Razing San Francisco: The 1906 Disaster as a Natural Experiment in Urban Redevelopment

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Abstract

Natural disasters that destroy urban areas leave opportunities to adapt city environments to contemporary needs. Since it is costly for developers to adapt durable real estate to changing economic conditions, such investments can be a significant factor in determining urban growth and development patterns over time. Exploiting the 1906 San Francisco fire as an exogenous reduction in the city's building stock, this paper examines residential density before and after the disaster using a unique dataset and the fire's boundary as a discontinuity in treatment. Evidence suggests that significant changes in the city's structure occurred upon redevelopment following the disaster. Specifically, by 1915, residential density had increased substantially in areas razed by fire relative to unburned areas, an effect which persists into 1931. Additionally, using the estimated treatment effect and historical rent data, this study estimates that redevelopment costs were at least 65 percent of annual residential rental income in early twentieth century San Francisco. These findings suggest that thriving cities experience substantial rigidities in the form of durable capital investments.

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San Francisco is gone. Nothing remains of it but memories.

- Jack London

...I expect to see the great metropolis replaced on a much grander scale than ever before.

- George C. Pardee, Governor of California

1 Introduction

Whether primarily urban or rural, natural disasters often leave immense destruction in their wakes. However, they also leave opportunities for change. Landowners and developers must decide if, when, and how to reconstruct damaged areas. What can economists learn about urban development from studying a rebuilt city affected by a large-scale disaster? Using the destruction from the 1906 San Francisco earthquake and fire as a laboratory, this study seeks to understand the role of durable capital investments in determining urban development patterns. All else equal, significant differences between pre- and post-disaster city land use imply that the durability of urban capital is an important barrier to redevelopment, which the disaster eliminates.

Several studies by economists have incorporated natural disasters in some fashion. Although much of the empirical work has focused on the macroeconomic consequences of natural disasters (Skidmore and Toya (2002); Kahn (2005); Noy (2009)), other work has focused on consequences at the city or regional level. In their paper on the bombing of German cities during World War II, Brakman et al. (2004) test the hypothesis that bombings had a large effect on city growth in subsequent years. For Germany as a whole, the authors find that large shocks have a significant, although temporary, effect on subsequent city population growth. Using the Allied bombings of Japanese cities during WWII as a shock to city size, Davis and Weinstein (2002) find that large localized shocks have little impact on the population density of such areas or the spatial organization of an entire economy. These studies are primarily concerned with the response of city population growth and city-size distributions to large shocks. Together, they suggest that cities are able to rebuild and return to normal growth patterns fairly quickly following large disruptions.

Other studies have focused on the implications of disasters for urban land use and manufacturing in various cities. For instance, Rosen (1986) analyzes the process of rebuilding a city following a major calamity. She studies three large urban fires in American history in the cities of Chicago, Boston, and Baltimore, with a particular focus on the politics of disasters in the context of city reconstruction. She interprets the changes that result in city structures as the culmination of power struggles between citizens, elites, and politicians. A study by Fales and Moses (1972) attempts to explain the distribution of population and industry in Chicago during the 1870s, exploiting the 1871 fire as a way to understand land use. Using population and manufacturing employment as their variables of interest, the authors find a negative distance gradient that is dependent upon location within various quadrants of the city. Although they use the fire as a way to understand land use patterns, their study does not compare pre- and post-disaster outcomes.

This paper seeks to understand the extent to which real estate investments act as a barrier to urban redevelopment in cities experiencing economic growth. Because such investments are durable and specific, they are a likely source of path dependence. In urban economic models, a no-arbitrage spatial equilibrium is achieved through the location decisions of consumers. At any given time, however, urban citizens may be constrained from making substantial changes due to the costs associated with adapting real estate and land use to contemporary needs. In the case of a city beset by a large-scale disaster which destroys thousands of buildings, a unique opportunity to make such changes is presented as the costs of doing so are severely mitigated.

Consider San Francisco, a city which experienced significant population growth leading into the early twentieth century.[1] In the sample constructed for this paper, roughly 50 percent of housing units in 1899 and 60 percent in 1905 were dense forms of housing, namely flats and apartment units. This number had increased to nearly 80 percent by 1915 and almost 90 percent by 1931. Figure 1 shows evidence of this dramatic shift in residential investment. It is clear from these data that city developers moved away from single dwellings and multi-dwelling units and into denser forms of housing. What accounts for this overall change in residential development? This paper argues that the 1906 disaster provided the means for such a change by significantly reducing the costs of adapting the city's structure to contemporary needs.

Reorganizing a city's capital environment is a costly endeavor, one that is rarely (if ever) undertaken in wholesale fashion. However, history provides laboratories for studying such accelerated development. Using the city of San Francisco, this study focuses on the boundary of the fire that burned following the 1906 earthquake and compares residential structure inside and outside the boundary both before and after the disaster. Employing a differences-in-differences (DID) approach and a unique dataset, evidence of a significant increase in residential density is found in areas destroyed by the fire relative to unburned areas. Further, estimates based on this density increase suggest that redevelopment costs were at least 65 percent of annual rental income per acre in early twentieth century San Francisco. These findings imply that thriving cities face substantial barriers to redevelopment, a large source of which is the physical durability of buildings.

The paper proceeds as follows. Section 2.1 provides a brief history of the 1906 San Francisco disaster. Section 3 describes the economics of residential density and land use as it relates to urban economic theory. Section 4 describes and summarizes the data. Section

[1] Evidence of the consequent strain on the housing stock is seen in various articles that appeared in the *San Francisco Chronicle* prior to the fire. For example, in May 1904, one journalist wrote, "Home-site buying is in full swing. It is the result of the rapid growth of San Francisco's population...with the consequent crowding of people...where they have learned that the excess of demand over supply of dwellings meant for them such expenditures for rent or board as to leave nothing from their incomes for savings."

5 presents the estimation methods and results. Section 6 concludes.

2 The 1906 San Francisco Earthquake and Fire

2.1 A Brief History

Due to their dense nature, cities have historically been susceptible to fires. The most destructive urban conflagrations in American history occurred in Chicago (1871), Boston (1872), and San Francisco (1906). The San Francisco fire was the most devastating by most measures, destroying entire business and industrial areas, and thousands of residential buildings. Burning over the course of three days following a tremendous earthquake on April 18, the fire spread from a locus in the center of the financial district. A report by the National Oceanic and Atmospheric Administration (NOAA (1972)) asserts that the fire consumed roughly 4.7 square miles (2,831 acres) and 28,188 total buildings, of which 24,671 were wood. Estimated property damage from the disaster in 1906 dollars is $400,000,000, $320,000,000 of which was caused by the fire alone. An estimated majority of San Francisco's population became homeless as a result of the fire, amounting to between 200,000 and 250,000 people (Fradkin (2005)). Documented estimates of the number of deaths range from 498 (Greely (1906)) to over 3,000 (Hansen and Condon (1989)). The pinnacle of California's development in the late nineteenth century, the city by the bay quickly became a focus of regional and national charity. Aid from U.S. military agencies, private donations, and charitable organizations made up the bulk of relief funds.

The earthquake caused damage in many other nearby cities, including Berkeley, Oakland, and San Jose. In San Francisco, the fire added havoc for several days following the initial shock. Figure 3 shows the overall coverage of the fire, represented by the darkest area on the map. As is evident, only a few small areas escaped the flames within the fire's boundary. The buildings which suffered only from earthquake damage were much less compromised relative to those which were razed by fire. In dollar terms, estimated property damage by the fire quadrupled that done by the earthquake alone, representing 80 percent of total damage. It is important to note that some researchers believe this estimate is understated. For instance, Tobriner (2006) estimates that fire damage may actually account for 95 percent of the total property damage inflicted by the disaster.

In the early twentieth century, San Francisco was a well-worn, yet thriving, metropolis. Having begun as a mining outpost in the mid-nineteenth century, it became a center of trade, industry, and commercial interests over the following decades. Boasting a population of over 340,000 in 1900, it quickly cemented its reputation as the premier city of the American West. Population data in Table 1 indicate the city's growth trajectory during this time. Between 1900 and 1910, in spite of the disaster, the city grew by over 74,000 people. This growth was consistent with that experienced in other decades before and after the 1906 earthquake. Thus, at the turn of the century, San Francisco was thriving with seemingly great expectations for its future. Even the disaster did not seem to dim the optimism of its populace; the Pan-Pacific International Exposition was held in San Francisco in 1915 and showcased with great acclaim the reconstruction of the city.

Like other major cities at the turn of the century, San Francisco can be described by its neighborhoods. Prominent areas that evolved over its history and remained distinct through the period under study are shown in Figure 4 and described in Table 2. Each of these neighborhoods suffered destruction, but the areas primarily hit were South of Market, Mission District, Nob Hill and North Beach. Pacific Heights and Western Addition also received extensive damage near the fire's boundary. These neighborhoods will act as controls in the estimations presented later in the paper.

2.2 The Fire and its Boundary

Because the boundary of the fire is important in identifying the effect of interest in this study, it is imperative to understand how it came to be. As Figure 3 shows, portions of the fire's coverage are strongly delineated by long portions of streets. The widest of such streets acted as helpful firebreaks in some areas, but were not enough to curb the conflagration in other areas. If streets were not always sufficient to douse the flames, how were certain blocks spared while adjacent blocks burned? As this section describes, some areas were helped by the presence of railway lines, favorable winds, or the waterfront. Other areas had the help of dynamite, water pumped from local reservoirs or cisterns, or intense efforts by citizens and firefighters.

Lasting three days, the main fire began shortly after the earthquake struck on the morning of Wednesday, April 18. It erupted in the downtown area and South of Market, spread north into Nob Hill and south into Mission District by Thursday, and reached the North Beach area by Friday before burning out at the bay. Figure 4 displays these areas. The fire spread primarily because most of the city's water mains, many of which were located in soft ground (i.e., made land), were broken during the earthquake. Upon realization of this occurrence, efforts were quickly diverted into using other means to fight the blaze. These methods ranged from dousing the flames with barrels of wine on Telegraph Hill to using dynamite to destroy buildings in the path of the fire in order to create firebreaks (Tyler (1906)).

An excellent account of the disaster is given by Davies (2012), in which she describes how the fire was stalled in various portions of the city. Much can be learned by combining her account with the spatial analysis of pre-disaster residential density from 1899/1900, as shown in Figure 10. A cursory glance at the map reveals that pre-disaster densities were most similar across razed and unburned areas in Western Addition and Mission District. Such outcomes are supported by the work of Davies (2012), which suggests that the fire was checked in the Western Addition neighborhood by intense firefighting efforts and the presence of water (p30). She also describes successful efforts to stop the fire in Mission District, where citizens rallied to save their homes and where water was also available from a hydrant and cistern (p36). Together, these two neighborhoods represent areas of the city where firefighting efforts were most successful, and consequently where the fire's destruction was least dependent on the land use of the area. As a result, pre-disaster densities are most similar across razed and unburned blocks in these neighborhoods.

Other neighborhoods, however, were not as successful in curbing the fire. South of Market, the area of the city burned during the first day, was caught largely by surprise. The few blocks spared were saved primarily by favorable winds which blew the fire in a northwesterly direction (Thomas and Witts (1971), p101-102). Along with the wind, several blocks may have also been helped by the presence of railway lines that ran both along and directly on them, as well as through firefighting efforts that saved many Southern Pacific sheds in the area (Thomas and Witts (1971), p171). North Beach also experienced difficulty in fighting the fire. As Davies (2012) notes, the North Beach neighborhood was the last area to burn, and consequently firefighters were exhausted by this time (p38-39). The only thing working in this area's favor was the supply of water from the bay, which was pumped and directed toward several blocks, ultimately saving them from destruction.

It is evident from these accounts that there were many efforts to stop the fire. However, some were unsuccessful, and may have even propagated the flames. What is perhaps most informative is that these efforts were not intended to push the fire in any single direction, but rather to create a firebreak to stop it in its tracks. It can thus be argued that although efforts may have influenced the spread and direction of the fire, they were not conducted with intention of burning specific areas of the city. However, in combining analysis of the map shown in Figure 10 with the accounts given above, this study will consider an estimation using a subsample which includes only blocks in the Western Addition and Mission District neighborhoods, areas in which there are no statistically significant pre-disaster differences in average residential density. Such blocks were arguably the most exogenous portions of the fire's boundary, as firefighting efforts were most successful in these areas.

2.3 Reconstruction and Regulatory Changes

San Francisco had an amazing opportunity to rebuild the city following the disaster. Not only was much of the urban landscape leveled, but there was also a far-reaching city plan finished by a popular urban planner named Daniel Burnham just days before the earthquake. The plan included the widening and redirecting of many streets, and the inclusion of more parks throughout the city. Burnham also envisioned a large civic center from which a radial network of streets would emanate. Although there was much debate about seizing the opportunity to rebuild according to the plan, the only significant change occurred near the civic center, where several blocks were taken for the city's use. According to Kahn (1979), "In San Francisco, a strong commitment to private property rights prevented the expansion of public authority." In the rush to rebuild, businessmen were eager to revive trade and landowners were not agreeable to giving up portions of their property for the sake of reorganizing the city's layout. This episode provides evidence that preferences for widespread change in infrastructure were dominated by private interests.

As previously described, over 200,000 people became homeless after the fire. However, even with such displacement, the city was not under extreme pressure to immediately house all of them. Many citizens fled San Francisco for nearby areas. Southern Pacific offered free passage out of the city to 300,000 people over eight days following the fire. Many left for nearby areas, and some migrated as far as Los Angeles. The remaining individuals were housed in temporary camps constructed throughout the city, where 50,000 people lived in June and 17,000 by the fall of 1906 (Douty (1977)). According to Tobriner (2006), thousands of people still remained homeless several years after the earthquake. This outcome suggests that the city's developers did not hastily rebuild in order to house the homeless, but instead rebuilt in a manner that reflected the expectations for permanent housing demand.

Another key to this study is understanding the regulatory environment surrounding the reconstruction of San Francisco. Did the city rebuild in a largely free market setting, or did regulation somehow influence the change shown in this paper? While a number of changes to the city's building code were proposed, few were implemented. Among the most important are a moderate expansion of the city's fire limits where buildings were required to be constructed of non-combustible materials, a new fireproof roof area where building roofs were required to be non-combustible, and the legal permissibility of concrete in buildings. Height limitations and fire-resistant walls in wood-frame buildings were also proposed, but either defeated or ignored (Fradkin (2005)). In the end, as many have criticized, the city was largely left to rebuild itself with little interference from the city's building department. The remaining portion of this section relies heavily on Tobriner (2006), who provides an excellent account of pre- and post-disaster building regulations.

The fire limits, which covered primarily the downtown area, expanded moderately following the disaster. Perhaps of greater economic consequence was the new widespread fireproof roof area implemented shortly after the fire. This area covered almost all of the burned area of the city except Mission District. As a result of these regulatory changes, buildings within these areas became more costly to construct relative to buildings constructed outside these limits. Thus, due to their potential to at least partially determine residential density, the fire limits and fireproof roof area are considered in the econometric analysis in an alternative specification, the results of which are shown in Table 9. They are not included in the main analysis since they may be interpreted as responses to, and thus outcomes of, the disaster.

Some important changes were also proposed in the building code, most of which were ignored or rescinded in the rush to rebuild. Perhaps the most important was the adoption of concrete in load-bearing walls. Prior to the earthquake, such building material was viewed with suspicion, although the bricklayers' union also fought vigorously against allowing it in the codes. There were also proposals for height limitations. However, engineers and architects worked feverishly to defeat these proposals, and eventually won. Ultimately, wood remained the main ingredient in the reconstruction of San Francisco. It was cheap and believed to be much safer in earthquakes than other building materials. Thus, aside from the fire district and fireproof roof area, very little change occurred in the regulatory environment that might affect the results of the study.

Although not directly related to the fire, San Francisco passed its first zoning ordinance in 1921. However, as Weiss (1988) notes, zoning decisions were made by the Board of Supervisors until 1928, when a commission was established to oversee zoning practice in the city. As Weiss states, "In the freewheeling 1920s, the San Francisco Board of Supervisors...would frequently grant almost any zoning change requested by any property owner..." (p317). The City Planning Commission acted more stringently, but the Great Depression quickly suppressed the realization of their newfound powers as little building activity occurred during this time. Thus, evidence from Weiss (1988) suggests that zoning played a relatively minor role until after the Great Depression, which is a time period beyond the scope of this study.

To provide a sense of the reconstruction that took place following the disaster, Figure 5 shows the level of total building permits granted for each fiscal year from 1902 through 1914, which is the year construction began on the Panama-Pacific Exposition site. The data provide evidence of the rapid reconstruction that took place in San Francisco. Building trends upward from 1902 to 1905, and spikes as a result of the disaster in 1906. There are no building permit data for the fiscal year ending 1906. Much undocumented reconstruction took place immediately after the fire. Hence cumulative building between 1906 and 1914 is greater than what the figure indicates. The building trend flattens beginning in 1910 and returns to a pre-disaster level by 1914. As Table 3 indicates, the cumulative total of documented buildings constructed in San Francisco after the fire and before the Exposition is 28,507, which is composed of buildings in both razed and unburned areas. The table also reveals that the material composition of buildings did not change drastically following the fire.[2]

3 The Economics of Urban Land Use

3.1 The Role of Durable Capital

The foundation of current theory in urban economics was introduced by Alonso (1964), who adapted the von Thunen (1826) model of location-dependent land rent around a central market to fit the structural reality of modern urban areas. Mills (1967) and Muth (1969) further developed the model so that, together, their studies formed the basis of the static monocentric city model. In the model, there is a premium for land located near the central business district (CBD) due to consumer commuting costs that increase with distance to the city center. In spatial equilibrium, consumers located farther from the CBD are compensated with larger dwelling units through lower housing prices. This results in a negative land rent gradient with respect to distance from the CBD. Given this gradient, housing developers substitute toward more capital in production by building taller structures, and hence denser living accommodations, near the CBD. Changes in population, income, and commuting costs all imply changes in the equilibrium structure of the city.

As Brueckner (2000) notes, an implicit assumption in the static model is that city capital is malleable, meaning that a city can be rebuilt every period to achieve a new equilibrium. Perhaps more realistic are the various dynamic models that have accounted for the durable nature of capital investments in a city.[3] With time and redevelopment costs introduced as components in the development decision, implications arise for urban growth and residential

[2]Building permit data were gathered from annual San Francisco Municipal Reports. These reports are described in the Data Sources section of the paper.

[3]An excellent review of such models, along with comparisons to static model predictions, is given in Brueckner (2000).

density patterns. The unifying theme in most dynamic urban models is that time influences land prices (through population growth, income growth, or changes in commuting costs), which in turn influence both spatial and temporal development decisions. As such, residential density patterns will vary depending on model parameter values.

An influential study on urban density gradients is Harrison and Kain (1974). Their study is perhaps the first to empirically analyze urban form and development from an historical perspective. They emphasize a disequilibrium approach to urban growth, resulting inherently from the durable nature of residential and nonresidential capital. Their econometric model of cumulative urban growth, where density in any single period is a function of various factors present in that time period and previous densities, is consistent with findings based on static model predictions. Specifically, they find declining density gradients in major U.S. cities over the twentieth century, arguably caused by population growth, income growth, and improvements in transportation technology.

Recognizing the need to explain urban phenomena in a world of durable capital and changing economic conditions, Anas (1978) laid the groundwork for theory that incorporates the dynamic nature of urban residential investment. Understanding that such investment is a cumulative process, Anas develops a model which predicts a short-run equilibrium that qualitatively differs from the static model. In essence, with time a factor and irreversible housing development an important component, urban areas can spatially grow over time and end up being larger than in the static case where a city is rebuilt whenever new demand pressures arise. Authors who later expanded on the Anas model include Wheaton (1982a) and Fujita (1982).

In a model that incorporates the decision to redevelop land for housing, Brueckner (1980) shows that while irregular local density contours may occur because of redevelopment, the general density gradient remains like that predicted in the static model. With income and commuting costs growing over time, a negative structural density gradient still emerges, while structural density at a particular point is an increasing function of a building's construction date. Thus, newer parts of the city will exhibit denser living accommodations and redevelopment will occur in older areas.

Although dynamic models differ in their predictions of urban development patterns and density, they each stress the importance of past investment as a determinant of urban form. It is thus evident that urban economists recognize the need to incorporate a sense of history in their models. Since the structure of a city is durable and specific, and redevelopment involves significant costs, cities exhibit the legacy of past investment decisions. This legacy can lead to deficient city structures and density patterns, which in turn affect the agglomeration economies that contribute to urban growth (Jacobs (1961)). As a result, a city can be more an artifact of its history, and less a product of its expectations for the future. In the case of a large-scale urban disaster that destroys a significant amount of capital stock, there are new opportunities to deviate from a particular path and achieve a new equilibrium. The further the deviation from the previous state, the more weight past investments and the costs of redevelopment carry in determining urban growth patterns. In this vein, recent work by Bleakley and Lin (2012) reveals the important role path dependence plays in contemporary city locations. The rest of the paper is devoted to understanding this role in determining the residential structure of a city.

3.2 Urban Redevelopment

The decision to redevelop land is an important theme in urban economics, as discussed in Brueckner (1980), Wheaton (1982a), and Wheaton (1982b). In theory, redevelopment occurs when the value of redeveloped land exceeds its current use value by the costs of redevelopment. Empirical research by Rosenthal and Helsley (1994) provides support for this rule using house sales data from Vancouver, British Columbia. Munneke (1996) analyzes redevelopment in the context of commercial and industrial property sales data and also finds evidence in support of the theory. In their work on teardowns and land values in the Chicago area, Dye and McMillen (2007) show that the sales price of property to be torn down, or redeveloped, is approximately equal to its land value. Together, these studies indicate that redevelopment costs can be prohibitive in achieving new land use outcomes.

Urban economists and historians who study cities understand the costly nature of adapting urban environments to contemporary needs. Hochman and Pines (1980) cite the importance of adjustment costs in adapting urban land uses to new equilibrium outcomes. In her book on urban fires, Rosen (1986) provides an account of the barriers associated with redevelopment. Such constraints include the physical durability of buildings, demolition and replacement costs, technological barriers, real estate market imperfections (e.g., land assembly problems, under-investment due to negative externalities in location). As Table 3 shows, technology was not a likely barrier to pre-disaster change in the material composition of buildings and was therefore not likely to inhibit developers from constructing desirable buildings in early twentieth century San Francisco. The remaining barriers can be summarized in the form of costs to redevelopment (i.e., adjustment costs), namely demolition, construction, and transaction costs.

Urban developers must weigh various factors when considering whether to redevelop land. They must consider the value of land in its current use, its value in a redeveloped state, and the costs associated with redevelopment. In a simple setting, a developer is interested in earning revenue per acre from a particular plot, denoted as R. At any time, the developer can choose to earn the revenue commensurate with the plot's current use, R_{current}, or redevelop the plot in response to new economic conditions to earn R_{new}. Given demolition (D), construction (C), and transaction (T) costs, a developer will choose to redevelop when

$$R_{\text{new}} - r(D + C + T) > R_{\text{current}}, \tag{1}$$

where r is a discount rate.

Notice in (1) that when costs are exceedingly prohibitive, land owners will be less likely to redevelop. In such a setting, R_{new} would need to be sufficiently high, or R_{current} sufficiently low, to warrant such a decision. However, if an enormous fire reduces the costs associated with urban redevelopment and renders $R_{\text{current}} = 0$, then redevelopment reflecting new economic conditions (which earns R_{new}) is extremely likely. Although this outcome is obvious, the main point to gather from this analysis is the importance of the barriers to redevelopment, or the costs encompassed in D, C, and T, in influencing the decision to redevelop under normal circumstances. The physical durability of buildings increases demolition and transaction costs.[4] When an urban fire reduces buildings to rubble, these costs become much less salient.

4 Data

4.1 Data Construction

Fire insurance maps, principally produced by the Sanborn-Perris Map Company, are an exceptional data source for information on urban development in the nineteenth and twentieth centuries. These documents were created for companies that insured buildings in urban areas against the risk of fire. Drawn at a scale of 50 feet to an inch, the maps contain detailed information on residential, commercial, and industrial buildings for thousands of cities and towns. Fire maps were produced for San Francisco in 1899/1900, 1905, 1913/1915, and

[4] It is perhaps obvious why the physical durability of buildings increases demolition costs. The effect on transaction costs may be less clear. Consider the case of land assembly as an example. A bargaining problem may exist between parcel neighbors who may not be able to agree on the value of the land to be assembled. The presence of a building likely complicates such bargaining and serves to inhibit potential agreement. Investment in new buildings may also be prohibited when developers are unable to capture all the gains from building such structures. This outcome may occur in older neighborhoods, for example, where the prevalence of dilapidated buildings may hold R_{new} sufficiently low to discourage redevelopment.

1928/1931.[5] These volumes most closely capture the 1906 disaster. Residential data are gathered from these surveys so that the resulting dataset is longitudinal, with pre-disaster waves in 1899/1900 and 1905 and post-disaster waves in 1913/1915 and 1928/1931.[6] Figure 6 provides an example of two sheets (each roughly 13 by 24 inches) from Volume 5 in the 1905 set. Figures 7 and 8 show digital copies of the maps used in gathering the data.

The fire maps allow for counting the number of residential units on each block, further distinguishing between single dwellings, multi-dwelling units, flats, and apartment units. Single dwellings are stand-alone residential units; multi-dwelling units share a common wall with another residential unit; flats occupy one floor (or partitioned floor) of a building; and apartment units are small living areas within an apartment building. Thus, single dwellings represent the least dense form of housing in the study and apartment units the most dense. These residential count variables are gathered for relevant blocks of San Francisco given the data from the fire maps. With the assistance of Geographical Information Systems (GIS) and other forms of technology, a net residential density measure is constructed, which equals the number of residential units per acre of residential land.[7] This density measure is an important land use outcome depicted in most urban economic models. In this measure, residential acreage excludes all vacant, nonresidential, and mixed uses of land, thus providing an accurate depiction of the intensity of residential land use at each point in time.[8]

The unit of analysis is a city block. The spatial organization of city blocks in San Francisco remained unchanged after the disaster, thus providing a reliable unit of comparison across time periods.[9] In each survey, observations were drawn from both sides of the fire's

[5] The city being a large area to cover, the volumes were typically produced over a span of multiple years. The 1905 volume is corrected from the 1899/1900 volume, and the 1928/1931 survey is corrected from the 1913/1915 survey.

[6] See the Data Appendix and Data Sources sections of the paper for details on the data-gathering process.

[7] Details of the data construction are given in the Data Appendix.

[8] For the remainder of the paper, 'residential density' or 'density' will refer to net residential density.

[9] Some blocks filled in a street, or added a street, following the disaster. This change in acreage over time is taken into account through the density measure described in the text.

boundary. For the post-disaster period, treatment was determined using a map created in 1908 by the State Earthquake Investigation Commission, shown in Figure 3.[10] Blocks which were completely consumed by the fire are in the treatment group, while unburned blocks are in the control group. Additionally, blocks which were only partially affected by the fire are in the treatment group if the majority of block acreage was burned; those having a minority of acreage affected are in the control group.[11]

Figure 9 shows the final group assignment for the sample. In keeping with the natural experiment approach, the overall objective in deriving this sample was to gather a considerable amount of observations while maintaining close proximity to the fire's boundary. There are trade-offs to this approach as statistical power increases with sample size, yet blocks become more dissimilar farther from the boundary. Taking these considerations into account, the total sample size is 421 city blocks, with 185 blocks in the treatment group and 236 blocks in the control group.

Blocks are further distinguished by the neighborhoods in which they are located. As discussed in Section 2.1, Table 2 describes the neighborhoods that existed around the time of the disaster while Figure 4 shows their location in the city. Each block's straight-line distance to city hall is also constructed. Due to its prominent and central location in San Francisco, distance to city hall is the primary distance variable used in the study.[12] Additionally, the fire limits and fireproof roof area variables used in an alternative specification were constructed from maps depicted in Tobriner (2006). Together, all of these variables act as controls in the reduced-form regressions presented in Section 5.2.

[10] To facilitate the GIS work, a digital copy of the map was downloaded from www.davidrumsey.com.

[11] Results from various robustness checks are presented in Section 5.2.2 where blocks partially affected by the fire are either in the treatment group, the control group, or excluded from the analysis. The results relied upon in this study are robust to such changes in the definitions of the treatment and control groups.

[12] Models using distance to city hall are slightly superior in explaining the variation in the dependent variables used in the study. Robustness checks using distance to downtown are performed and described in Section 5.2.2, revealing no qualitative difference between specifications.

4.2 Data Summary

To provide an overview of the composition of the housing stock and land use in the sample, Table 4 presents totals and proportions for relevant residential categories. Residential units are the sum of single dwellings, multi-dwelling units, flats, and apartment units. The land use data display acreage in residential, mixed, and vacant uses, with the remainder in various nonresidential land uses.

The data reveal a dramatic change in the housing stock following the fire. For instance, the total housing stock shifts away from low density housing (single and multi-dwelling units) before the disaster to higher density housing (flats and apartment units) afterward. In fact, no apartment buildings exist in this sample in the 1899/1900 survey. Roughly 50 percent of housing was devoted to flats in 1900 and nearly 60 percent to flats and apartment units in 1905. Several years after the fire, flats and apartment units made up nearly 80 percent of the stock and almost 90 percent by 1931. As the table shows, and Figure 2 displays, these changes are most dramatic in the area razed by fire. In reconstructing the city, developers greatly adjusted the composition of the housing stock by shifting construction into denser buildings.

Table 4 also corroborates evidence that the city's housing stock was quickly rebuilt following the fire. By 1915, residential units in the razed area had reached over 70 percent of the amount present in 1905 and exceeded this amount by 1931. Residential units increased in the sample overall for both razed and unburned areas near the fire's boundary, where developers expanded the housing stock over 35 percent between 1905 and 1931. As described in Section 2.1 and shown in Figure 5, much of the increase in the housing stock in the unburned area is due to development following the disaster. Of course, significant changes in the razed area are due to reconstruction after 1906.

As shown in Table 5, land use also changed considerably over the period of study. The most dramatic changes are in the residential category, where residential acreage overall declines over 15 percentage points after the disaster. As the panel reveals, land use changes in the razed portion of the city following the fire are responsible for most of the decrease in residential acreage. Also important for this study are the changes in vacant land over this time period, particulary in the burned area of the city. Perhaps unsurprisingly, vacant acreage makes up over 26 percent of total acreage in the razed area in the 1913/1915 survey. However, the last survey reveals that vacant land makes up only 9 percent of total acres in the razed area, roughly on par with such use in the unburned portion of the city. This outcome suggests that by 1931, San Francisco landowners had almost completely developed the land left vacant by the disaster.

Table 6 presents the means and standard deviations for key variables at the block level. Residential units are the sum of residential categories previously described. To aid the analysis, the table depicts residential acreage for the average city block in the sample. The primary outcome variable studied in this paper is residential density, or residential units per residential acre. This measure excludes the area devoted to public roads, reservoirs, parks, commercial and industrial uses, mixed uses, and vacant lots. The distance variables are given in quarter-mile units and the neighborhood variables represent the distribution of neighborhood locations.

In the 1899/1900 survey, the average razed block in the sample has 56 residential units and unburned blocks contain 22 units. These figures increase slightly by 1905. Although this initial difference is large, it is less dramatic when average residential acreage per block is considered. In the razed area before the disaster, the average block's residential acreage is 2 acres; in the unburned area, this figure is roughly 1.3 acres. Although the blocks on either side of the fire's boundary are separated only by streets, there are stark differences in average residential density between the two groups prior to the fire. Average residential density in the razed area is nearly twice that for blocks located just outside the boundary. However, as the table also shows, razed and unburned areas experience similar changes in residential density between 1900 and 1905.

Table 6 also reveals that residential land use changes more dramatically in the razed area relative to the unburned area over the sample's time period. For the average razed city block, these changes are substantial, representing a nearly 50 percent decline in residential acreage between 1900 and 1931. As the data suggest, these changes differ in the unburned area, whose average block experiences a much milder 7 percent decline in residential acres over this time period. Ultimately, developers rebuilt a larger housing stock than existed prior to 1906 and used much less land to do so.

5 Estimation Methods and Results

5.1 Identification Strategy

A key to identification in this study is the sharp delineation between the blocks consumed by the fire and those left unburned. The boundary of the fire represents the point at which blocks were differentially treated by the disaster. The study assumes blocks located directly across from one another on either side of the fire's boundary exhibit similar development trends over time. A DID approach is employed to identify the fire's effect on average residential density.

As section 2.2 describes, citizens and firefighters employed immense efforts to stop the fire on all fronts. Even so, this paper presents results of an estimation using certain parts of the boundary that are arguably most exogenous to land use. These are areas where firefighting efforts were most successful in stalling the fire and thus land use was not likely a factor in the development of the fire's boundary. As shown later, the main results of the study hold when using this subsample.

While buildings outside the fire's boundary suffered some damage, the bulk of total damage was inflicted by the fire. As Section 2.1 describes, estimated damage by the fire at least quadrupled the damage done by the earthquake alone. After the fire consumed its last building, adjustment costs in the razed area were reduced significantly relative to those in the unburned portion of San Francisco. Ultimately, the fire was vastly more destructive than the earthquake. On the blocks spared by the fire, the earthquake damaged some buildings beyond repair but largely left buildings in a reparable state. Thus, while the control group was not completely devoid of destruction, its ultimate state was one of only moderate disrepair relative to the treatment group. This made structural change more costly in the unburned area. The results of the study are interpreted in light of this fact.

The focus of this paper is on the importance of adjustment and transaction costs in achieving new urban outcomes in residential density. If such costs inhibit urban redevelopment (e.g., innovations in residential density patterns), then significant differences between San Francisco's pre- and post-disaster structure should be seen across the treatment and control groups. The following section presents estimation results of average residential density changes for blocks located near the boundary of the fire.

5.2 Regression Model

5.2.1 Residential Density

To motivate the analysis, consider Figures 7 and 8. The bottom blocks in each figure were razed by the fire, while the top blocks were spared. Figure 7 is from the 1899/1900 survey and Figure 8 is from the 1913/1915 survey.[13] Although it is difficult to see the detail of the buildings, the figures present a before-and-after look of a small area of San Francisco as it appears on the Sanborn maps. While the upper blocks experience some alterations over this time period, the bottom blocks experience a more dramatic change as a result of having to rebuild from the ashes.

[13]Figure 8 is inverted to correspond with Figure 7.

The goal of this section is to provide a quantitative approach to understanding this phenomenon through a regression framework. Let D_{it} be residential density on block i at time t. To motivate the analysis, consider the following model for residential density:

$$D_{it} = \alpha + \gamma d_t + \delta(R_i \cdot d_t) + (X_i \cdot d_t)'\beta + \theta_i + \varepsilon_{it}\,, \tag{2}$$

where R_i equals one for blocks razed by fire, d_t are time dummies, X_i are observable time-invariant block characteristics, θ_i are block fixed effects, and ε_{it} is an error term. The regressors in X_i include a distance variable and neighborhood dummies. The distance variable is considered because urban economic models suggest that changes in density across time periods may partly be a function of distance to a city's center, an effect that is likely not constant over time. Neighborhood dummies capture the heterogeneous effect across different areas of San Francisco, which may also exhibit time-specific effects. As Table 2 shows, neighborhoods also act as a useful proxy for income and sociodemographic characteristics. The average treatment effect of the fire on residential density is δ.

Table 7 presents the results from estimation of (2). Column 1 shows the results for a specification which simply interacts R_i with a variable indicating post-fire. In this estimation, the average treatment effect is 20 units per acre, a coefficient which represents the effect across both post-disaster periods. Column 2 shows the results when considering the treatment effects over separate years, while also estimating the relative change between razed and unburned areas between 1900 and 1905. The treatment effect is strong in 1915, a result which persists into 1931. The effect in 1905 is not significantly different from zero, a result which suggests that razed and unburned areas experienced similar changes in residential density between 1900 and 1905.

The model in column 3 includes distance to city hall as an explanatory variable, with the distance effect allowed to vary across years. Although they decrease, the coefficients on the 1915 and 1931 treatment variables again remain strong at over 15 and 18 units per acre, and both are significant at the 1% level. Distance to city hall is strongly correlated with the change in residential density in the estimation shown in column 3. The coefficient on this variable is interpreted relative to 1900. As such, the distance effect in 1931 is almost double that in 1915, and ten times that in 1905. The results in column 4 include a more flexible functional form for distance to city hall. In this case, distance has no differential effect in 1905 or 1915 relative to 1900, while it does in 1931. However, this effect disappears in the paper's main specification presented in column 5. There is no significant difference in the treatment coefficients between these specifications.

Column 5 presents results when including time-specific neighborhood dummies in the estimation of (2). Compared to the result in column 4, the treatment coefficient in column 5 becomes larger and remains significant at the 1% level. When including neighborhood-time dummies, the coefficients on the distance variables are no longer significant, evidence that they are capturing neighborhood effects rather than a distance effect. Although not reported in this table, negative effects (relative to the pre-disaster period) are prominent in South of Market and North Beach after the disaster, which are the working-class areas of early twentieth century San Francisco. In contrast, the richer neighborhood of Nob Hill experiences positive residential density effects over both post-disaster time periods.

As is evident, the treatment coefficient remains strong when estimating (2) with a full set of regressors. In this estimation, the average treatment effect in 1915 is a significant increase of 17 residential units per residential acre. Again, this effect persists into 1931. For the average razed block in the sample, this is a relative increase of nearly 14 residential units in 1915 and 22 units in 1931. The coefficient representing the treatment group in 1905 is marginally significant in this specification, thus suggesting a small differential change across groups leading up to the fire. However, this coefficient is insignificant in all other specifications presented in this table.

It is possible that there is some unobserved interaction between razed and unburned blocks located closest to the fire's boundary that is driving the results shown in Table 7. For example, if unburned blocks on the boundary received some development impetus from being directly across from the razed area, the main result may be biased. It may also be the case that razed blocks directly on the boundary were reconstructed in a different fashion from interior blocks due to their location near unburned roads and infrastructure. One way to address this is to estimate (2) using subsamples that distinguish between blocks directly on the fire's boundary and those interior to such blocks. Figure 9 shows these subsamples, while columns 1 and 2 in Table 8 report the estimation results. A constant and a full set of regressors are included in each estimation. As column 1 reveals, the average treatment effect remains positive for blocks located on the boundary, but is weaker and significant at the 5% level as residential density experiences a relative increase of 13 units in 1915, an effect which again persists into 1931. For blocks interior to the boundary, the average treatment effect is large and strongly significant at a 28 unit relative increase in 1905 and 39 unit increase in 1931. These results suggest that, for residential density, the fire had a larger effect on blocks interior to the fire's boundary than for those located on the boundary, a result which is consistent with the monocentric urban model's predictions of premiums for land located nearer to a city's center. Of slight concern might be the fairly strong effect in column 2 of the treatment group in 1905, but this estimation is not representative of the main specification used in the paper.

Columns 3 and 4 present estimation results for subsamples where positive residential density is observed in at least one or all periods. These estimations address the concern that blocks without residential development may be driving the results presented in Table 7. By excluding such blocks, the sample is restricted to those blocks with a tendency to be developed with residential structures. As the table reveals, the post-disaster average treatment effects of the fire remain strong and significant at the 1% level in both subsamples.

The treatment group effect in 1905 is only significant in the specification presented in column 3.

A primary concern in this study is the existence of pre-disaster differences among many of the variables. This outcome suggests that the fire's boundary may not be completely exogenous to residential density. For example, blocks which exhibited less residential density at the time of the earthquake may have provided a convenient firebreak as they likely had more open space. In this case, it is informative to restrict the sample to those blocks which exhibit no statistically significant pre-disaster differences in land use. These blocks are primarily located in Western Addition, Mission District, and the area where the fire crossed Van Ness Avenue near Pacific Heights. The construction of this subsample is motivated by the discussion of the fire's boundary in Section 2.2, where the determination to include particular blocks is based on an understanding of the fire's origin and spread and the efforts to fight the fire. Figure 10 also provides a useful illustration of pre-disaster similarities in residential density among these areas of the city.

Column 5 of Table 8 presents the estimation results when restricting the sample to blocks that are initially comparable in residential density. In this estimation, the treatment coefficient in 1915 remains significant at the 1% level and is stronger than the main result at a relative increase of 21 residential units per residential acre. However, the 1931 treatment effect weakens slightly and is significant at the 10% level. This estimation suggests that pre-disaster differences in residential density may be biasing the treatment coefficient against the hypothesis of post-disaster increases in residential density in the razed area. This result is expected if sparser blocks in the pre-disaster period have characteristics which are unfavorable to high levels of density, so that inclusion of such blocks likely biases the treatment coefficient downward.

5.2.2 Robustness Checks and Alternative Specifications

This section presents results of robustness checks and alternative specifications of the residential density model used in the study. The primary objectives are to test the sensitivity of the results to the assignment of city blocks to treatment and control groups, as well as to determine whether the general results change when using distance to downtown rather than distance to city hall, including regulatory variables, or incorporating mixed residential units in the density measure. The results derived in Section 5 are robust to these alternative specifications.

Table 9 presents the estimation results of the exercises previously described. All models include a constant and a full set of regressors. For reference, row A presents the original results shown in Table 7. The estimation in row B tests the sensitivity of the results to the use of distance to city hall in the base specification by alternatively using distance to a prominent downtown building. In urban economic models, the CBD is essentially a point in space. Of course, this is not true in reality, making the location of the center of the CBD difficult to determine exactly. In this specification, the center of the city is the location of the Phelan Building on Market Street, located midway between the city hall and the waterfront. Results using this measure differ little from the base specification. Thus, the use of a different city center has no qualitative effect on the results presented in the study.

Section 2.3 describes the changes in the fire limits and fireproof roof area of the city after 1906. These variables are not included in the paper's main specification because they can be interpreted as outcomes of the fire itself, thus contaminating the results. Nevertheless, row C provides the results of a specification with these regulatory variables included as regressors. There is no major disparity between the results of this specification and those of the base estimation.

The specification in row D shows estimation results where blocks partially affected by the fire are in the treatment group. In row E, partially affected blocks are in the control group. In row F, all partially affected blocks are excluded from the sample, so that only those completely razed or completely unburned are considered in the estimation. The table provides evidence that results presented in Section 5.2 are robust to alternative definitions of the treatment and control groups. No qualitative (and very small quantitative) differences exist between row A and rows D, E, and F.

Row G displays the results of estimating (2) where the dependent variable includes mixed residential units in the numerator (in addition to residential units) and mixed acres in the denominator (in addition to residential acres). Mixed residential units are defined as residential units which share a building with nonresidential occupants, such as a commercial store or a small factory. This measure ultimately suffers from the inclusion of nonresidential land uses in the denominator, which provides a misleading account of net residential density. However, it offers an alternative look at residential density when incorporating all residential units that exist in the sample, whether such units are solitary or mixed with other building uses. The resulting coefficient from this exercise is stronger than the base specification by over 4 units per acre in both post-disaster periods. Overall, qualitatively similar treatment effects persist in each of these estimations.

5.3 Redevelopment Costs

As Section 3.1 describes, land rents and residential density are positively correlated. However, estimating the relationship is made difficult by the scarcity of vacant lot sales, which are the best indicator of the value of vacant land. Such scarcity plagues any land valuation study. As Section 3.2 describes, in the redevelopment decision, developers and property owners are concerned with the revenue received from a given building or property. All else constant, rent per acre increases with density. When the revenue received upon redevelopment exceeds the revenue earned in current use by various costs, redevelopment should occur.

How prohibitive are such costs? Using estimates from the previous section and rental data extracted from the *San Francisco Real Estate Circular*, this section estimates the magnitude of annualized redevelopment costs as a percentage of annual rental income per acre. The *Circular* was a monthly publication by Thomas Magee & Sons, the most prominent real estate group in San Francisco during this time. Each month, the company produced a list of property for sale by its firm under the heading, "Investments in Apartments, Houses, and Flats."[14] Information for each property usually included an asking price, general location, total monthly rent, number of units, and lot dimensions. Using this information, a rent per unit measure was derived for hundreds of residential properties for sale by Thomas Magee & Sons. The rent figures, gathered every two years for the month of January, suggest average annual rent per residential unit of \$435 over the period 1899 to 1905, a period characterized by stable prices.

Using this data, average rent per acre is derived by the following: $\frac{rent}{unit} \times \frac{units}{acre} = \frac{rent}{acre}$. Combining the estimate of the treatment effect in 1915 (and subtracting the 1905 effect) with the rent data, the foregone annual rent per acre from not redeveloping is roughly $\frac{\$435}{unit} \times \frac{15\ units}{acre} = \$6,525$. Average residential density in 1905 was roughly 23 units per acre across all blocks in the sample, so that average pre-disaster annual rent per acre equates to $\frac{\$435}{unit} \times \frac{23\ units}{acre} = \$10,005$ in 1905. Rearranging (1) yields the following:

$$r(D + C + T) < R_{\text{new}} - R_{\text{current}}, \tag{3}$$

so that redevelopment occurs when $R_{\text{new}} - R_{\text{current}}$ exceeds the total costs of redevelopment. In the current setting, $R_{\text{new}} - R_{\text{current}} = \$6,525$, representing the gains developers could have realized before the disaster by building denser buildings. Dividing (3) by average annual

[14] For some years, these investments were listed under alternative headings denoting different areas of the city.

rental income yields

$$\frac{r(D+C+T)}{\$10,005} < \frac{\$6,525}{\$10,005} = 0.65, \tag{4}$$

which represents annualized redevelopment costs as a fraction of annual rental income. Thus, these costs are at least 65 percent of annual rental income in San Francisco during the early twentieth century.

5.4 Discussion of the Results

Several conclusions can be drawn from this study. First, between 1906 and 1915, residential density increased dramatically in the razed area relative to the unburned area, an effect which persists into 1931. Essentially, when given the opportunity to rebuild in the face of substantially reduced redevelopment costs, developers built more housing units per residential acre (seemingly, as a consequence of new economic conditions) relative to areas where such costs were more prohibitive. The main conclusion is that residential land was used more intensively in the razed area after the fire, a result which is consistent with the notion that land use patterns may have been deficient prior to the disaster.

Ultimately, the relative increase in residential density is achieved through changes in the composition of the housing stock following the disaster and the amount of land needed for such stock. There is a change in this composition toward denser housing, such as flats and apartment units, in the razed area. Also, land devoted to residential use declined by nearly 50 percent in the razed area between 1900 and 1931. Demand pressures on the pre-disaster housing stock, attributable to the population growth witnessed in San Francisco during this time, are likely the reason for such a shift.

Another conclusion from this study involves the results from the redevelopment cost estimations. This study finds that redevelopment costs are at least 65 percent of annual rental income from housing. The magnitude of this figure might explain why developers in

San Francisco were unable to make seemingly beneficial innovations in residential land use prior to the disaster.

Overall, stark changes in residential density and land use occurred as a result of the fire. This suggests that the durability of real estate is an important determinant of urban structure and development. Additionally, the fire may have acted as a coordination mechanism encouraging real estate transactions and development that used the city's land more efficiently. The implication of the dynamic urban models described in Section 3.1 is that capital durability produces different urban patterns than a static model with malleable capital. If durability is not very important, then San Francisco should have experienced relatively little change after reconstruction. As is shown in this paper, this is simply not the case.

6 Conclusion

The approach of this paper is to exploit the San Francisco earthquake and fire of 1906 in order to measure the city's post-disaster change in residential density and land use. Urban disasters provide a unique setting in which the durability constraint to achieving a new urban equilibrium is suddenly and exogenously eliminated. What happens after such a constraint is removed? This paper provides evidence of a dramatic change in residential density and land use following the San Francisco disaster, thereby suggesting an important role for adjustment and transaction costs in determining patterns of urban development.

After the 1906 disaster, San Francisco was rebuilt in a manner that diverged from its previous capital structure. Specifically, residential density increased significantly in the razed area of the city relative to the unburned area, an effect which persists at least into 1931. This relative increase was generally due to rebuilding the housing stock on much less land than was used before the disaster. The large magnitude of redevelopment costs as estimated in this paper, which amount to at least 65 percent of annual rental income in early twentieth century San Francisco, is likely the reason for the large effect of the fire on residential density. This increase is interpreted as the response of developers to the city's population growth and the severe reduction in redevelopment costs that occurred as a result of the fire.

Although this is a case study of a single urban area in a specific time period, the results may be generalized to other cities experiencing the type of growth witnessed in San Francisco at the dawn of the twentieth century. This study provides evidence that a significant legacy is present in the form and structure of urban areas. If cities are indeed important for the growth of human capital and economic development (Lucas (1988)), it is important to understand this legacy and find ways to facilitate the adaptation of urban land use to evolving economic conditions.

Data Appendix

Access to the Sanborn maps was obtained through the Los Angeles Public Library, which subscribes to Digital Sanborn Maps, 1867-1970, the online digital database created by ProQuest, LLC. Physical maps were also occasionally referenced in the Geography Map Library at California State University, Northridge. The maps for a particular edition (or year) contain several large volumes, each with many sheets that cover several city blocks each. In San Francisco, there are six volumes in the 1899/1900 edition and ten volumes in the 1913/1915 edition. On average, each volume contains over 100 sheets. The sheets are extremely detailed, providing an account of the buildings that existed on each city block at the time of the survey. City blocks and building footprints are drawn at a scale of fifty feet to one inch. Aside from footprints (which must be physically measured), details at the building level include heights (in feet and stories), construction type, and many other construction details. As described in the text, the maps allow for gathering count data on single dwellings, multi-dwellings, flats, and apartment units for each block.

Another important variable in the study is each city block's acreage, which was calculated using Geographical Information Systems (GIS) technology. The initial primary source is a shapefile obtained from the City and County of San Francisco government website (www.sfgov.org). This shapefile consists of polygons describing the shape of city blocks as they exist today. Perhaps unsurprisingly, most of the blocks today are the same size and shape as they were over one hundred years ago. For those blocks which changed over the course of the century, the Sanborn maps acted as a template to adjust block shapes so that dimensions used in the study are those from the respective Sanborn surveys. GIS also facilitated the calculation of straight-line distances and the assignment of neighborhood locations as described in the text.

The residential density measure used in the study excludes all nonresidential land uses so that only acreage devoted to residential land use is included. In this study, residential acreage includes the land devoted to residential use as defined by lot lines delineated in the Sanborn maps.[15] Residential land as measured here thus includes the land occupied by residential unit (single dwellings, multi-dwellings, flats, and apartment units) footprints, as well as open space and outbuildings, that together comprise the lots devoted to residential use. Mixed use land includes land on which buildings devoted to a mixture of residential and nonresidential (e.g., commercial, industrial, etc.) uses reside, while nonresidential land includes only land devoted to nonresidential uses. Vacant land comprises the vacant lots as described by the Sanborn maps. If a particular lot had a residential unit and a separate nonresidential building devoted to commercial or industrial use, the land acreage was split according to each use's proportional coverage on the lot.

Utilizing digital access to the Sanborn maps, the proportion of land devoted to each type of land use was calculated using a computer program which allows the capability of measuring shapes on a computer screen. Such programs are utilized by engineers and designers who regularly read digital blueprints and need to calculate measurements from these blueprints. Once the land use proportions of each city block were determined, they were multiplied by each block's total acreage (as calculated using GIS) to determine the acreage devoted to each type of land use on each city block.

Primary Data Sources

The following digitized insurance maps were accessed through the Los Angeles Public Library's (www.lapl.org) subscription to Digital Sanborn Maps, 1867-1970, which is owned by ProQuest, LLC. The digital copies were filmed by ProQuest from microfilm copies available

[15] San Francisco Block Books describing lot dimensions from 1901 and 1909/1910 (accessed through www.archive.org) were referenced when lot lines on the Sanborn maps were somewhat unclear, as was the case for buildings with walls lying directly on a lot line.

in the Library of Congress collection.

Insurance Maps of San Francisco California 1899, Volume One (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1899, Volume Two* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1899, Volume Three* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1900, Volume Five* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1900, Volume Six* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1913, Volume One* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1913, Volume Two* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1913, Volume Three* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1913, Volume Four* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1914, Volume Six* (New York: Sanborn-Perris Map Co.); *Insurance Maps of San Francisco California 1914, Volume Seven* (New York: Sanborn-Perris Map Co.)

The following municipal reports were obtained from The Internet Archive (www.archive.org), a non-profit organization that provides access to many historical documents in digital format.

San Francisco Municipal Reports for the Fiscal Year 1902-1903, Ending June 30, 1903 (San Francisco: Commercial Publishing Co., 1904); *San Francisco Municipal Reports for the Fiscal Year 1903-1904, Ending June 30, 1904* (San Francisco: J.B. McIntyre, 1905); *San Francisco Municipal Reports for the Fiscal Year 1904-1905, Ending June 30, 1905* (San Francisco: Pacific Printing and Engraving Co., 1907); *San Francisco Municipal Reports for the Fiscal Year 1905-6, Ending June 30, 1906, and Fiscal Year 1906-7, Ending June 30, 1907* (San Francisco: Neal Publishing Co., 1908); *San Francisco Municipal Reports for the Fiscal Year 1907-8, Ended June 30, 1908* (San Francisco: Neal Publishing Co., 1909); *San Francisco Municipal Reports for the Fiscal Year 1908-9, Ended June 30, 1909* (San Francisco: Neal Publishing Co., 1910); *San Francisco Municipal Reports for the Fiscal Year 1909-10, Ended June 30, 1910* (San Francisco: Neal Publishing Co., 1911); *San Francisco Municipal Reports for the Fiscal Year 1910-11, Ended June 30, 1911* (San Francisco: Neal Publishing Co., 1912); *San Francisco Municipal Reports for the Fiscal Year 1911-12, Ended June 30, 1912* (San Francisco: Neal Publishing Co., 1913); *San Francisco Municipal Reports for the Fiscal Year 1912-13, Ended June 30, 1913* (San Francisco: Neal Publishing Co., 1915); *San Francisco Municipal Reports for the Fiscal Year 1913-14, Ended June 30, 1914* (San Francisco: Neal Publishing Co., 1916)

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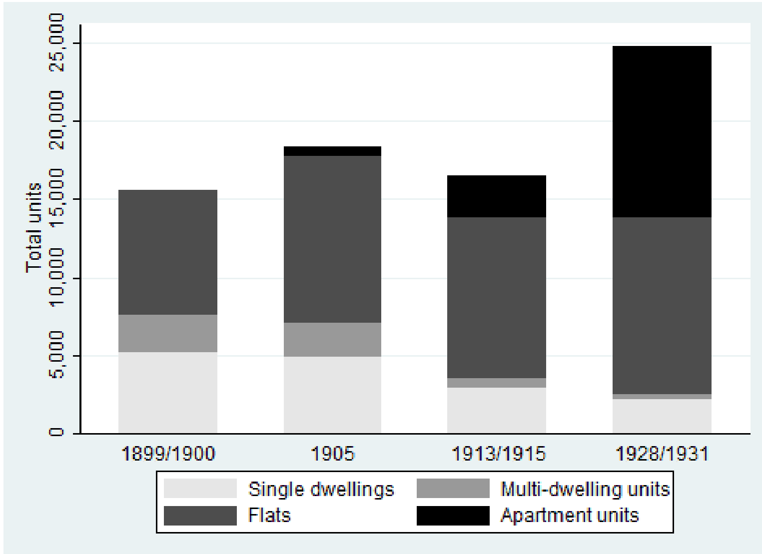

Figure 1: Sample housing stock
Source: see text.

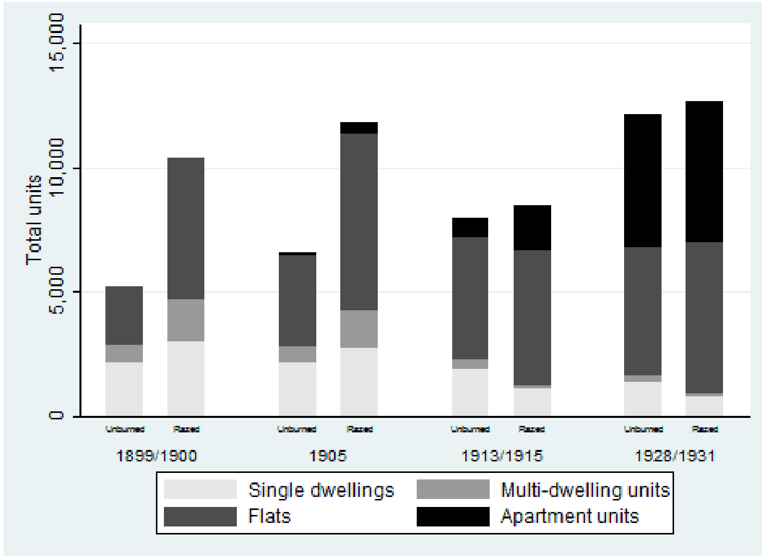

Figure 2: Sample housing stock by group
Source: see text.

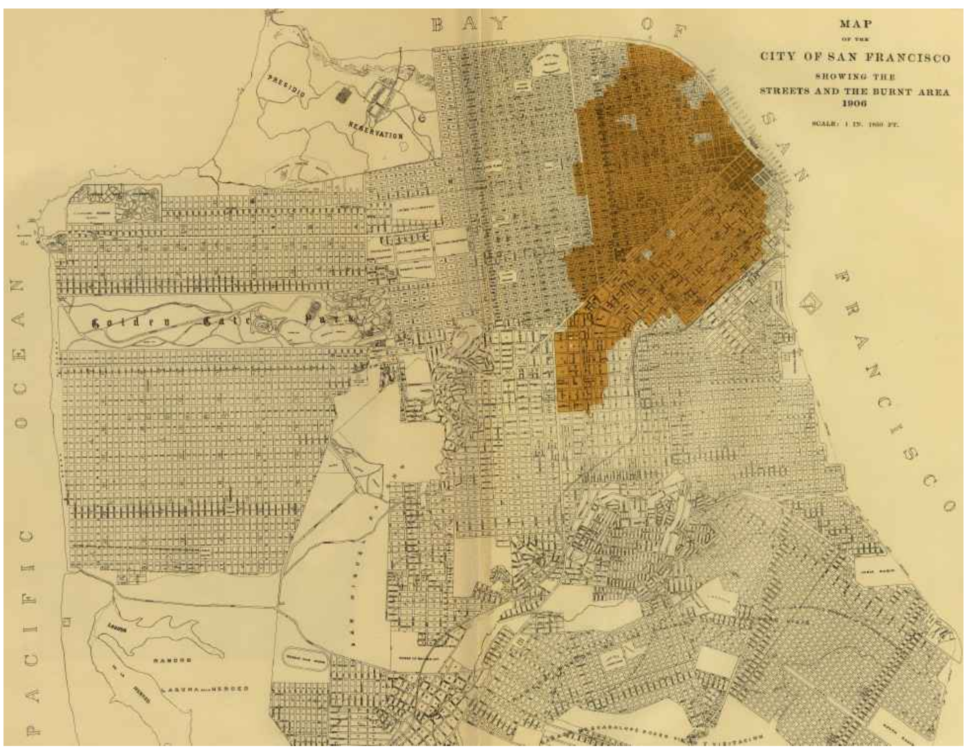

Figure 3: Fire coverage from the 1906 San Francisco disaster as depicted by SEIC (1908)
Source: David Rumsey Historical Map Collection (www.davidrumsey.com).

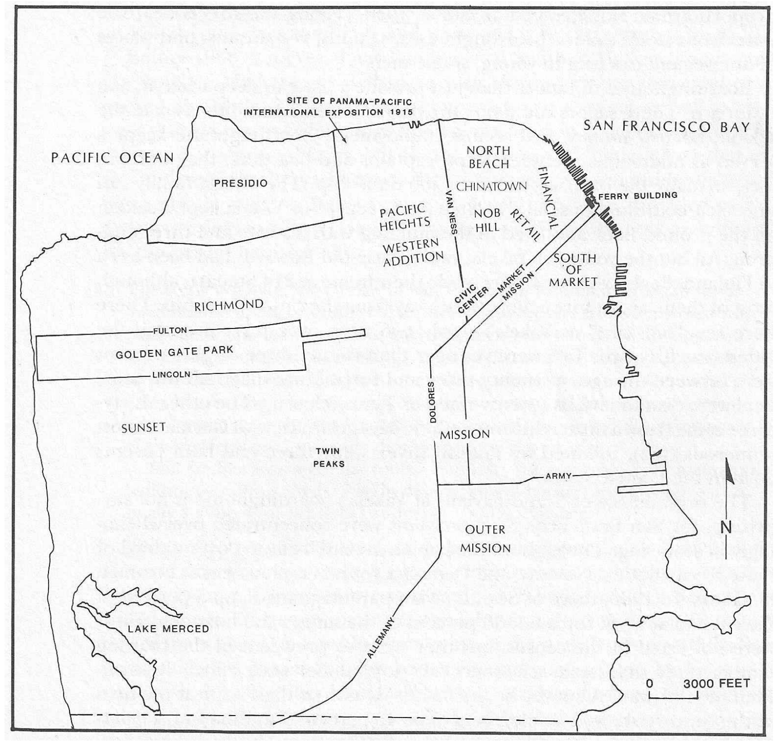

Figure 4: Residential areas
Source: Issel and Cherny (1986).

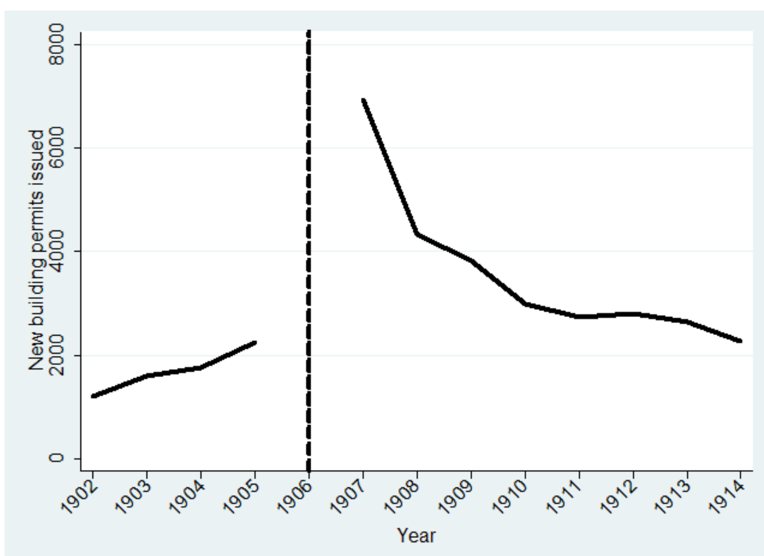

Figure 5: Permits issued for new buildings, 1902-1914
Source: San Francisco Municipal Reports as cited under Data Sources.

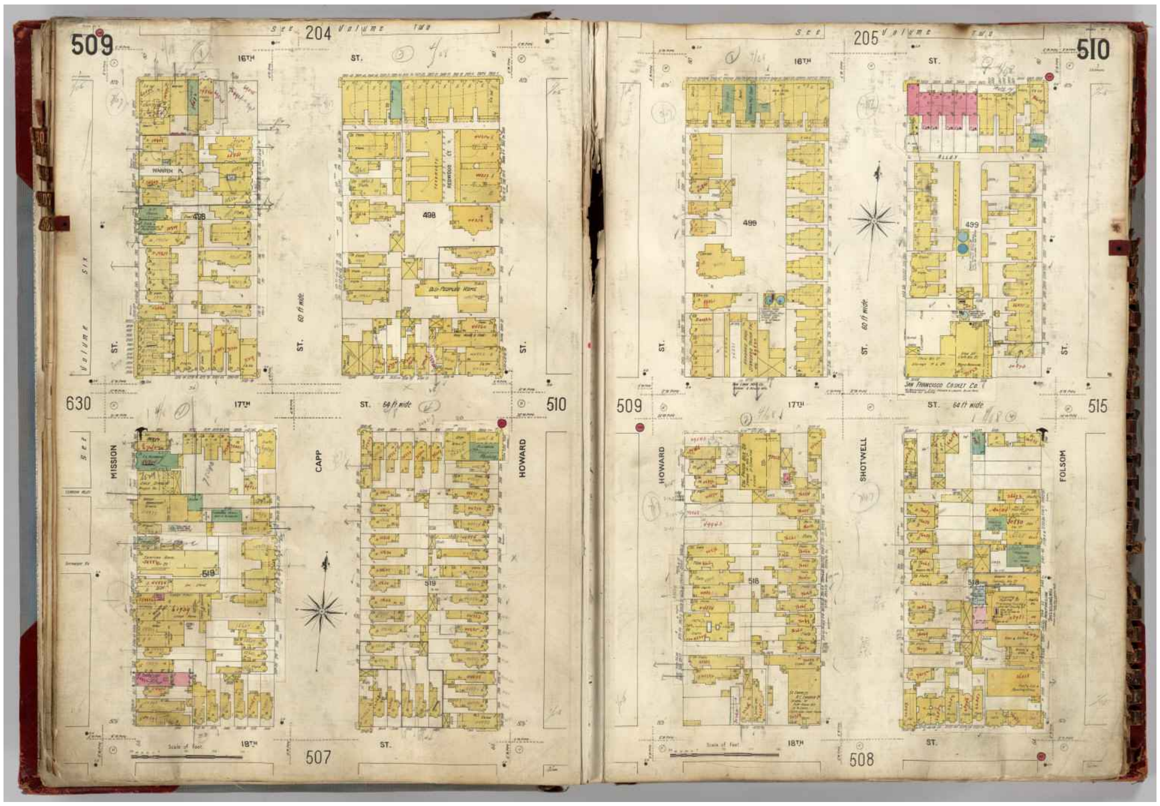

Figure 6: Map sheets 509-510 from 1905 Sanborn Map, Volume 5
Source: David Rumsey Historical Map Collection (www.davidrumsey.com).

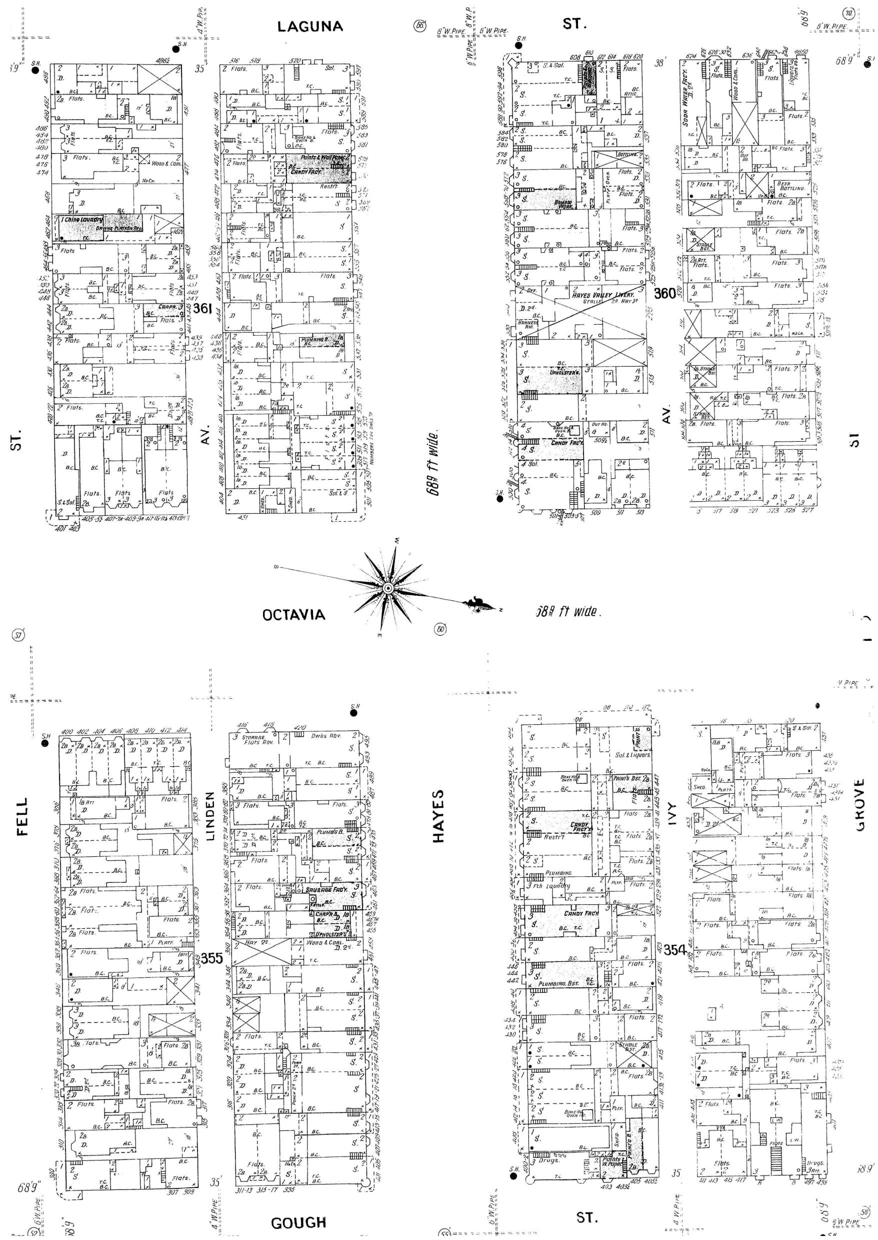

Figure 7: Before the fire (1899/1900 volume)
Source: ProQuest Digital Sanborn Maps, 1867-1970 (accessed through www.lapl.org).

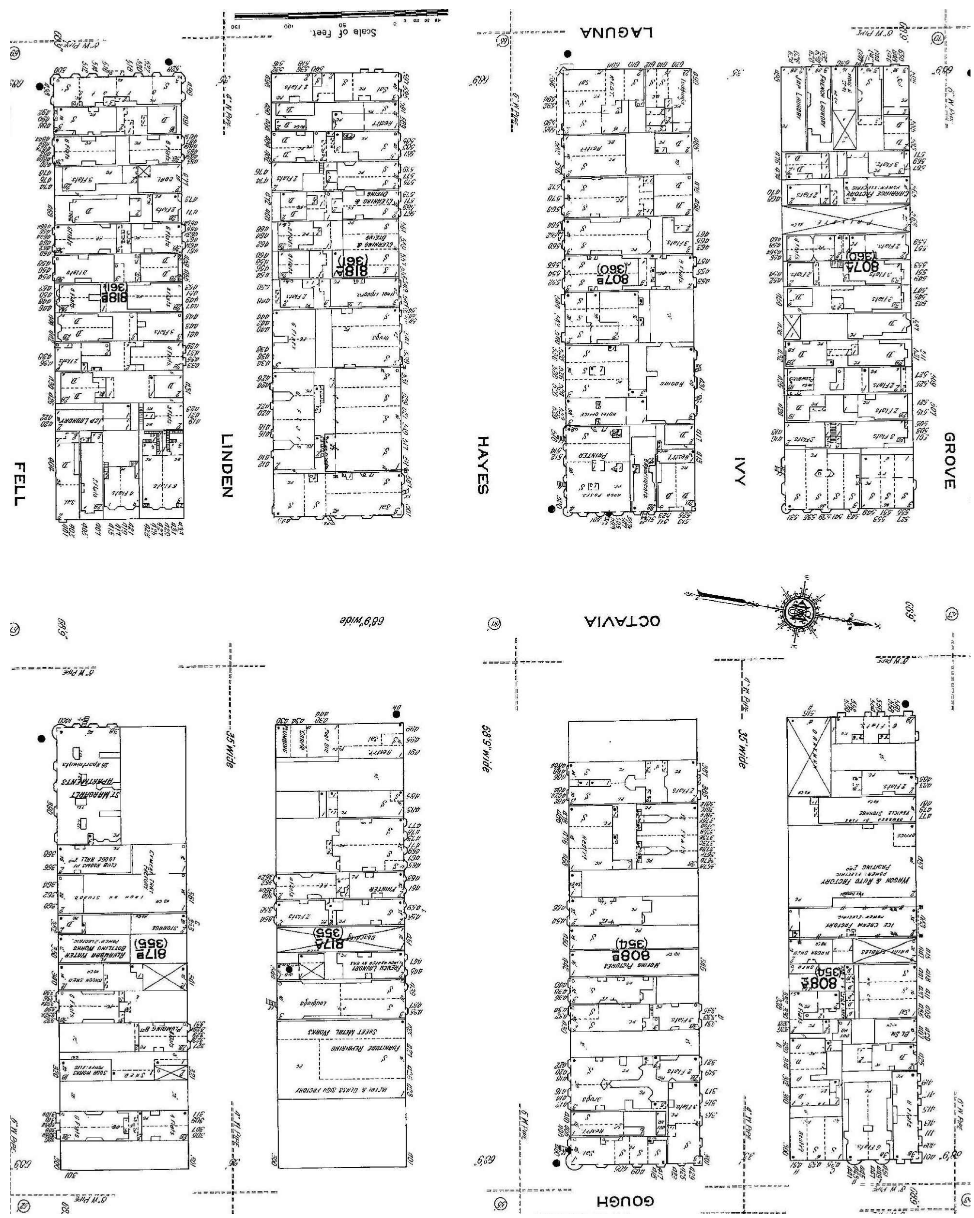

Figure 8: After the fire (1913/1915 volume)
Source: ProQuest Digital Sanborn Maps, 1867-1970 (accessed through www.lapl.org).

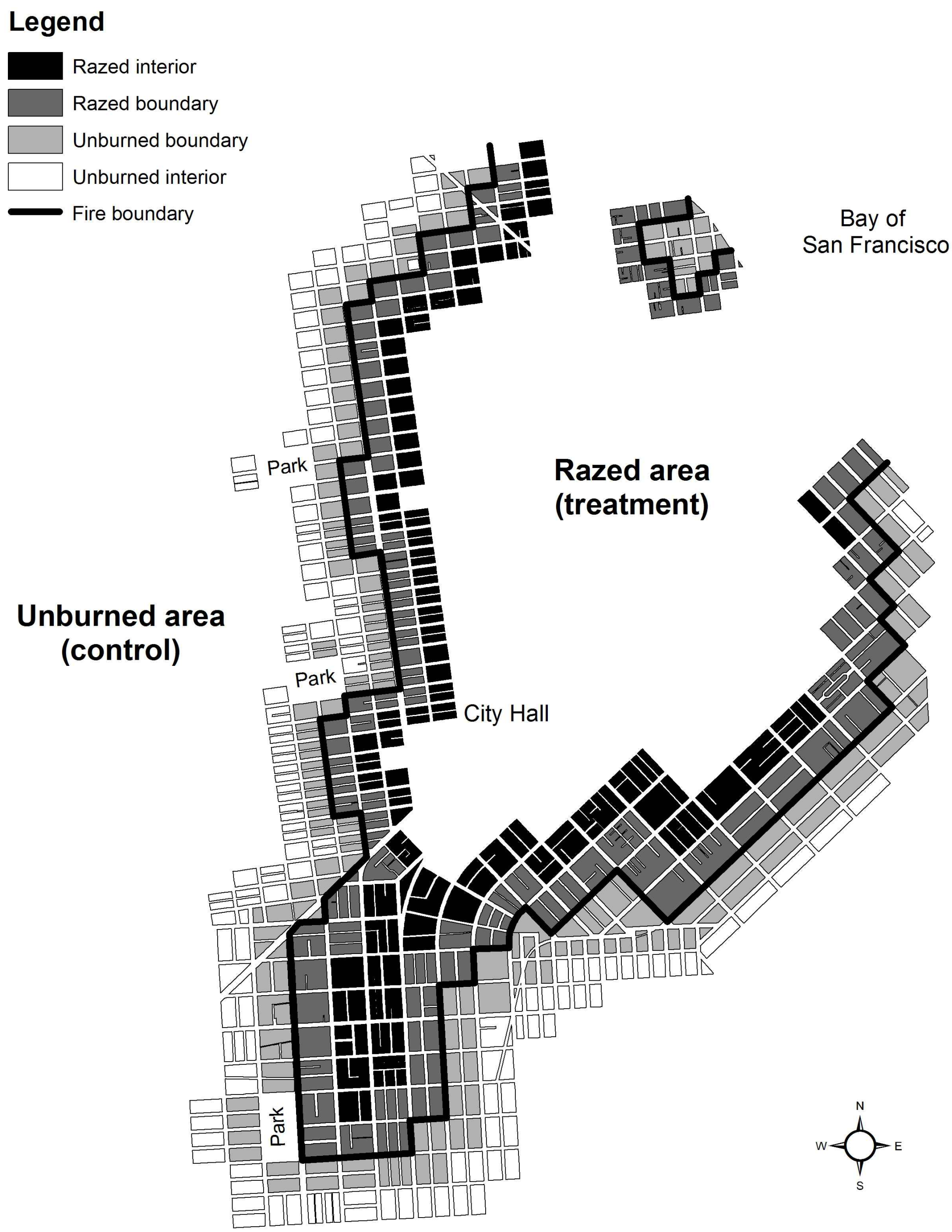

Figure 9: Treatment and control group assignment
Source: see text.

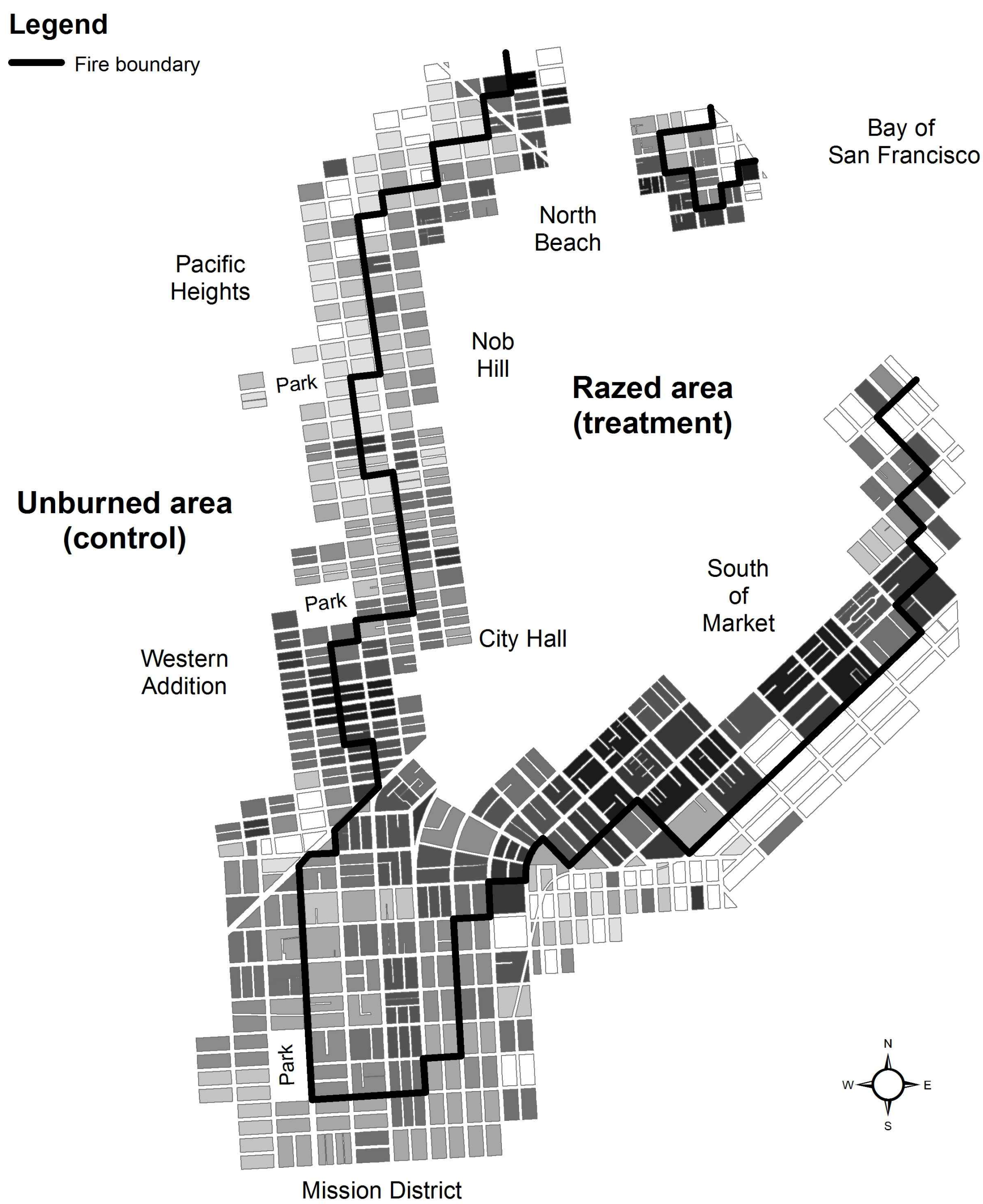

Figure 10: Pre-disaster residential density
Notes: Darker shades represent greater residential density. Source: see text.

Table 1: San Francisco population, 1860-1930

Year	Population	% increase
1860	56,802	
1870	149,473	163
1880	233,959	57
1890	298,997	28
1900	342,782	15
1910	416,912	21
1920	506,676	21
1930	634,394	25

Source: U.S. Census data.

Table 2: San Francisco neighborhoods and their general composition

Neighborhood	Composition
South of Market	Lower-class, single men, some families
Mission District	Families, homeowners, entrepreneurs
Western Addition	Middle-class and upper middle-class, homeowners
Pacific Heights, Nob Hill	Upper-class
North Beach	Working-class, families, single men

Source: Issel and Cherny (1986).

Table 3: Buildings destroyed by fire and buildings reconstructed

Type	Buildings destroyed by fire	Documented buildings constructed, 1906-1914
Wood	24,671	25,440
Brick	3,168	2,699
Brick/wood	259	-
Corrugated iron/wood	33	-
Concrete	-	194
Stone	15	-
Steel	42	174
Total	28,188	28,507

Sources: San Francisco Conflagration Report, San Francisco Municipal Reports.

Table 4: Sample housing stock

	Razed		Unburned		Total	
	Total	Perc.	Total	Perc.	Total	Perc.
1899/1900 survey:						
Residential units	10,338	100.0	5,193	100.0	15,531	100.0
Single dwellings	3,016	29.2	2,158	41.6	5,174	33.3
Multi-dwelling units	1,657	16.0	734	14.1	2,391	15.4
Flats	5,665	54.8	2,301	44.3	7,966	51.3
Apartment units	0	0	0	0	0	0
Mixed units	732	7.1	214	4.1	946	6.1
1905 survey:						
Residential units	11,818	100.0	6,567	100.0	18,385	100.0
Single dwellings	2,705	22.9	2,113	32.2	4,818	26.2
Multi-dwelling units	1,536	13.0	685	10.4	2,221	12.1
Flats	7,101	60.1	3,631	55.3	10,732	58.4
Apartment units	476	4.0	138	2.1	614	3.3
Mixed units	1,241	10.5	439	6.7	1,680	9.1
1913/1915 survey:						
Residential units	8,487	100.0	7,967	100.0	16,454	100.0
Single dwellings	1,068	12.6	1,849	23.2	2,917	17.7
Multi-dwelling units	132	1.6	455	5.7	587	3.6
Flats	5,435	64.0	4,870	61.1	10,305	62.6
Apartment units	1,852	21.8	793	10.0	2,645	16.1
Mixed units	804	9.5	542	6.8	1,597	9.7
1928/1931 survey:						
Residential units	12,673	100.0	12,058	100.0	24,731	100.0
Single dwellings	787	6.2	1,385	11.5	2,172	8.8
Multi-dwelling units	89	0.7	247	2.0	336	1.4
Flats	6,084	48.0	5,125	42.5	11,209	45.3
Apartment units	5,713	45.1	5,301	44.0	11,014	44.5
Mixed units	1,468	11.6	749	6.2	2,217	9.0

Notes: Mixed units are not included in the residential unit count, but are shown as a percentage of residential units to indicate their relative importance.
Source: see text.

Table 5: Sample land use

	Razed		Unburned		Total	
	Total	Perc.	Total	Perc.	Total	Perc.
1899/1900 survey:						
Total acres	721	100.0	720	100.0	1,441	100.0
Residential	363	50.3	295	41.0	658	45.7
Nonresidential	270	37.4	260	36.1	530	36.8
Mixed	27	3.7	12	1.7	39	2.7
Vacant	61	8.5	153	21.3	214	14.9
1905 survey:						
Total acres	721	100.0	720	100.0	1,441	100.0
Residential	359	49.8	311	43.2	670	46.5
Nonresidential	293	40.6	280	38.9	573	39.8
Mixed	32	4.4	15	2.1	47	3.3
Vacant	37	5.1	114	15.8	151	10.5
1913/1915 survey:						
Total acres	722	100.0	724	100.0	1,446	100.0
Residential	156	21.6	281	38.8	437	30.2
Nonresidential	365	50.5	341	47.1	706	48.8
Mixed	10	1.4	11	1.5	22	1.5
Vacant	191	26.5	91	12.6	282	19.5
1928/1931 survey:						
Total acres	719	100.0	724	100.0	1,443	100.0
Residential	186	25.9	274	37.8	460	31.9
Nonresidential	457	63.6	385	53.2	842	58.4
Mixed	15	2.1	12	1.7	27	1.9
Vacant	62	8.6	55	7.6	117	8.1

Source: see text.

Table 6: Summary statistics per city block

	Razed		Unburned	
	Mean	Std. dev.	Mean	Std. dev.
1899/1900 survey:				
Residential units	55.88	49.29	22.00	26.89
Residential acres	1.96	1.26	1.25	1.20
Residential density	27.67	17.96	14.58	13.39
1905 survey:				
Residential units	63.88	52.86	27.83	32.25
Residential acres	1.94	1.30	1.32	1.26
Residential density	31.93	17.45	16.78	19.10
1913/1915 survey:				
Residential units	45.88	45.46	33.76	40.80
Residential acres	0.84	.866	1.19	1.33
Residential density	54.50	56.89	22.93	24.33
1928/1931 survey:				
Residential units	68.50	68.37	51.44	57.34
Residential acres	1.00	1.11	1.16	1.36
Residential density	70.28	56.89	33.13	36.03
Time-invariant variables:				
Distance to city hall (1/4 miles)	3.99	1.82	4.53	1.52
South of Market	.211	.409	.212	.409
Mission District	.211	.409	.267	.443
Western Addition	.243	.43	.275	.448
Pacific Heights	.011	.104	.114	.319
Nob Hill	.065	.247	0	0
North Beach	.141	.348	.064	.244
Modern-day Russian Hill	.119	.325	.068	.252
Observations	185		236	

Source: see text.

Table 7: Reduced-form estimations

	Dep. variable: residential density				
	(1)	(2)	(3)	(4)	(5)
Razed × post-fire	20.145***				
	(4.500)				
Razed × 1905		2.063	1.428	1.429	2.596*
		(1.291)	(1.344)	(1.177)	(1.501)
Razed × 1915		18.481***	15.474***	15.008***	17.405***
		(4.372)	(3.729)	(3.265)	(4.270)
Razed × 1931		23.872***	18.381***	15.665***	21.739***
		(5.778)	(4.853)	(4.267)	(5.090)
Distance to center × 1905			-1.165***	-1.152	1.046
			(0.393)	(2.102)	(2.017)
Distance to center sq. × 1905				-0.001	-0.172
				(0.268)	(0.247)
Distance to center × 1915			-5.513***	-9.385	-1.862
			(1.455)	(9.124)	(9.612)
Distance to center sq. × 1915				0.452	0.019
				(0.940)	(1.027)
Distance to center × 1931			-10.067***	-32.653**	-24.711
			(1.985)	(14.371)	(17.038)
Distance to center sq. × 1931				2.634*	2.278
				(1.502)	(1.808)
Constant	20.330***	20.330***	20.330***	20.330***	20.330***
	(1.144)	(1.144)	(1.094)	(1.090)	(1.026)
Time dummies	Yes	Yes	Yes	Yes	Yes
Neighborhood-time dummies	No	No	No	No	Yes
Observations	1,684	1,684	1,684	1,684	1,684
R^2	0.200	0.201	0.255	0.266	0.344

Notes: Individual cluster robust standard errors are given in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level. The mean and standard deviation of the dependent variable are 32.533 and 40.450.

Table 8: Reduced-form estimations with subsamples

	Dep. variable: residential density				
	(1) Boundary	(2) Interior	(3) Density > 0 in one period	(4) Density > 0 in all periods	(5) Initially comparable
Razed × 1905	-0.166	7.510***	2.924***	-0.746	-0.179
	(2.203)	(2.269)	(1,820)	(2.780)	(1.205)
Razed × 1915	12.703**	27.530***	19.381***	37.180***	21.284***
	(5.234)	(9.562)	(4.993)	(7.567)	(5.653)
Razed × 1931	12.798**	38.816***	24.647***	37.181***	14.038*
	(5.565)	(12.478)	(5.901)	(8.068)	(7.707)
Observations	972	712	1,484	1,156	476
R^2	0.354	0.361	0.351	0.563	0.460
Mean	30.173	35.755	36.918	42.737	40.539
Std. dev.	38.437	42.866	41.169	40.856	34.778

Notes: Individual cluster robust standard errors are given in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level. A constant and a full set of corresponding regressors are included in all estimations, minus fire limits and fireproof roof area.

Table 9: Robustness checks and alternative specifications

	Dep. variable: residential density		
Specification	(1) Razed × 1905	(2) Razed × 1915	(3) Razed × 1931
A. Base	2.596*	17.405***	21.739***
	(1.501)	(4.270)	(5.090)
B. Distance to downtown	2.474*	15.711***	17.149***
	(1.428)	(3.513)	(4.534)
C. Regulatory variables included	2.595*	15.940***	20.723***
	(1.502)	(3.764)	(4.616)
D. Partially affected blocks	2.112	15.264***	19.375***
in treatment group	(1.495)	(4.057)	(4.874)
E. Partially affected blocks	2.525*	16.469***	20.733***
in control group	(1.447)	(4.349)	(5.178)
F. Partially affected blocks	2.604*	17.521***	22.146***
excluded from analysis	(1.576)	(4.525)	(5.415)
G. Dependent variable includes	3.685**	21.801***	26.249***
mixed residential units†	(1.429)	(4.463)	(5.301)

Notes: Robust standard errors are given in parentheses. *, **, *** indicate statistical significance at the 10%, 5%, and 1% level. A constant and a full set of regressors are included in all regressions.

†Residential acres include mixed acres in the residential density measure.