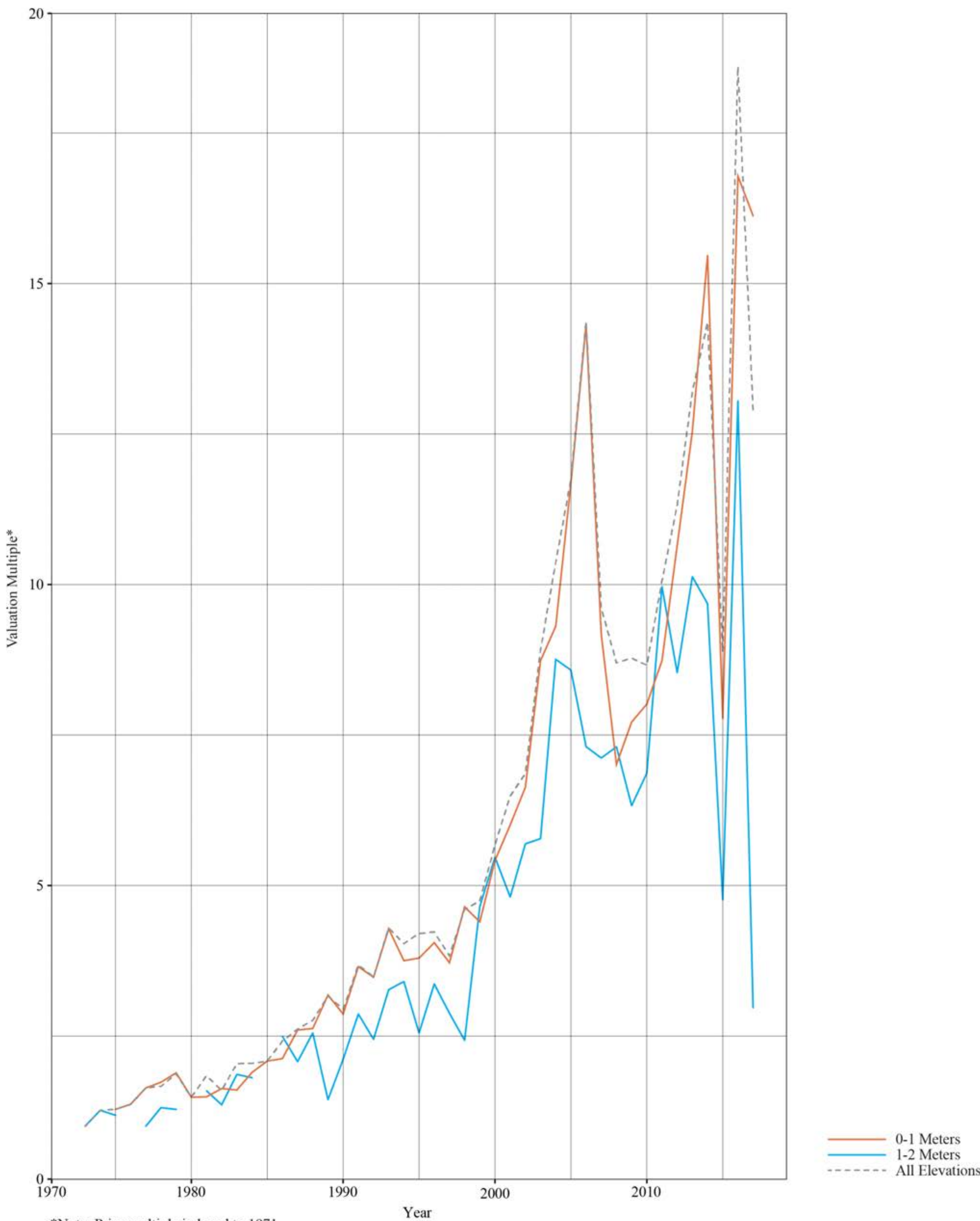
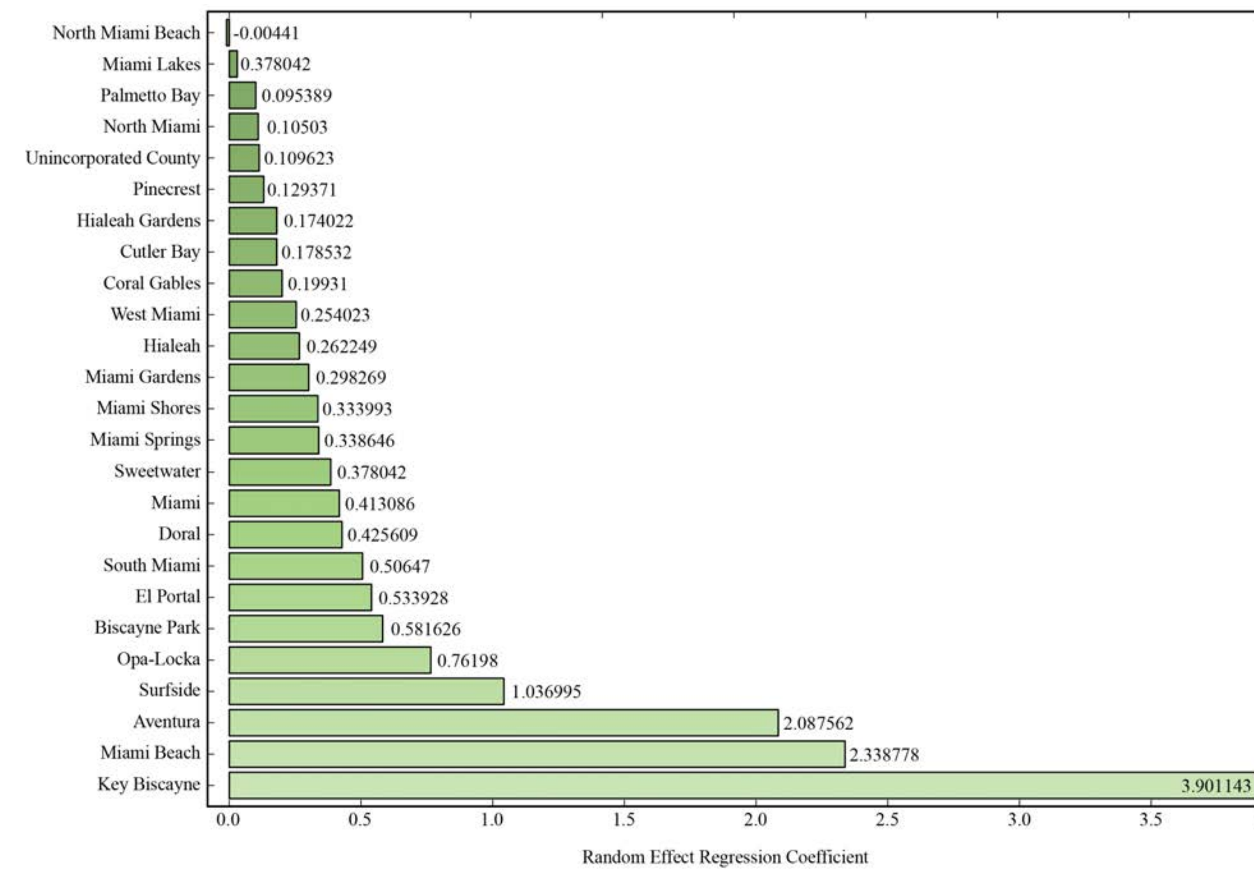


Figure 7: Indexed Valuation Multiple by Elevation Cohort for Miami Beach Properties in Miami-Dade County



*Note: Price multiple indexed to 1971.

Figure 8: Random Effect Regression Coefficients for Elevation Effect on Price Appreciation by Jurisdiction

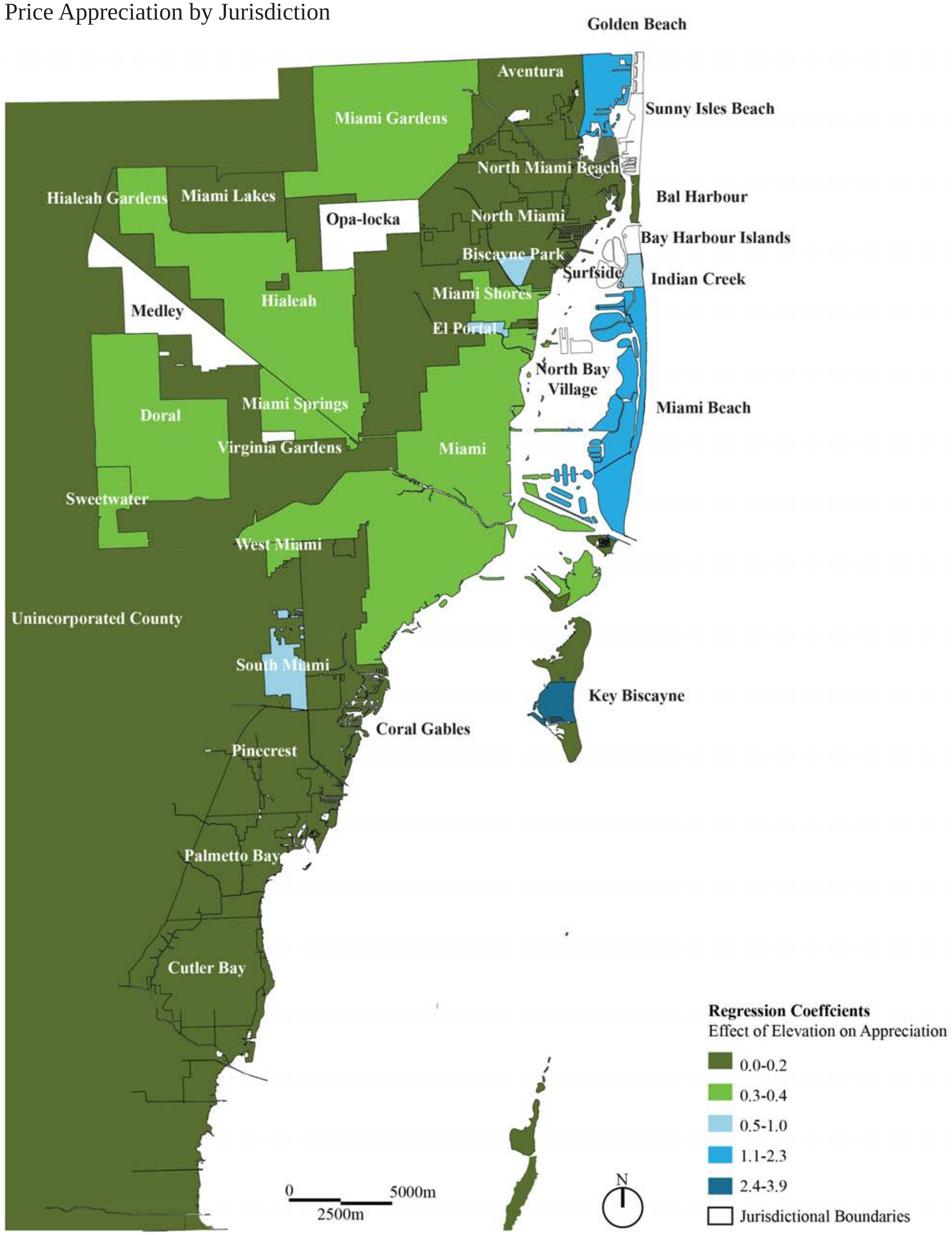


Regression Findings

Utilizing a linear mixed effects model, the price appreciation index was regressed for elevation, construction year, date of sale, and square footage, within each of the jurisdictions (e.g., each of the selected municipalities plus unincorporated MDC) in MDC with each variable representing a different group. Thereafter, the method sought to obtain the specific effect of elevation on price appreciation for each of these jurisdictions, excluding municipalities (n=6) with less than 200 single-family units (n=-672). Holding date of sale, year of construction, and building square footage constant, elevation was found to have a positive effect on price appreciation in 24 of the 25 jurisdictions under study. Those 24 jurisdictions represent 98.1% of the 107,312 properties subject to the regression. Only North Miami Beach exhibited a negative relationship between elevation and price appreciation, albeit a weak one.

Figure 8 highlights the range of elevation regression coefficients for the subject jurisdictions. As Figure 9 represents, the 3 jurisdictions with the strongest coefficients are all on the coast. Overall, 13 (54%) of the 24 jurisdictions with positive coefficients are land-locked, although nearly all of the land-locked jurisdictions have significant collections of lakes and drainage canals. Detailed regression results can be found in Appendix Table 2. The largest single jurisdiction represented in the sample, unincorporated MDC (n=58,804; 54%), showed a positive correlation. Overall, the sample of all subject properties showed a positive correlation between elevation and appreciation when controlling for the aforementioned variables.

Figure 9: Map of Random Effect Regression Coefficients for Elevation on Price Appreciation by Jurisdiction



Note: Only the study area of Miami-Dade County is shown; jurisdictions in white did not have adequate data for analysis.

Discussion

It is difficult to identify the effect of elevation on price appreciation independent of other variables and locational factors. There are many spatial qualities at play that cannot be easily controlled for. The historical development patterns of MDC are complex, and uneven patterns at different elevations runs in contradiction to many American cities where the historical patterns of development dictated 'high' concentrations of wealth and corresponding value (e.g., Boston, New Orleans, New York, San Francisco). Although, Coral Gables and Coconut Grove (within City of Miami) are consistent with this pattern. Since elevation was the only locational factor, it is possible that the results simply demonstrate a correlation between location and price appreciation. However, the jurisdictions that exhibit a positive relationship between elevation and price appreciation represent the vast majority of all housing units, including single-family, multi-family, condominium and cooperative properties in MDC.

This overall positive correlative effect provides evidence in support of validating the Elevation Hypothesis. This evidence is in addition to the observations of positive relationships between price appreciation and elevation cohorts in jurisdictions accounting for 76% (n=82,068) of the sample population. However, inferential connections between the results of the two modes of analysis is inconclusive for some jurisdictions. In the case of Miami Beach, there was an observed negative relationship between price appreciation and elevation cohorts, yet the city had the second highest regression coefficient. This could be explained by the two different analytical methods, wherein elevation breaks in the regression were more precise than the coarse cohorts of 1 meter. However, more precise elevation measurements may be inconsequential in the real world wherein the path of water may not be obstructed by such nuances in elevation. In addition, historical development patterns of single-family houses on Miami Beach are largely concentrated on lower elevations. Future research will need to find resolution between observations and meaningful breaks and location of elevation. That is to say that not all elevation represents equal units of risk or nuisance given the underlying bathymetry and surface water management capacities of MDC.

There is perhaps more robust evidence supporting a validation of the Nuisance Hypothesis. The logic behind the formulation of the Nuisance Hypothesis was based on the proposition that increased nuisance flooding may have been negatively impacting low elevation properties in the market. Interviews with real estate brokers suggested a certain intelligence about high nuisance portions of MDC among the brokers. While the findings support the hypothesis, they do not necessarily speak to a validation of the causal logic. However, in some areas, lower elevation properties are grossly underperforming relative to other elevation cohorts. Likewise, this trend appears to have accelerated in and around 2000. While measurements of SLR on the East Coast of the U.S. were observed to accelerate in the 1990s (Miami-Dade Sea Level Rise Task Force, 2014; Davis and Vinogradova, 2017), observed incidents of increased flooding (of different types) in MDC appear to have accelerated just after 2000 (Wdowinski, et al., 2016). This pattern of acceleration was observed not just in a majority of the sample, as represented in Figures 4 (All Properties), Figure 5 (unincorporated MDC), and, to a lesser extent, in Figure 6 (Miami), but also in areas such as El Portal, Miami Shores, and North Miami Beach, which are subject to ongoing tidal flooding and King Tides (*see* Appendix Figures 2, 4, and 5, respectively).

The evidence supports a validation of the Elevation Hypothesis with the broader inference that higher elevation properties may have a slight advantage in terms of higher rates of price appreciation that may be increasing with time. By contrast, the evidence supporting a validation of the Nuisance Hypothesis suggests that the lowest elevation properties may be at a price disadvantage. In relating these findings to a theory of climate gentrification, the connections are numerous. The Elevation Hypothesis provides support for the long-term occurrence of the Superior Investment Pathway. Over time, it could be argued that higher elevation properties in MDC will become more attractive for investors because of their superior rates of appreciation.

This may also be viewed within the context of the Nuisance Hypothesis wherein the lowest elevation properties are not appreciating at the same rate and therefore are inferior investments—assuming that rate of appreciation is the primary or significant factor for investment. The heuristics of real estate investment suggest that this rational maximization through long-term appreciation does not always hold (Salzman and Zwinkels, 2017). If real estate investors/owner see a relative disadvantage or opportunity cost to their lower elevation properties, then this may be one of many other factors that lead to spatial relocation or the disposition of a particular asset. Arguably, this may reinforce a Cost-Burden Pathway if lower-to-middle income property owners have more at stake in terms of their overall portfolio. The cost burden may be increased by virtue of a cycle of declining tax rolls and fewer and fewer tax payers and income. In all cases, this article provides support for the proposition that climate change impacts could exacerbate environmental and locational effects and qualities in property that are already reflected to a certain extent in the housing market of MDC. Uncovering these effects and qualities is a critical first step for monitoring the arguably incremental occurrence of CG.

Conclusions

Why is CG important as a distinct category of gentrification? Often conventional forms of gentrification are measured relative to a (dis) proportionality of impact on vulnerable populations (Brown-Saracino, 2010). The drivers of such impacts are often the incidental increase in property values based on locational consumer preferences and speculative investments increasingly driven by global capital markets (Hackworth, 2001; Lees, Shin, and Lopez-Morales, 2016). These drivers are often matters of intangible perception and market behavior with varying degrees of rationalization and intention (Schlichtman, Patch, and Hill, 2017). In the case of CG, the physical and environmental characteristics of properties are the primary drivers. While other theories of gentrification, such as ‘green gentrification,’ accounted for positive amenities in driving gentrification, no theory has fully accounted for both the positive and negative physical and environmental characteristics driving displacement and instability (Bryson, 2013; Curran and Hamilton, 2017; Gould and Lewis, 2017). With all types of gentrification there are both positive and negative externalities (Lees, 2008; Freeman, 2011). Conventional forms of gentrification have largely been referenced to have largely localized distributional effects without regard to globalized neoliberal urban influences (Smith, 2002). The multi-scalar implications for CG challenge not only scale but also the specific directional relationship of financial and social capital transfers by and between any two or more geographies and populations. As such, the potential widespread and multi-scalar implications for CG suggest that matters of distributional and procedural justice are even more critical as larger and more diverse populations may be benefited and burdened by such phenomena.

Even if CG is otherwise validated to serve as an accurate description, what can the public

sector do to mitigate the negative consequences? The public sector has two primary points of contact. First, it has been argued that land use planning will need to take a more proactive role in driving adaptation from various hazards and risks. In coastal locations, such as MDC, there is arguably an inevitability to densification on higher elevation properties as SLR accelerates. In areas increasingly prone to forest fires, such as Los Angeles, there may need to be wholesale abandonment of areas that are unusually at-risk from conflagrations. These adaptive land use actions will be tasked with evaluating the consequences of these relocations and densifications. Likewise, these adaptations are not limited to land use. Adaptations for hazard mitigation, risk management and engineered resilience will all have economic and social consequences beyond the immediacy of their locations. As the Resilience Investment pathway highlights, there may be significant unintended consequences to such investments and actions.

Housing markets and consumer behaviors are complex. Positive relationships and correlations between elevation and price appreciation are not necessarily causal to ongoing climactic change and the occurrence of extreme weather patterns and events. However, this article demonstrates that the elevation of one’s home in the past, present and future matters in terms of long-term price appreciation and valuation. Future research will be tasked with understanding preferences and heuristics among relevant parties. In particular, there is a need to understand threshold dynamics that help define limitations in adaptation investments and behavior. CG itself represents a type of adaptation that may be adaptive or maladaptive depending from what perspective one frames the analysis. What this article does provide are examples of two viable methodologies for measuring relationships that are consistent with a theory of CG. The question is whether climate change and CG will accelerate faster than existing data proxies can reasonably measure? Does this matter? Could just one well-located climate-hedged real estate investment begin to catalyze CG across a broader sub-market or community? Are certain communities destined to be subject, in probabilistic terms, to CG by virtue of their physical and environmental characteristics? A diagnostic understanding of CG provides another step in a long journey of societal adaptation that seeks to refine our understanding of vulnerability in the name of protecting our most vulnerable populations from long-term maladaptation in human settlements.

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List of Tables and Figures

Appendix

Appendix Table 1: Sample Properties by Elevation in Multiplicative Price Index

Jurisdiction	Total (n)	% of Total	0-1 meters	1-2 meters	2-3 meters	3-4 meters	4-5 meters	5-6 meters
1 Miami Beach	1,580	1.46%	1,297	282	1	0	0	0
2 Unincorporated County	58,804	54.46%	652	30,033	24,709	3,111	263	36
3 Miami	7,234	6.70%	593	1,456	2,867	1,507	710	101
4 Miami Gardens	4,990	4.62%	544	3,060	1,237	149	0	0
5 West Miami	328	0.30%	0	79	248	1	0	0
6 Miami Lakes	2,112	1.96%	0	2,054	58	0	0	0
7 Hialeah	5,988	5.55%	27	5,208	753	0	0	0
8 Virginia Gardens	133	0.12%	1	129	3	0	0	0
9 Coral Gables	4,227	3.91%	58	598	2,195	1,145	181	50
10 Miami Shores	1,276	1.18%	107	145	973	51	0	0
11 North Miami Beach	2,037	1.89%	150	410	1,378	99	0	0
12 Pinecrest	2,016	1.87%	0	572	1,155	207	72	10
13 Cutler Bay	3,678	3.41%	2	2,536	1,061	78	1	0
14 Doral	2,232	2.07%	1	2,142	89	0	0	0
15 Palmetto Bay	3,260	3.02%	1	1,496	1,167	526	70	0
16 Surfside	388	0.36%	351	37	0	0	0	0
17 North Miami	2,227	2.06%	124	859	884	356	4	0
18 Aventura	287	0.27%	1	278	8	0	0	0
19 South Miami	924	0.86%	0	270	424	211	18	1
20 Opa-Locka	386	0.36%	1	225	154	6	0	0
21 Hialeah Gardens	773	0.72%	0	773	0	0	0	0
22 Biscayne Park	335	0.31%	3	282	50	0	0	0
23 Miami Springs	1,108	1.03%	65	1,006	37	0	0	0
24 Sweetwater	349	0.32%	0	348	1	0	0	0
25 Key Biscayne	541	0.50%	435	106	0	0	0	0
26 North Bay Village	139	0.13%	128	11	0	0	0	0
27 El Portal	232	0.21%	28	72	109	22	1	0
28 Sunny Isles Beach	141	0.13%	89	52	0	0	0	0
29 Bay Harbor Islands	104	0.10%	84	20	0	0	0	0
30 Medley	12	0.01%	0	9	3	0	0	0
31 Bal Harbour	43	0.04%	28	15	0	0	0	0
32 Golden Beach	95	0.09%	73	14	8	0	0	0
33 Indian Creek	5	0.00%	1	4	0	0	0	0
Total	107,984	100.00%	4,844	54,581	39,572	7,469	1,320	198

Positive Observed Relationship between Elevation and Valuation
Negative Observed Relationship between Elevation and Valuation
Inconclusive Relationships
Inadequate Granularity in Elevation Data
Inadequate Data

Appendix Table 2:Regression Results for Elevation Effects on Price Appreciation by Jurisdiction

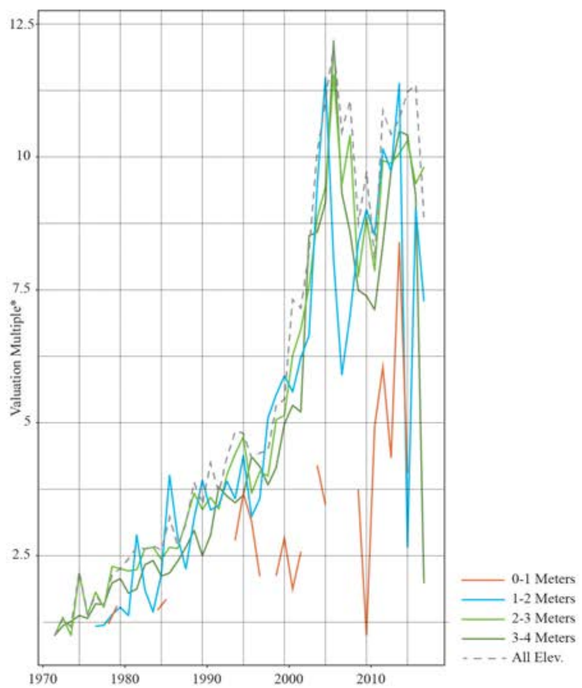
Mixed Linear Model Regression Results

Model:	MixedLM	Dependent Variable:	price_relative_ind
No. Observations:	107894	Method:	REML
No. Groups:	33	Scale:	27.8970
Min. Group Size:	5	Likelihood:	- 333046.9037
Max .Group Size:	58804	Converged:	No
Mean Group Size:	3272.2		

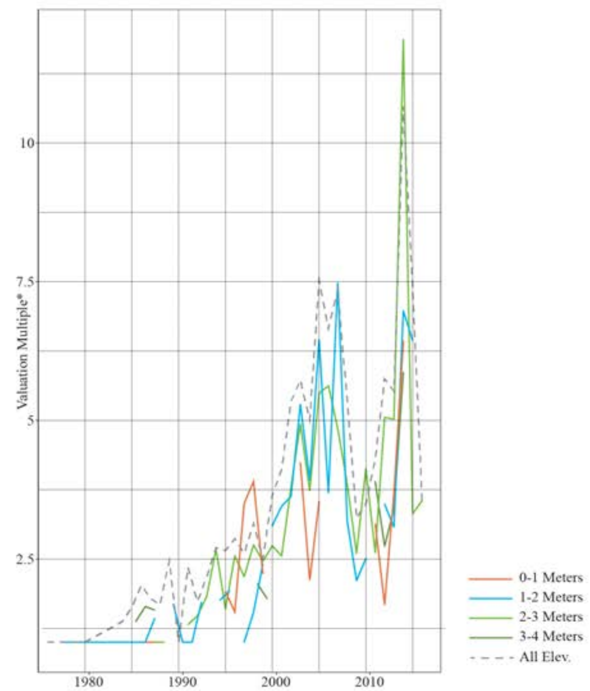
	Coef.	Std. Err.	z	P>|z|	[0.025	0.0975]
Intercept	- 561.170	3.592	- 156.249	0.000	-568.209	- 554.130
YearBuilt	- 0.020	0.001	- 20.187	0.000	-0.022	- 0.018
LivingSqFt	0.001	0.000	30.023	0.000	0.001	0.001
Sale_Date_1	0.303	0.002	177.429	0.000	0.300	0.306
Elevation RE	3.587	0.305				

Appendix Figures 1-4: Partially Positive Relationship between Indexed Valuation Multiple and Elevation Cohort

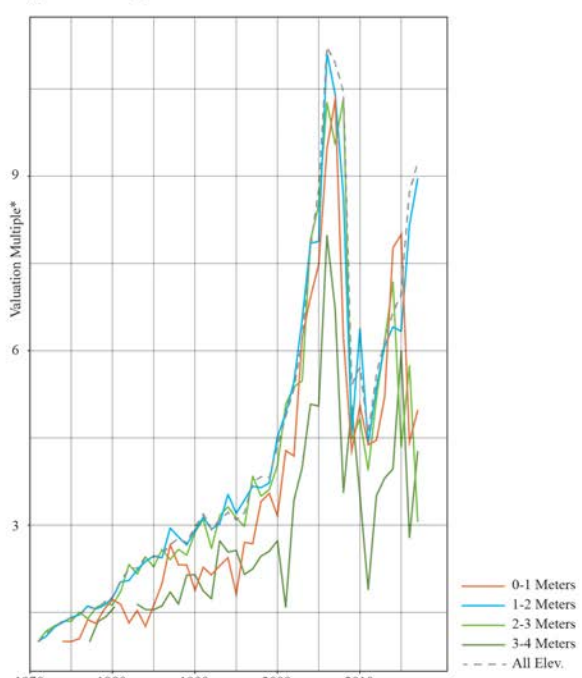
Appendix Figure 1: Coral Gables



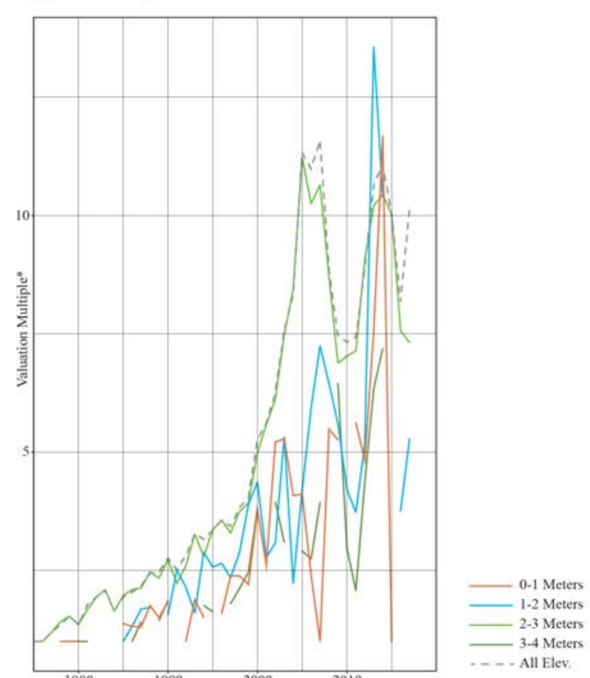
Appendix Figure 2: El Portal



Appendix Figure 3: Miami Gardens



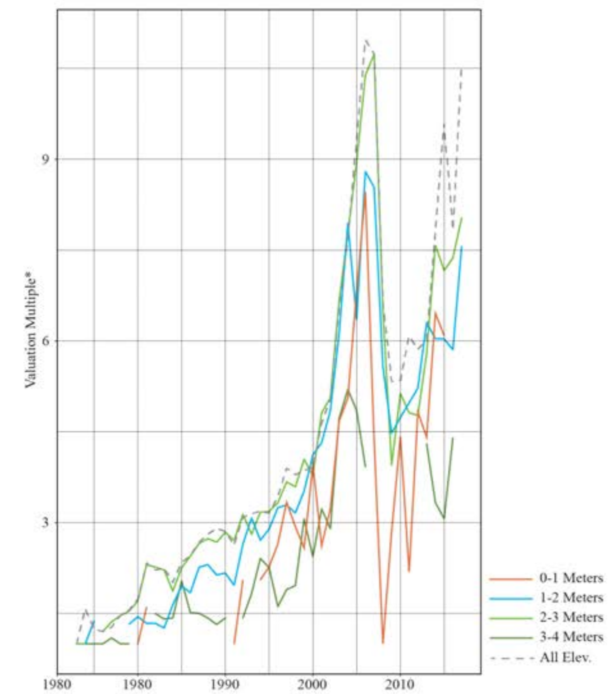
Appendix Figure 4: Miami Shores



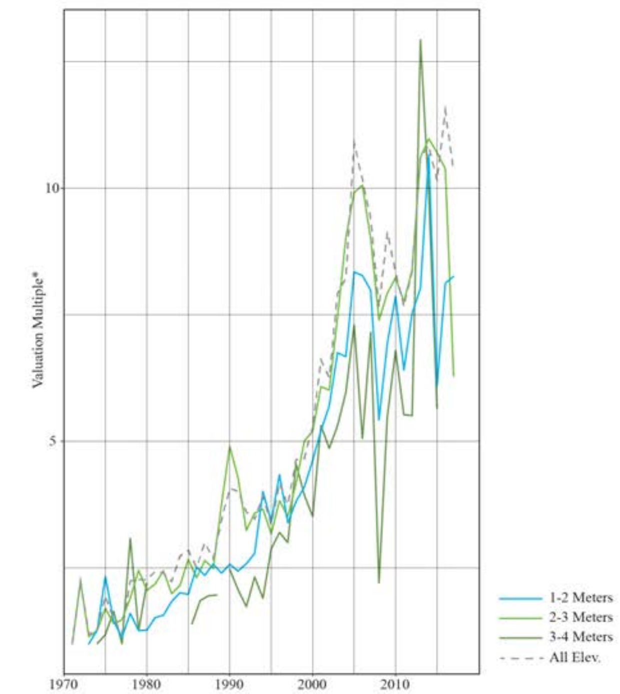
*Note: Price multiple indexed to 1971.

Appendix Figures 5-8: Partially Positive Relationship between Indexed Valuation Multiple and Elevation Cohort

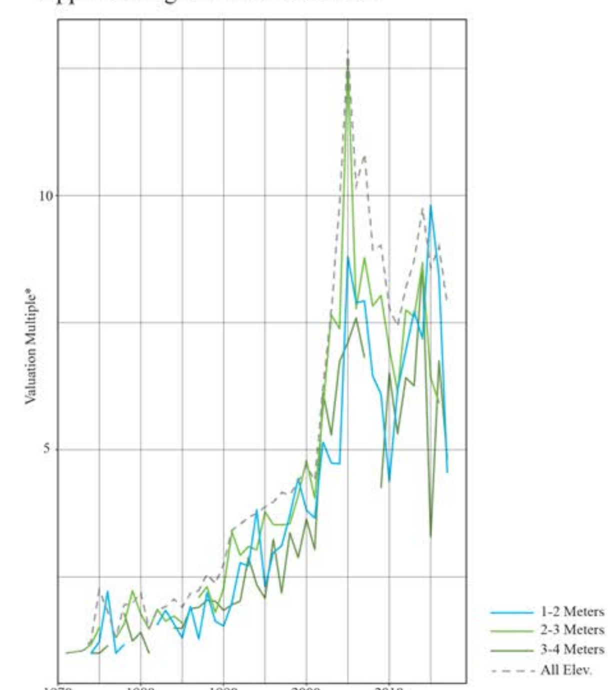
Appendix Figure 5: North Miami Beach



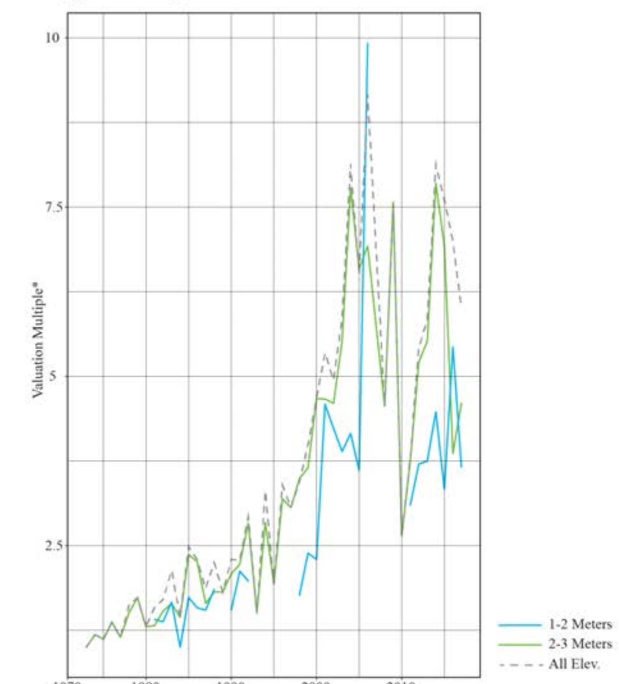
Appendix Figure 6: Pinecrest



Appendix Figure 7: South Miami



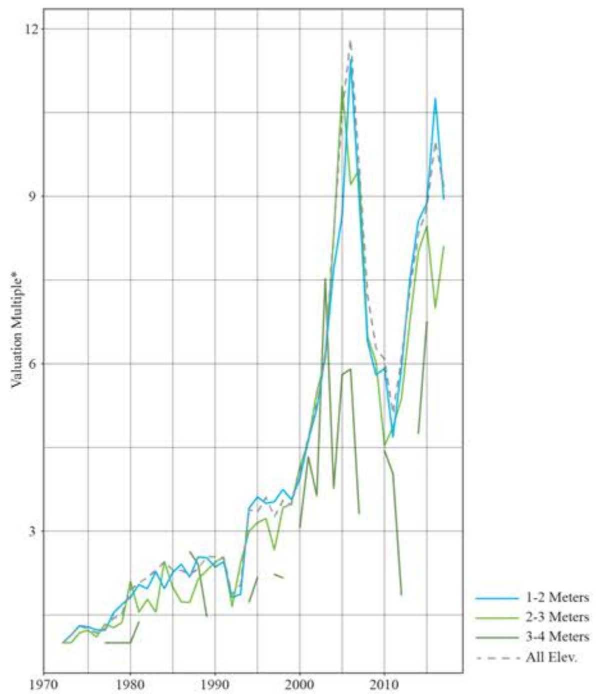
Appendix Figure 8: West Miami



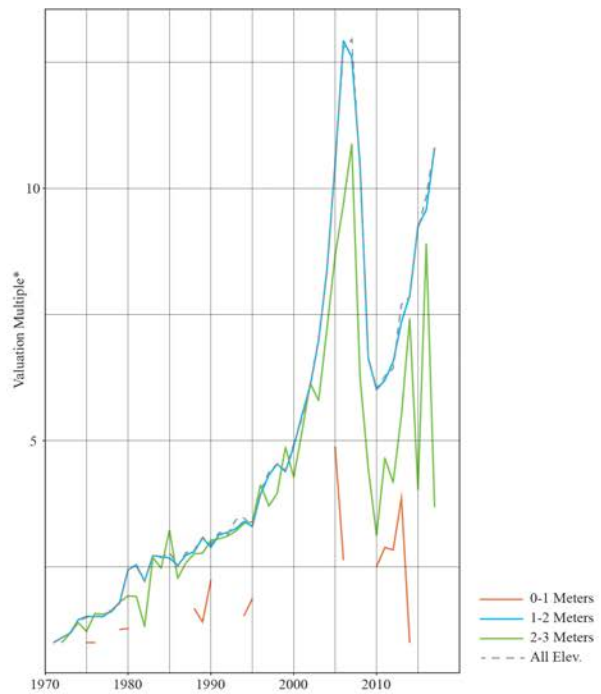
*Note: Price multiple indexed to 1971.

Appendix Figures 9-12: Partially Negative Relationship between Indexed Valuation Multiple and Elevation Cohort

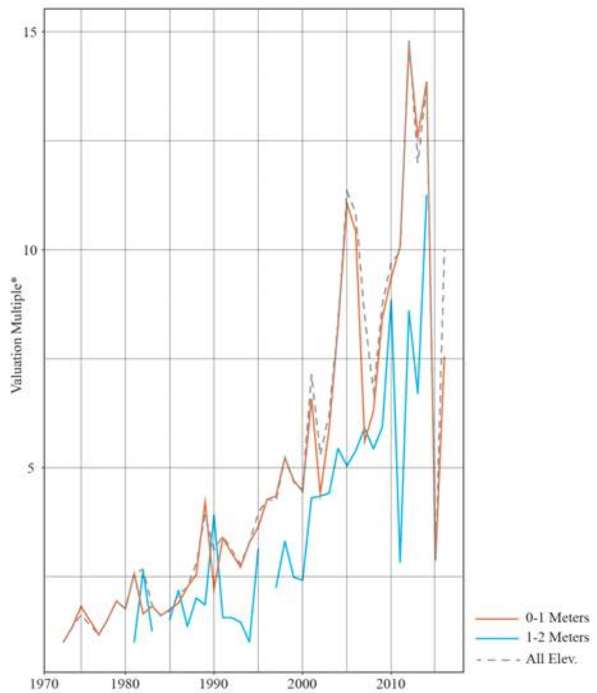
Appendix Figure 9: Cutler Bay



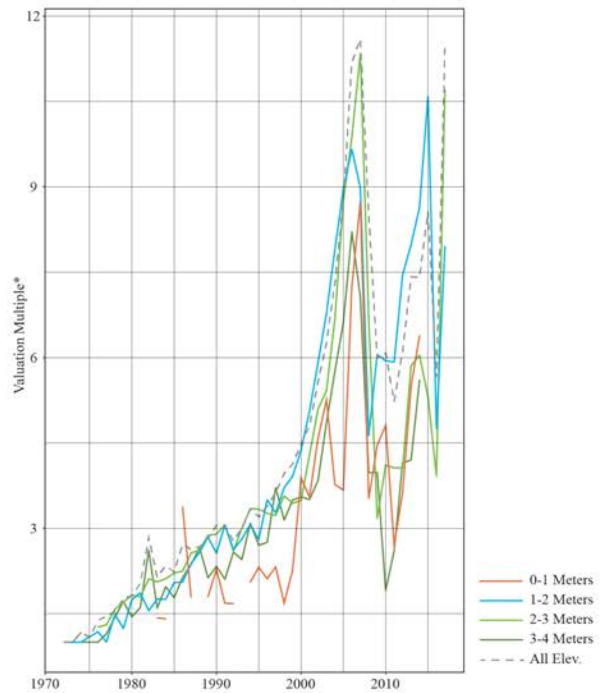
Appendix Figure 10: Hialeah



Appendix Figure 11: Key Biscayne



Appendix Figure 12: North Miami



*Note: Price multiple indexed to 1971.

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