Razing San Francisco: The 1906 Disaster as a Natural Experiment in Understanding Urban Land Use

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Abstract

Natural disasters that destroy urban areas leave opportunities to adapt a city's environment to contemporary needs. Since the durability of real estate inhibits cities from easily adapting to changing economic conditions, non-optimal land use patterns may emerge and persist over time. This outcome implies that path dependence in durable capital may be a significant factor in determining urban growth and development. Exploiting the 1906 San Francisco fire as an exogenous reduction in the capital stock, this paper examines the changes in residential density following reconstruction using a unique dataset and the fire's boundary as a discontinuity in treatment. Evidence suggests significant changes in the city's structure between 1899 and 1915, much of which is explained by the destruction caused by the disaster. Specifically, residential density increases significantly in areas razed by fire relative to unburned areas, and is accompanied by a relative shift in land acreage away from residential and mixed uses. These findings imply that thriving cities experience a substantial barrier to redevelopment and land use changes in the form of durable capital.

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

- Jack London

The work of rebuilding San Francisco has commenced and 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 wake. However, they also leave opportunities for change. Land owners 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 investment 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. Because such investment is durable and specific, it is 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, dynamic cities may be in disequilibrium. For instance, city dwellers may be somehow constrained from moving to other areas, land use patterns may be inefficient, and structural densities within the city may be non-optimal. Such inefficiencies arise partly due to the costs associated with adapting durable real estate to contemporary needs. In the case of a city beset by a large-scale disaster, if there are significant changes in the city's capital structure following reconstruction, and it was optimally reconstructed to fit contemporary needs, then the implication is that durable investments play an important role in determining urban development patterns.

Consider San Francisco in the early twentieth century. In the sample constructed for this paper, roughly 50 percent of housing units in 1899 were dense forms of housing, namely flats and apartment units. By 1913, this number had increased to nearly 80 percent. Figure 1 shows evidence of this dramatic shift in residential investment. It is clear from these data that city developers moved away from single 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 adaptation. 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 significant changes in the city's structure and land use patterns is found in areas destroyed by the fire relative to unburned areas. This finding implies that thriving cities may be held back by past capital investments, suggesting a vital role for path dependence in understanding long-run urban development.

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 as it relates to urban economic theory. Section 4 describes and summarizes the data. Section 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). By most measures, the San Francisco fire was the most devastating. 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 the relief effort.

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 2 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 indicates 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 earthquake and fire. 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 at least through World War I are shown in Figure 3 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 be used as control variables 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, particular attention must be paid to it and its relation to the fire fighting effort. As Figure 2 shows, portions of the fire's coverage are strongly delineated by straight lines. In the case of South of Market (SOMA), the fire stopped at the railways. In the north, areas such as Western Addition and Pacific Heights were largely spared due to the width of Van Ness Avenue, which runs at 125 feet from the bay in the north to Market Street in the south. A natural question in this study is how the fire's boundary came to be. If the fire spread due to either decisions made by fire fighters based on land use depicted in this study, or was influenced by the land use itself, the boundary may be partially endogenous and hence bias the study's results.

The fire ensued shortly after the earthquake struck at 5:12 A.M. on Wednesday, April 18. It began in the downtown area and SOMA, spread north into Nob Hill and south into Mission District by Thursday, and spread into North Beach by Friday before burning out at the bay.[1] The fire spread primarily because 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 a firebreak (Tyler (1906)). As Tyler notes, and Morris (1906) corroborates, the fire burned unchecked on Wednesday as fire fighters secured all dynamite within the city and destroyed many buildings in the path of the fire, a method which only left heaps of debris to stoke the flames.

Arguably, the first day of burning was the most exogenous with regard to the boundary of the fire. With virtually no water with which to fight the flames, and the misuse of explosives which did not serve to halt the fire, the city was essentially at the mercy of the wind. The first substantial success against the fire occurred late Thursday with dynamiting along a stretch of Van Ness Avenue (Fradkin (2005)).[2] According to Tyler, this location was the

[1]See Figure 3 for a map of the city which displays these areas and the major streets discussed in this section.

[2]Thomas and Witts (1971) provide an account of the fire in a timeline fashion. According to the authors, the fire had crossed a portion of Van Ness Avenue on Thursday around midnight while dynamiting along Van Ness. Morris (1906) describes this effort as occurring on Friday. Whatever the timeline, all versions

only successful dynamiting effort amid at least twenty such episodes, although Fradkin also describes a successful effort in the Mission District. Tyler attributes the success at Van Ness to several things: the fire fighters began the effort hours before the fire reached the area, the avenue was wide, and it was lined with nice homes having much open space between them. Although there is no evidence to suggest it, fire fighters may have arrived there early due to the nature of the occupants of the houses that lined the west side of the avenue, who were often wealthy and influential in the community. As Morris asserts, the portion of the city west of Van Ness and north of McAllister was the finest area of San Francisco.

On Friday, the fire spread northeastward from the northern end of Van Ness Avenue. The principal cause of this portion of the fire may be due to careless dynamiting (Fradkin (2005)). A medicine plant on the corner of Van Ness and Green had been dynamited, and with the combination of thousands of gallons of alcohol stored in the building, created another fire front that would be fought over the next day. This front moved northward and eastward until it was stopped at the bay and near water reservoirs in the North Beach area. By 7:15 A.M. on Saturday, the fire had been declared over (Thomas and Witts (1971)).

The area of the boundary of most concern is the dynamite line along Van Ness Avenue, where fire fighting efforts may have possibly hinged on the fact that nice homes on spacious lots were located on the west side of the avenue. However, it is more likely that the efforts to stop the blaze in this area of the city were largely due to the width of Van Ness (one of the widest streets in the city), which helped to serve as a firebreak in itself. Also of concern may be blocks in the North Beach and SOMA areas, where the fire was stopped largely by the presence of railways, water reservoirs, and the bay. Thus, an estimation presented later in the paper will consider a sample excluding blocks from these portions of the boundary. Ultimately, the results using this subsample differ very little from the main results of the study.

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describe this episode as ultimately successful.

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. One journalist of the time wrote, "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 politicians wanted to restore the tax base. 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 even 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 did not hastily rebuild in order to house its citizens, but instead rebuilt in a manner that reflected the expectations for permanent housing demand.

A 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, a new fireproof roof area, 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 included those areas of the city in which buildings were required to adhere to specific regulations in construction, such as the use of non-combustible materials like brick. These limits did expand moderately following the disaster. Perhaps of greater economic consequence was the new widespread fireproof roof area implemented shortly after the fire. Buildings constructed within this area were required to have fireproof roofs, which essentially meant a higher cost of construction per building relative to areas lying outside the limits. Aside from most blocks in the Mission District, nearly all areas within the fire's boundary were affected by this regulation. Due to their potential to partially determine residential density, the fire limits and fireproof roof area will be considered in the analysis.

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 hard 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 thought 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.

To provide a sense of the reconstruction that took place following the disaster, Figure 4 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. The cumulative total of documented buildings constructed in San Francisco after 1906 and before the Exposition is 28,507, which is composed of replacement buildings as well as structures to meet general demand conditions. Of these buildings, 25,440 were wood-framed, 2,699 were brick, 194 were concrete, and 174 were steel-framed.[3]

3 The Economics of Urban Land Use

This study is primarily concerned with two general outcomes: residential density and the land acreage devoted to various uses. Residential density, represented as the number of residential units per unit of residential land area, is an important measure used by urban planners and modeled by urban economists. It is a depiction of residential land use within a city and is highly correlated with population density. Generally, cities with greater land rents overall are characterized by denser living accommodations, and hence greater residential density. Residential density can change over time throughout a given city as a result of changes in the economic forces that shape land rents and hence urban development. Primary factors include changes in population, income, and commuting costs.[4]

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

[4] This outcome assumes a competitive land and housing market in which municipalities do not determine residential density patterns based on other factors.

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.[5] With time and redevelopment costs introduced as components in the development decision, implications arise for urban growth and residential 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 influences 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

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

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 (1982) 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. As their research has shown, depending on the strength of the durable housing assumption, structural density may be deficient due to changes in the surrounding economic climate to which it is costly to adapt. Since the structure of a city is durable and specific, and redevelopment involves significant demolition and conversion costs, cities exhibit the legacy of past investment decisions. These circumstances can lead to deficient city structures and density patterns, which in turn affect the agglomeration economies that contribute to urban growth (Jacobs (1961)).

In urban settings, current investment decisions are dependent upon the investment decisions of the past. As a result, a city can be more an artifact of its history, and less a product of its expectations for the future. If a thriving city were indeed malleable and optimally reconstructed whenever necessary, one could imagine a different city structure each period. 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 investment carries in determining urban growth patterns. In this vein, recent work by Bleakley and Lin (2010) reveals the important role path dependence plays in determining contemporary city locations. The rest of the paper is devoted to understanding this role in determining the residential structure and land use of a city.

4 Data

4.1 Data Construction

An exceptional data source for information on urban development in the nineteenth and twentieth centuries are the fire insurance maps created for companies that insured buildings in urban areas against the risk of fire. They are maps of cities and towns containing detailed information on residential, commercial, and industrial buildings located throughout the city. The main producer of such volumes was the Sanborn-Perris Map Company, who completed fire maps for San Francisco in 1899/1900 and 1913/1915.[6] These volumes most closely capture the 1906 disaster. Residential data are gathered from these volumes so that the resulting dataset is longitudinal, with a pre-disaster wave in 1899/1900 and a post-disaster wave in 1913/1915.[7] Figure 5 provides an example of two sheets (each roughly 13 by 24 inches) from Volume 5 in the 1899/1900 set. Figures 6 and 7 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) technology, a net residential density measure is constructed, which equals the number of residential units per acre of residential land.[8] This density measure is the primary land use outcome depicted in 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.[9]

The unit of analysis is a city block. City blocks in San Francisco remained virtually unchanged after the disaster, thus providing a reliable unit of comparison across time periods.[10] In each survey, observations are drawn from both sides of the fire's boundary. Blocks razed

[6]The volumes were typically produced over a span of multiple years and drawn at a scale of fifty feet to an inch.

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

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

[9]For the purpose of the paper, residential density will refer to net residential density.

[10]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.

by the fire are in the treatment group, while unburned blocks are in the control group. A map created in 1908 by the State Earthquake Investigation Commission, shown in Figure 2, provides the delineation between groups.[11] Blocks which were completely consumed by the fire are in the treatment group. Blocks which were only partially affected by the fire are in the treatment group if the majority of acreage on the block was affected by the fire; those having a minority of acreage affected are in the control group.[12]

Figure 8 shows the final group assignment for the sample. The overall objective in deriving this sample is to assign equal total acreage to each group (razed and unburned) while maintaining close proximity to the fire's boundary. Table 3 reveals the success of this objective, where a difference of only a single acre exists between the razed and unburned groups in the 1899/1900 survey.

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 3 shows their location in the city. Each block's straight-line distance to city hall and downtown 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.[13] Additionally, the fire limits and fireproof roof area variables were constructed from maps depicted in Tobriner (2006). Together, all of these variables act as controls in the reduced-form regressions presented in Section 5.3.

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

[12] Results from various robustness checks are presented in Section 5.3.3 where blocks partially affected by the fire are in either 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.

[13] 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 5.3.3, 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 3 presents totals and proportions for each residential and land use category. Residential units as described in Panel A are the sum of single dwellings, multi-dwelling units, flats, and apartment units. Panel B displays land use data where residential, nonresidential, mixed use, and vacant acres make up total acres.

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 identifiable apartment buildings exist in this sample in the 1899/1900 survey. Roughly 50 percent of housing was devoted to flats several years before the fire. Fifteen years later, flats and apartment units made up nearly 80 percent of the stock. As the table shows, these changes are most dramatic in the area razed by fire, which suggests that in reconstruction the city greatly adjusted the composition of its housing stock.

Land use also changed considerably over the period of study. The most dramatic changes overall are in the residential and nonresidential categories, where residential acreage declines by nearly 35 percent and nonresidential acreage increases by the same percentage. As the panel reveals, land use changes in the razed portion of the city following the fire are responsible for most of the change in residential acreage.

The table also corroborates evidence that the city rebuilt quickly following the fire. By the 1913/1915 survey, residential units in the razed area had reached over 80 percent of the amount present around 15 years earlier. Residential units increased in the sample overall for both razed and unburned areas near the fire's boundary, where the city expanded its housing stock over 5 percent during this period. As described in Section 2.1 and shown in Figure 4, much of the increase in the housing stock in the unburned area is probably due to general building trends from 1900 to 1906, with the remainder due to development following the disaster. Of course, significant changes in the razed area are due to reconstruction after 1906.

Table 4 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 land use 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. Although this initial difference is large, it is less dramatic when average residential acreage per block is considered. In the razed area, 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. For this reason, the study relies on the assumption that general development trends would have been the same across groups if not for the disaster. Average residential density in the razed area is nearly twice that for blocks located just outside the boundary. Compared to the pre-disaster survey, average total residential density increases in the unburned area and stays relatively stable in the razed area.

Table 4 also reveals that post-disaster land use shifts more dramatically in the razed area relative to the unburned area. Most dramatic are the changes in residential and vacant acreage. As Table 3 shows, total residential acres in the razed area decline from 50 percent of total block acreage to nearly 20 percent, while vacant acres increase from roughly 9 to over 25 percent of total acreage. For the average razed city block, these changes are substantial, representing a nearly 60 percent decline in residential coverage and a 200 percent increase in vacant acreage. As the data suggest, these changes differ in the unburned area, which experiences a 5 percent decline in residential acres and a 40 percent decrease in vacant coverage. Both areas experience an increase in nonresidential development over the study's time period.

The regulatory variables reveal minor changes in the fire limits after the disaster across the blocks in the sample. The widespread fireproof roof area, implemented after 1906, covers most blocks in both the treatment and control groups. The distance variables show substantial differences across groups due to the concentric nature of the fire's coverage relative to city hall and downtown. Likewise, there are differences in the distributions of neighborhood locations. All of these characteristics are included in the estimations presented in Section 5.

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 and land use acreage.

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.

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 equilibrium outcomes in residential density. If such costs inhibit urban development (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 sections present estimation results of average residential density and land use changes for blocks located near the boundary of the fire.

5.2 Differences in Differences

To motivate the analysis, consider Figures 6 and 7. The bottom blocks in each figure were razed by the fire, while the top blocks were spared. Figure 6 is from the 1899/1900 volume and Figure 7 is from the 1913/1915 volume.[14] 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.

A quantitative approach to understanding this phenomenon is depicted in Table 5, which summarizes the levels and changes in residential density for all blocks using data obtained from the Sanborn maps. Columns 1 and 2 present average densities in the razed and unburned areas, while column 3 shows the difference in average density between blocks differentially affected by the fire.

[14]Figure 7 is inverted to correspond with Figure 6.

In the razed area, average residential density increases significantly after the fire in both the razed and unburned areas. While the increase is 57 percent for unburned blocks, it is substantially more at 97 percent for unburned blocks. Ultimately, residential density for blocks razed by fire increases relative to density for those across the boundary. The relative increase, with a t statistic of 4.66, is almost 19 residential units per residential acre. For the average city block in the razed area, which has 0.84 residential acres, this change amounts to a relative increase of 16 residential units.

5.3 Regression Model

5.3.1 Residential Density

The estimates from the previous section do not account for other sources of variation in average residential density, such as distance to the center of the city, neighborhood locations, and block-specific regulatory changes. The goal of this section is to control for these factors in 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:

$$D_{it} = \alpha + \lambda R_i + \gamma d_t + \delta(R_i \cdot d_t) + (X_i \cdot d_t)'\beta + Z'_{it}\rho + \theta_i + \varepsilon_{it}\,, \tag{1}$$

where R_i equals one for blocks razed by fire, d_t is an indicator variable for observations after the fire, X_i are observable time-invariant block characteristics, Z_i are observable time-varying block characteristics, θ_i are block fixed effects, and ε_{it} is an error term. Given two time periods, a first-differencing transformation of (1) yields the following:

$$\Delta D_i = \delta R_i + X'_i\beta + \Delta Z'_i\rho + \gamma + \nu_i\,, \tag{2}$$

where γ is a secular time period effect, $\nu_i = \Delta\varepsilon_i$ is an error term, and other variables are as previously defined. The time-specific block characteristics 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. Neighborhood dummies capture the heterogeneous time-specific effect across different areas of San Francisco. The regulatory variables described in Section 2.3 are included in Z_i. The average treatment effect of the fire on residential density is δ.

Table 6 presents the results from estimation of (2). Column 1 shows the results without controls for distance to city hall, neighborhood location, or regulatory changes. This estimation is comparable to the results given in Table 5, except that (2) is estimated using robust standard errors. The model in column 2 adds the regulatory variables discussed in Section 2.3. The average treatment effect of the fire declines, but remains strong and significant at the 1% level.

The model in column 3 includes distance to city hall as an explanatory variable. Although it decreases, the coefficient on the treatment variable again remains strong and 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 must be interpreted relative to the pre-disaster period.

Column 4 presents results when including neighborhood dummies in the estimation of (2). Compared to the result in column 2, the treatment coefficient in column 3 becomes larger and remains significant at the 1% level. When including neighborhood dummies, the coefficient on distance to city hall is no longer significant, evidence that the distance variable is capturing neighborhood effects rather than a distance effect. Negative effects (relative to the pre-disaster period) are prominent in South of Market and North Beach, 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 this time period.

As is evident, the average treatment effect of the fire remains strong when estimating (2) with a full set of regressors. In this estimation, the average treatment effect is a significant increase of 15 residential units per residential acre. For the average razed block in the sample, this is a relative increase of nearly 13 residential units and indicates a 90 percent increase over the mean change, or a 0.36 standard deviation increase in residential density over this period.

It is possible that there is some unobserved interaction between razed and unburned blocks located very near the fire's boundary that is driving the results shown in Table 6. 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 fashion conducive 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.[15] Columns 1 and 2 in Table 7 report estimation results using these subsamples. A constant and a full set of regressors are included in these estimations. As column 1 reveals, the average treatment effect remains positive for blocks located on the boundary, but is weaker and significant only at the 5% level as residential density experiences an increase of 9 units. For blocks interior to the boundary, the average treatment effect is large and significant at the 1% level at a 25 unit relative increase. 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 model's land use predictions based on distance to the city center.

Columns 3 and 4 present estimation results for subsamples where positive residential density is observed in one or both periods. These estimations address the concern that

[15]Figure 8 shows these subsamples.

blocks without residential development may be driving the results presented in Table 6. By excluding such blocks, the sample is restricted to those with a tendency to be developed with residential structures. As the table reveals, the average treatment effect of the fire remains significant at the 1% level in both subsamples. The effect is stronger in both cases at a 15 unit increase where residential density is positive in at least one period and a 22 unit increase where positive density is observed in both periods.

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. Short of including another pre-disaster period to establish trends in residential density, 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 in Western Addition, where the fire crossed Van Ness Avenue, and the Mission District. 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.

Column 5 of Table 7 presents the estimation results when restricting the sample to blocks that are initially most comparable in residential density. In this estimation, the treatment coefficient remains significant at the 1% level. At a relative increase of 14 residential units per residential acre, it is only one unit smaller than the coefficient shown in column 4 of Table 6. This result suggests that pre-disaster differences in residential density may not be significantly biasing the results of the study.

5.3.2 Land Use

Another outcome considered in this study is land use. As Tables 3 and 4 suggest, the significant change in residential density previously described was accompanied by dramatic changes in land use. To understand this phenomenon, Table 8 presents results of estimating (2) using equation-by-equation OLS where the dependent variable is the change in acreage devoted to four types of land use: residential, nonresidential, mixed (defined as land developed with buildings containing a mixture of residential and nonresidential uses), and vacant. This procedure uses the same set of regressors in each estimation and produces four sets of equation-specific parameters.

Of the four types of land use considered, the most dramatic changes occur in residential and vacant acreage. Column 1 reveals a relative decrease of nearly 1 residential acre for an average block in the razed area. This decline amounts to a nearly one standard deviation decrease in residential land use following the fire. The opposite occurs in vacant land use. In column 4, vacant acreage exhibits a relative increase on razed blocks of nearly an acre, which is a dramatic increase over the mean change across all blocks during this period. Each of these results is significant at the 1% level.

The results are less striking among nonresidential and mixed land uses. As column 2 reveals, there is no significant relative change in nonresidential land use in the razed area after the disaster. Column 3 presents the result for changes in mixed acres, which is very significant at a modest relative decrease of nearly one-tenth of an acre for the average razed block.

5.3.3 Robustness Checks

This section presents results of robustness checks of the residential density model specifications and variable definitions 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 including distance to downtown rather than distance to city hall or when mixed residential units are considered in the density measure. The results derived in Section 5 are robust to these alternative specifications.

Table 9 presents estimation results using alternative specifications. All models include a constant and a full set of regressors. Row 1 presents the original results shown in Table 6. The estimation in row 2 tests the sensitivity of the results to the use of distance to city hall in the base specification by using distance to a downtown prominent intersection.[16] In urban economic models, the CBD is essentially a point in space. This, of course, is not true in reality. The location of the center of the CBD can be difficult to determine exactly. In this specification, the center of the city is a prominent intersection in downtown San Francisco. Results using this measure differ only slightly from the base specification. Thus, the use of a different city center has no qualitative effect on the results presented in the study.

The specification in row 3 shows estimation results where blocks partially affected by the fire are in the treatment group. In row 4, partially affected blocks are in the control group. In row 5, 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 Sections 5.2 and 5.3 are robust to alternative definitions of the treatment and control groups for this study. No qualitative (and very small quantitative) differences exist between row 1 and rows 3 through 5.

Row 6 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

[16] In the new distance specification, the center of downtown is considered to be the prominent intersection at California Street, midway between Montgomery Street and Sansome Street.

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 result of this exercise is robust, and stronger by nearly 5 units per acre, when using this dependent variable.

5.4 Discussion of the Results

Several conclusions can be drawn from this study. First, residential density after reconstruction increased dramatically in the razed area relative to the unburned area. Assuming a competitive equilibrium outcome in the reconstruction of San Francisco after 1906, as well as common building trends across razed and unburned areas, evidence presented in this paper suggests that a deficient residential capital structure existed in San Francisco prior to the fire. When given the opportunity to reconstruct without facing the costs associated with adapting the urban environment, developers built more housing units per residential acre 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 suggests that land use patterns were non-optimal 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. There is a change in this composition toward denser housing, such as flats and apartment units, in the razed area. Demand pressures on the 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 land use estimations. In the razed area, there is a relative shift away from residential land. This shift is largely toward vacant land, the existence of which is a puzzle itself and a topic for future research. There is no relative post-disaster change in nonresidential land acreage.

Overall, stark changes in residential density and land use occur 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 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 non-optimality of residential density and land use in San Francisco during its period of rapid growth. 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, the city of San Francisco was rebuilt in a manner that diverged significantly from its previous capital structure. Specifically, residential density increases significantly in the razed area of the city relative to the unburned area. Land use also changes dramatically as land is shifted away from residential use and into other uses. The relative increase in residential density is generally due to rebuilding the housing stock with only slightly fewer units on much less land than was used before the disaster.

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 structures 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.[17] 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

[17]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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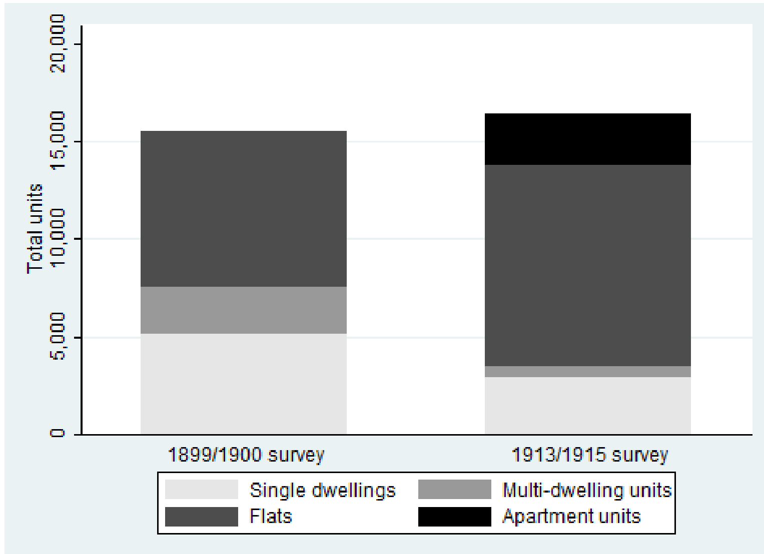

Figure 1: Sample housing stock
Source: see text.

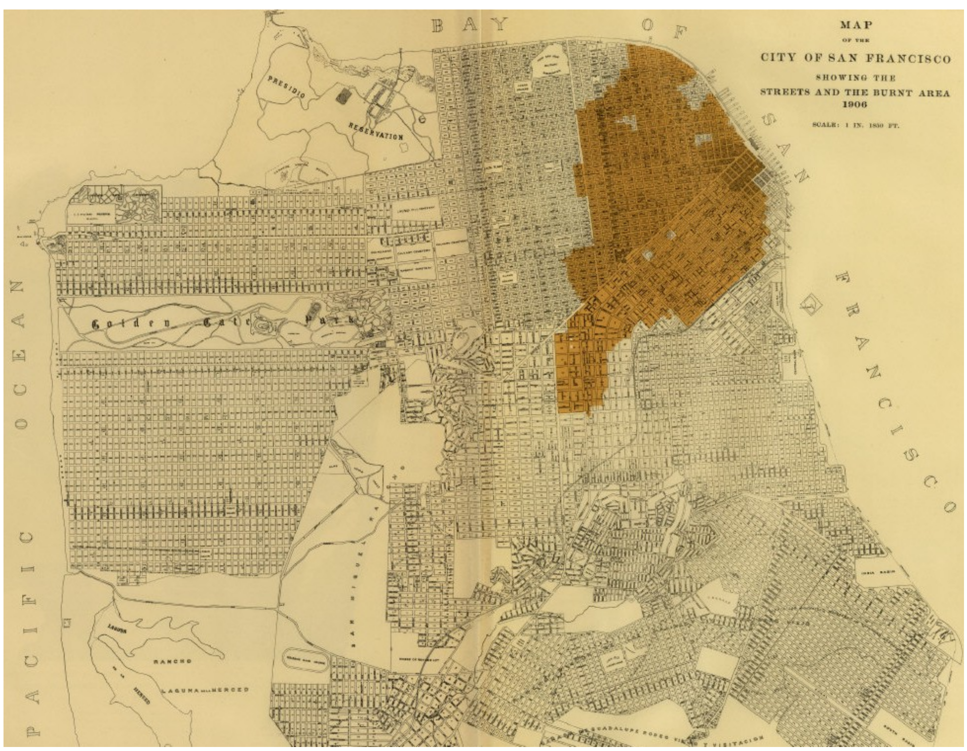

Figure 2: Fire coverage from the 1906 San Francisco disaster as depicted by SEIC (1908)
Source: David Rumsey Historical Map Collection (www.davidrumsey.com).

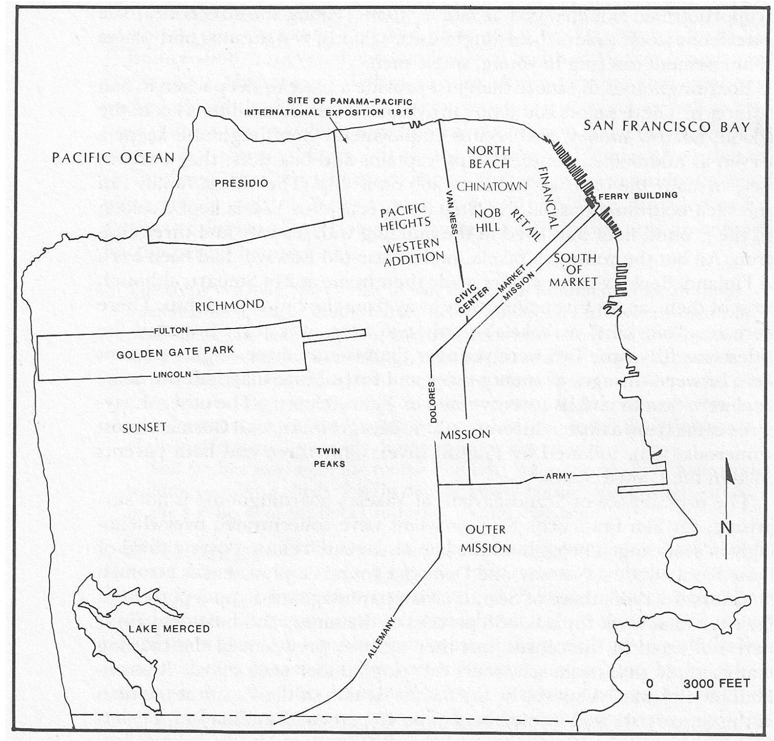

Figure 3: Residential areas
Source: Issel and Cherny (1986).

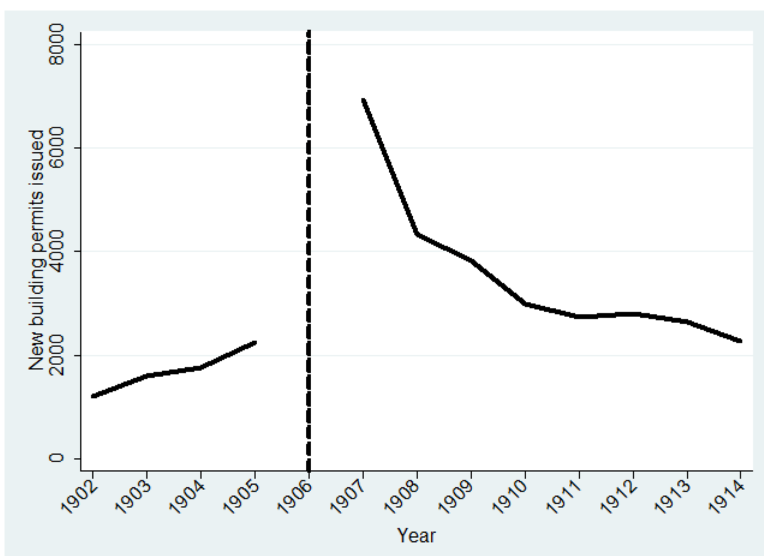

Figure 4: Permits issued for new buildings, 1902-1914
Source: San Francisco Municipal Reports as cited under Data Sources.

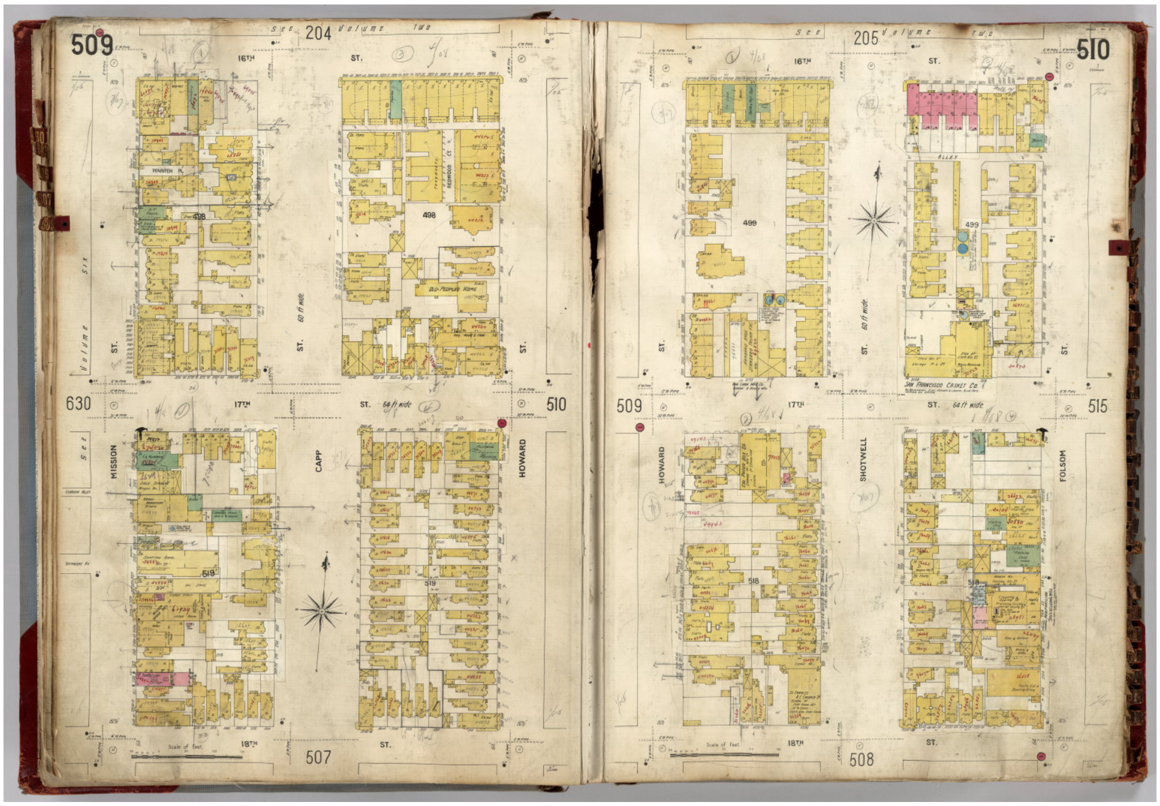

Figure 5: Map sheets 509-510 from 1900 Sanborn Map, Volume 5
Source: David Rumsey Historical Map Collection (www.davidrumsey.com).

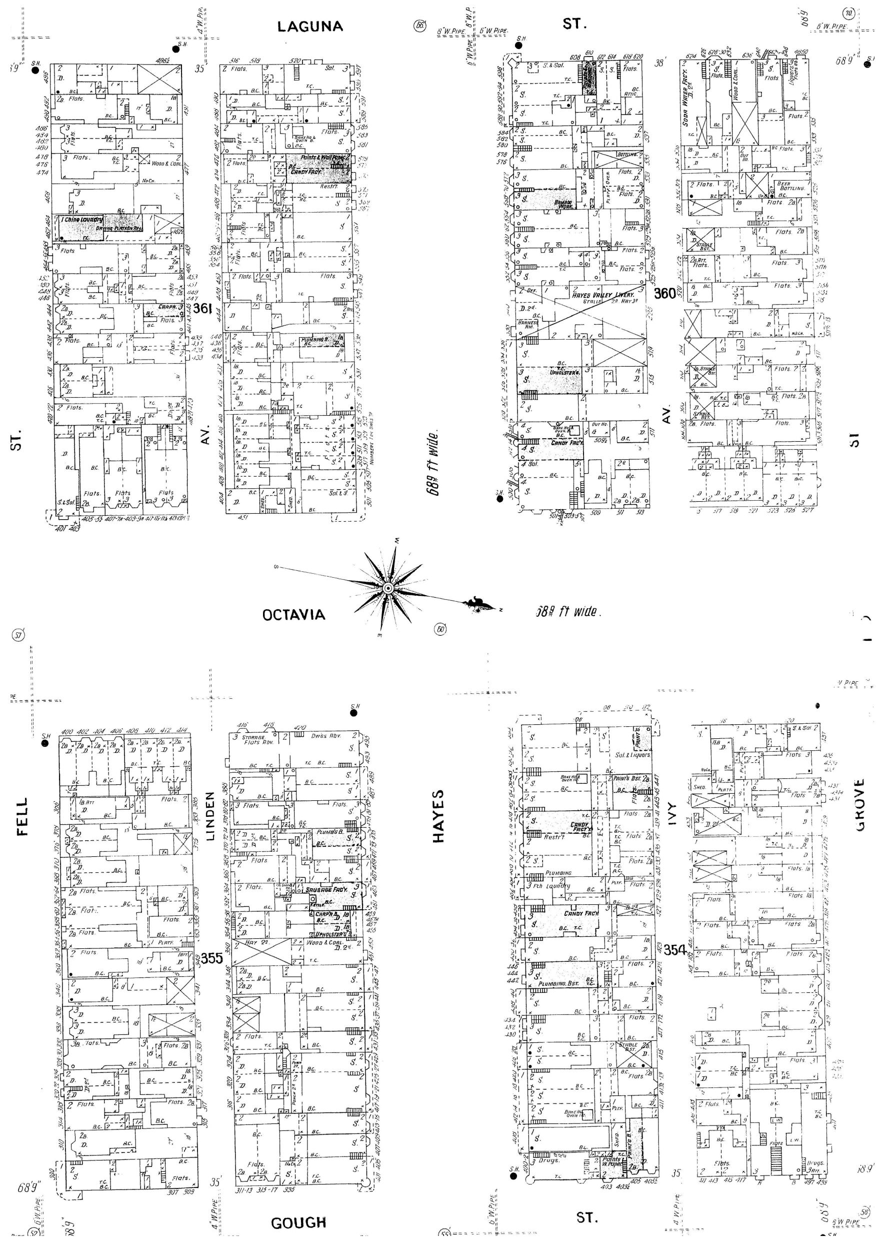

Figure 6: Before the fire (1899/1900 volume)
Source: ProQuest Digital Sanborn Maps, 1867-1970 (accessed through www.lapl.org).

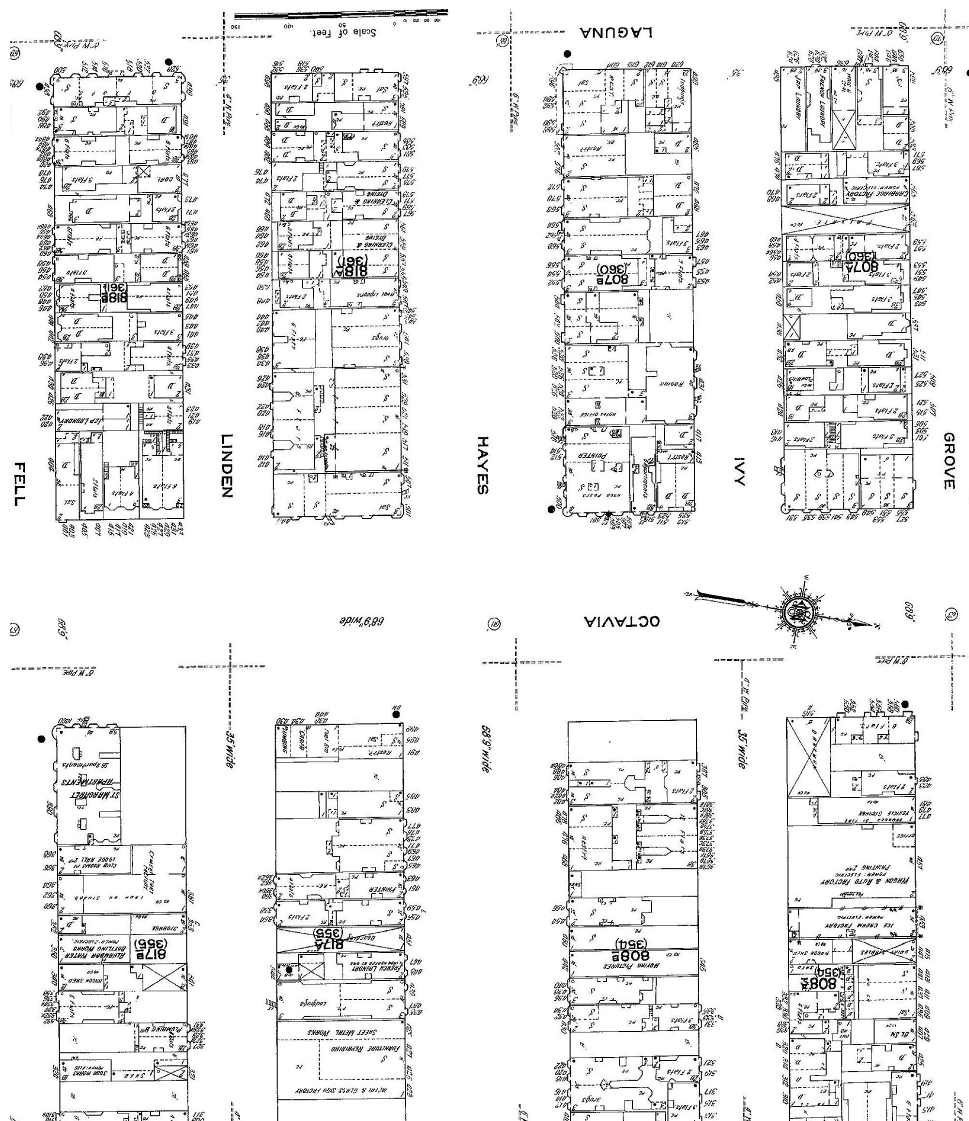

Figure 7: After the fire (1913/1915 volume)
Source: ProQuest Digital Sanborn Maps, 1867-1970 (accessed through www.lapl.org).

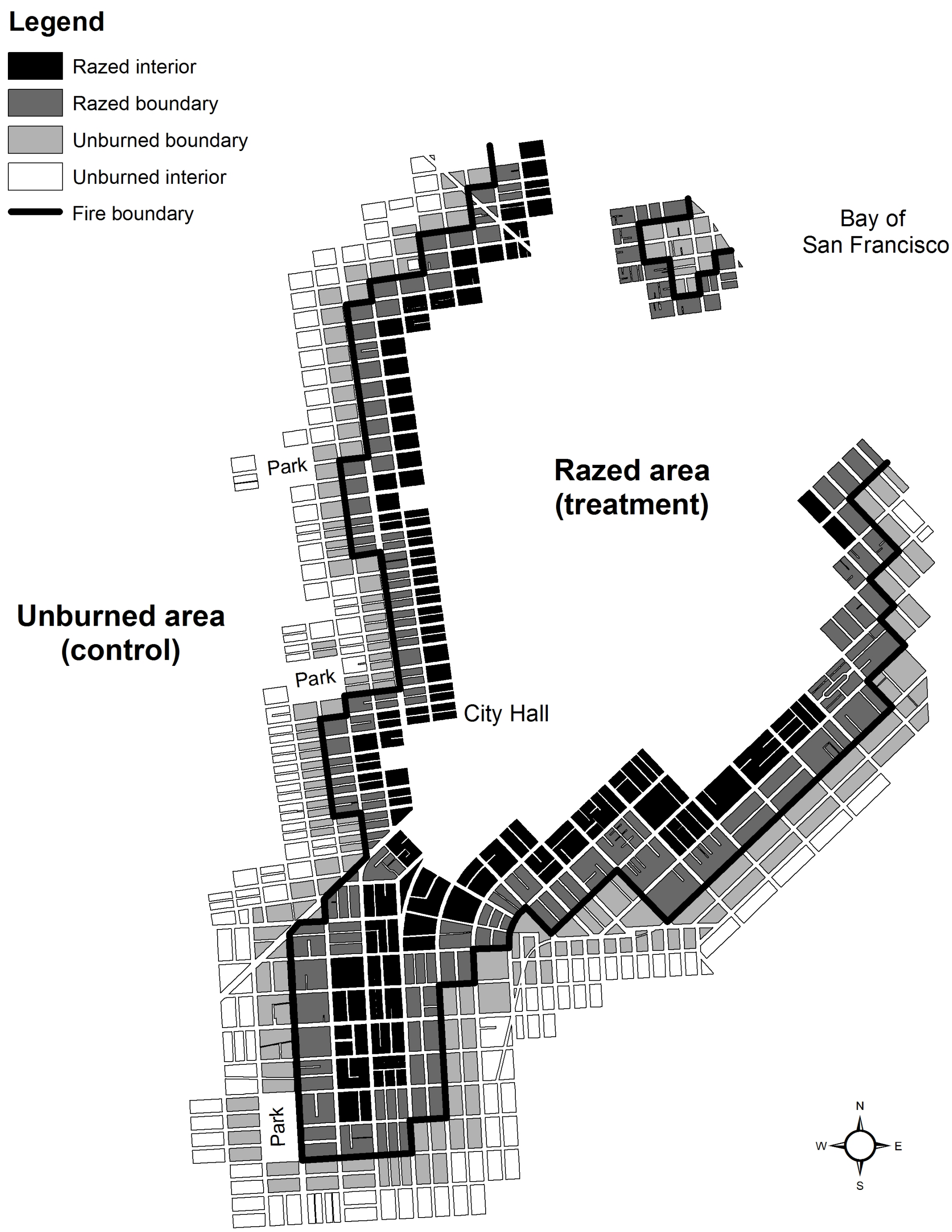

Figure 8: Treatment and control group assignment
Source: see text.

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: Sample housing stock and land use

	Razed		Unburned		Total	
Panel A: Housing stock	Total	Perc.	Total	Perc.	Total	Perc.
1899/1900 survey:						
Residential units	10,338	100	5,192	100	15,530	100
Single dwellings	3,015	29.2	2,156	41.5	5,171	33.3
Multi-dwellings	1,658	16.0	734	14.1	2,392	15.4
Flats	5,665	54.8	2,302	44.3	7,967	51.3
Apartment units	0	0	0	0	0	0
1913/1915 survey:						
Residential units	8,490	100	7,967	100	16,457	100
Single dwellings	1,068	12.6	1,849	23.2	2,917	17.7
Multi-dwellings	133	1.6	455	5.7	588	3.6
Flats	5,437	64.0	4,870	61.1	10,307	62.6
Apartment units	1,852	21.8	793	10.0	2,645	16.1
Panel B: Land use						
1899/1900 survey:						
Acres	721	100	720	100	1,441	100
Residential	363	50.3	299	41.5	662	45.9
Nonresidential	270	37.4	256	35.6	526	36.5
Mixed	27	3.7	12	1.7	39	2.7
Vacant	61	8.5	153	21.3	214	14.9
1913/1915 survey:						
Acres	722	100	724	100	1,446	100
Residential	156	21.6	281	38.8	437	30.2
Nonresidential	365	50.6	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

Source: see text.

Table 4: Summary statistics

	Razed		Unburned	
	Mean	Std. dev.	Mean	Std. dev.
1899/1900 survey:				
Residential units	55.88	49.29	22.00	26.90
Acres	3.90	2.39	3.05	1.66
Residential	1.96	1.26	1.26	1.21
Nonresidential	1.46	1.73	1.09	1.49
Mixed	0.15	0.17	0.05	0.13
Vacant	0.33	0.50	0.65	0.90
Residential density	27.67	17.96	14.60	13.40
Fire limits	.135	.343	.021	.144
Fireproof roof area	0	0	0	0
1913/1915 survey:				
Residential units	45.89	45.48	33.76	40.80
Acres	3.90	2.39	3.07	1.69
Residential	0.84	0.87	1.19	1.33
Nonresidential	1.97	1.98	1.44	1.67
Mixed	0.06	0.09	0.05	0.11
Vacant	1.03	0.89	0.39	0.57
Residential density	54.51	56.89	22.93	24.33
Fire limits	.211	.409	.025	.158
Fireproof roof area	.838	.370	.619	.487
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 5: Average residential density before and after the fire

	(1) Razed	(2) Unburned	(3) Razed - unburned
Before the fire	27.67	14.60	13.07
	(1.32)	(0.87)	(1.53)
After the fire	54.51	22.93	31.58
	(4.18)	(1.58)	(4.11)
Change in mean	26.85	8.33	18.52
	(4.39)	(1.81)	(3.97)

Notes: Standard errors are given in parentheses.

Table 6: Reduced-form estimations

	Dep. variable: Δ(residential density)			
	(1)	(2)	(3)	(4)
Razed by fire	18.518***	14.702***	13.202***	14.797***
	(4.370)	(3.379)	(3.068)	(3.988)
Δ(fire limits)		58.692*	51.421	47.230
		(31.760)	(31.257)	(31.376)
Δ(fireproof roof area)		-1.719	-3.973	-10.745***
		(2.440)	(2.445)	(4.017)
Distance to city hall			-4.607***	-2.187
			(1.247)	(1.448)
Constant	8.327***	9.142***	31.459***	31.810***
	(1.259)	(2.235)	(6.258)	(10.638)
Neighborhood dummies	No	No	No	Yes
Observations	421	421	421	421
R^2	0.049	0.116	0.148	0.208

Notes: 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 16.464 and 41.400.

Table 7: Reduced-form estimations with subsamples

	Dep. variable: Δ(residential density)				
	(1) Boundary	(2) Interior	(3) Density > 0 in one period	(4) Density > 0 in both periods	(5) Initially comparable
Razed by fire	9.025**	25.237***	15.480***	21.721***	13.877***
	(4.143)	(9.466)	(4.630)	(5.268)	(2.939)
Observations	243	178	370	312	74
R^2	0.263	0.171	0.204	0.475	0.451
Mean	14.728	18.835	18.734	24.956	14.616
Std. dev.	42.010	40.551	43.684	43.892	12.170

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 corresponding regressors are included in all estimations.

Table 8: Reduced-form estimations of land use changes

	Dep. variable			
	(1)	(2)	(3)	(4)
	Δ(res ac)	Δ(nonres ac)	Δ(mixed ac)	Δ(vacant ac)
Razed by fire	-0.889***	0.056	-0.084***	0.903***
	(0.092)	(0.110)	(0.020)	(0.111)
Δ(fire limits)	0.036	-0.024	0.041	-0.045
	(0.133)	(0.170)	(0.040)	(0.183)
Δ(fireproof roof area)	-0.321**	0.017	-0.009	0.243*
	(0.149)	(0.252)	(0.035)	(0.135)
Distance to city hall	0.209***	-0.140***	0.008	-0.086
	(0.046)	(0.052)	(0.008)	(0.054)
Constant	-0.729**	0.941**	0.013	-0.096
	(0.340)	(0.437)	(0.063)	(0.421)
Neighborhood dummies	Yes	Yes	Yes	Yes
Observations	421	421	421	421
R^2	0.416	0.082	0.128	0.308
Mean	-0.532	0.426	-0.040	0.159
Std. dev.	0.991	0.911	0.172	1.001

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 estimations.

Table 9: Robustness checks on alternative specifications

Specification	Dep. variable: Δ(residential density) Ind. variable: razed by fire
1. Base	14.797*** (3.988)
2. Distance to downtown	16.506*** (3.835)
3. Partially affected blocks in treatment group	12.890*** (3.808)
4. Partially affected blocks in control group	13.705*** (4.121)
5. Partially affected blocks excluded from analysis	14.834*** (4.274)
6. Dependent variable includes mixed residential units†	21.831*** (4.883)

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.