Wildland Fire Hazard and Urban Development Pattern: Why California Civil Code 1103 Fails to Protect Households from Wildfires

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1. Introduction

With increasing income and decreasing transportation costs, Americans are driving more every year in large part because of the increasingly spread out nature of metro areas. Housing development is reflecting this trend, which is particularly high in natural-amenity-rich areas such as forests, lakes or protected areas (Johnson and Beale, 1994; Radeloff et al., 2005; Radeloff et al., 2000). California is no exception to this trend. As cities become more crowded, affluent residents have increasingly moved towards the amenity-rich suburban area. In southern California, many of the newest and fastest growing suburbs are located in and around fire-prone ecosystems.

This development trend gives rise to serious ecological and socio-economic problems. Besides habitat loss and fragmentation (Theobald et al., 1997), and biodiversity decline (Soulé, 1991; Mckinney, 2002), human-caused wildfires in these areas are quite common (Hammer et al., 2007), and protection of structures from wildfires is most challenging (Cohen, 2000; Winter and Fried, 2001; Haight et al., 2004). This, in turn, impacts on housing development patterns as well. Southern California's Wildland-Urban Interface (WUI) is home to more than six million people, with over 800,000 living in the highest wildfire hazardous zones. During the 2007 fire season, at least half a million people from 346,000 homes were forced to evacuate, and over 3,000 homes and buildings were left in ruins, with estimated losses up to $2.5 billion (Burned Area Emergency Response, B.A.E.R.). Growing population in wildland areas, accompanied by a growing demand for services and skyrocketing costs for fire protection, is the most prominent issues in California's growing fire problems.

California attempted to address these issues in 1998 by passing a bill (AB 1195) to regulate natural hazard disclosure in property transactions after the severe Oakland Hills Firestorms in

1991. This law, California Civil Code Sec. 1103, mandates sellers to complete a Natural Hazard Disclosure Statement indicating whether the property in question is located in statutory wildfire, flood, and seismic–hazard zones. Sellers are required to disclose if their property is in a Very High Fire Hazard Severity Zone (VHFHSZ). Accordingly, California law (California Public Resources Code Sec. 4201) requires state government agency, California Department of Forestry and Fire Protection (CDF), to identify these areas.[1] California law (California Government Code 51178) also requires CDF to identify very high fire severity zones (VHFHSZ) and transmit this information to local agencies. A local agency shall then make the information available for public review. The zones serve several purposes: they are used to designate areas where exterior wildfire exposure protection building codes apply to new buildings. They can be used as a factor in real estate disclosure. In brief, the laws expect to manage wildfires and protect resources, life, and property from uncontrolled wildland fires.

Sec.1103 and its related laws[2] appear to have a high rate of compliance because they clearly articulate the liabilities of information disclosure for sellers and realtors. Such information disclosure is expected to enhance the efficiency of market allocation of land and development in hazardous areas, making land price and development pattern better reflecting the benefit and risk of living in the hazard zones. Numerous researchers also found out that land in a statutory flood hazard zone has negative effects on property price (Donnelly, 1989; Harrison et al., 2001; MacDonald et al., 1989; Troy and Romm, 2004). Compared with literature about flood zone designation, few studies address the issue of wildfire hazard zone designations, and the results seem counterintuitive in many ways. Donovan et al. (2007) conducted a case study in Colorado

[1] The Public Resources Code Section 4202 calls for zones to embrace relatively homogenous lands, which are based on factors such as fuel (material that can burn), slope and fire weather.
[2] The policies include California Civil Code 1103 (1102.6c) and 2694; California Government Code Section 51179 and 51183.5; California Public Resource Code 2621.9, 4125 and 4136.

Springs to analyze wildfire risks and housing prices both before and after a wildland fire rating was available to the public. They found out that fire risk and housing price are positively related before the information is released, but not afterwards. Troy and Romm (2004) used a hedonic method to access the 1998 California Natural Hazard Disclosure Law. They found out that some homes near fire-hazard severity zones were depreciated by 5.1% after a major fire storm in a statutory fire-zone, which is consistent with predictions in literatures of statutory flood hazard zone. However, their results also suggests that after the implementation of Sec. 1103, fire-zone homes near recent fires were only worth 3% more than comparable non-fire-zone homes, while fire-zone homes not near recent fires were worth 8% more. Troy and Romm (2004, 2006) conclude that California Natural Hazard Disclosure Law had no effect for the overall population of fire-zone houses. They (2007) suggest that higher amenity level in the fire-prone area that dominates residents' location choice is one possible reason. They also suggest that inconsistent designations in Local Responsibility Areas (by California Government Code 51179) may be accountable for overdevelopment in the wildfire hazardous area. The inconsistency involves interactions among residents and local authorities with state authorities, such as the efforts of residents and local agencies to change designation status (especially exempt themselves from any designation). However, their studies do not show the mechanism by which Sec. 1103 and its related laws fail to stop over-development and protect residents in wildfire hazardous areas.

The primary objective of this study is to explore the impact of wildland fire-zone designations on housing development patterns in both a general equilibrium framework and a quantifiable manner. We expand a classic urban economics model to include amenities and a public decision sector. We assume that residents choose their residential location and consumption bundle to maximize the expected utility subject to a budget constraint. Their utility comes from housing expenditures, non-housing expenditures, government services, and locational amenities. Potential wildfires add uncertainties to their utility maximization. Consequently, these uncertainties affect urban development patterns and community characteristics in the city. The model in this essay serves as a tool to promote understandings of important fire suppression issues involving residents and local authorities with state authorities, particularly, the intention of residents and local agencies to change the very designation status of high fire hazard severity zone (VHFHSZ). Our model also reveals the possible behaviors of residents and local governments and helps us understand why Sec. 1103 and its related laws fail to stop over-development in wildfire hazardous areas.

Based on the theoretical model, simulations are conducted. To understand the dynamics of fire regimes, we focus on the effects of fire-zone characteristics on local government service levels, housing development patterns and community profiles, including fire hazard occurrence, fire-zone area, heterogeneous natural amenity levels, and income mix. Sensitivity analysis is conducted to examine how results are affected by assumptions about the probability, size, and location of fire occurrence and the level of natural amenity. Parameters used in the simulation are estimated based on statistics of the Consumer Expenditure Survey and the U.S. Census 2000 of the California State government and the San Diego local government. Simulation results disclose the impacts on housing prices, development densities and income mix both inside and outside of the designed fire-zones after the disclosure of the fire-zone status.

This paper is organized as following: in the next section, a theoretical model is proposed, and equilibrium conditions are defined. The effects on optimal land bid rents, local government service levels and of major fire-zone characteristics (e.g., wildland fire occurrence probability, fire-zone area, natural amenity level, income mix, and government disaster assistance) are analyzed explicitly. In the third section, we conduct sensitivity simulation studies to analyze the impacts of various forms of fire-zone designation on metropolitan spatial profiles, namely, land value, housing development density and income mix. In the following sections, we review some policy flaws of Sec. 1103 and its related laws in combination with the results from simulation studies. The analysis explores the behaviors of households and local governments and helps us to understand the mechanism that leads to the failure of Sec. 1103 to protect households from wildfires. Following our analysis, we provide some policy suggestions.

2. The Model

In this section, we present an urban economics model that includes a public decision sector. In this model, households maximize their utility facing wildfire uncertainty. The local government maximizes the total land value subject to the local budget constraints. Equilibrium conditions determine not only the optimal level of both government services[3] and property tax rate, but the households' behavior and urban development patterns. To understand the dynamics of fire regimes, we also explore how the changes of important fire-zone characteristics affect the land prices, the optimal level of government services and income mix within this area.

2.1 Households' location choice

To begin with, we consider a simple open city model that includes only one circular metropolitan city. The production of non-housing goods and services are produced in the center of the city (CBD), whereas wage (y), price of non-housing goods (z) and commuting cost per mile (t) are all exogenous. All metropolitan residents work in the center of the city (CBD), and

[3] Government services include different services that a local government provides for her residents, for example public schools, public security management, and parks and recreation. A government service level is referred to as the quality that her service can achieve, for example the quality of public schools. The improvement on government services can be referred to as an improvement of government services on both variety and quality.

commute x miles between the CBD and their residences. All residents in the same income group are homogeneous, which means that they earn the same income and have identical preferences.

Households maximize their utility subject to their budget constraints by choosing their consumption bundles. Assuming their utility takes the von Neumann-Morgenstern expected utility form as

$$\max[U_k] = \max[E_k(u)] = \max[E(\pi_k)u_{1,k} + (1 - E(\pi_k))u_{0,k}] \tag{1.1}$$

$k = 1$ indicates residential location in the fire-prone area, and $k = 0$ otherwise. $u_{1,k}$ is the utility function when wildfire breaks out ($f = 1$), and $u_{0,k}$ when it does not ($f = 0$). By definition, $u_{1,k} \ll u_{0,k}$; this rules out the possibility that somebody may benefit from wildfires. Both $u_{0,k}$ and $u_{1,k}$ are continuous, quazi-concave, and twice differentiable. The probability of fire occurrence in the wildland is exogenously determined and uniform in fire-prone areas. Accordingly, for residents who live outside fire-prone area(s), the expected utility takes the form as

$$U_{k=0} = E_{k=0}(u) = u_{0,k=0} \tag{1.2}$$

and for residents who live within the fire-prone area(s), the expected utility takes the form as

$$U_{k=1} = E_{k=1}(u) = u_{1,k=1}E(\pi_{k=1}) + u_{0,k=1}(1 - E(\pi_{k=1})) \tag{1.3}$$

$u_{1,k}$ comes from the government disaster relief assistance, on which households have to depend entirely when wildfires break out; $u_{1,k=0} = 0$ and $u_{1,k=1} \geq 0$. $u_{0,k}$ comes from housing expenditures (h), non-housing goods (z), government services (g), and locational amenities (a). In specifics, $u_{0,k}$ takes the Cobb-Douglas form as

(1.4) $$u_{0,k} = h_k^{\alpha} z_k^{1-\alpha} a_k^{\gamma} g^{\mu}$$

a_k is locational natural amenity that is exogenously determined and takes the form as follows

(1.5) $$a_k = a_k(x \mid a_0, a_d, \delta, w_{OS}, c_{OS}) = a_0 + a_d w_{OS} \exp\{-\delta \mid x - c_{OS} \mid\}$$

c_{OS} is the center of the amenity source, such as a geographic center of a lake, a forest or a mountain. w_{OS}, a_d and δ are all exogenous parameters that defines the shape of amenity. a_0 is defined as the base-level amenity. The exponential function form determines that amenity level decreases from its center (c_{OS}). Except for expenditures allocated to housing goods, non-housing goods and commuting cost, residents need to pay property tax to fund local government services. The tax is levied at rate τ on the residents' housing expenditures ($p_k(x)h_k$). Accordingly, households' budget constraint is

(1.6) $$(1+\tau) p_k(x) h_k + z_k + tx = y$$

Solving the utility maximization problem of $u_{0,k}$ with the households' budget constraints in (1.6) yields the optimal housing and non-housing goods demand of residents as follows respectively,

(1.7) $$h_k^* = \frac{\alpha(y - tx)}{(1+\tau) p_k^*(x)};\ z_k^* = (1-\alpha)(y - tx)$$

Substituting (1.7) to equation (1.4), the corresponding indirect utility function and optimal bid price offered by households are given as

(1.8) $$\bar{v}_{0,k} = \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}(y - tx) a_k^{\gamma} g^{\mu}}{(1+\tau)^{\alpha} p_k^*(x)^{\alpha}};\ p_k^*(x) = \frac{\left(\alpha^{\alpha}(1-\alpha)^{1-\alpha}\right)^{1/\alpha} (y - tx)^{1/\alpha} a_k^{\gamma/\alpha} g^{\mu/\alpha}}{(1+\tau)\bar{v}_{0,k}^{\ 1/\alpha}}$$

The land bid rent in the traditional monocentric city model decreases monotonically, while the land bid price is allowed to change geographically and is consistent with Wu (2006, 2008) and Wu and Plantinga (2003). Suppose there is no information asymmetry on wildland fire occurrence, we substitute $E(\pi_{k=1}) = \pi_{k=1}$, $\bar{v}_{0,k=1} = (\bar{V} - \bar{v}_{1,k=1}E(\pi_{k=1}))\big/(1-E(\pi_{k=1}))$ and $\bar{v}_{1,k=1} = \bar{S}$ into the above optimal land bid rent function

$$p^*_{k=1}(x) = \frac{\left(\alpha^{\alpha}(1-\alpha)^{1-\alpha}\right)^{1/\alpha}(1-\pi_{k=1})^{1/\alpha}(y-tx)^{1/\alpha}a_{k=1}^{\gamma/\alpha}g^{\mu/\alpha}}{(1+\tau)(\bar{V}-\bar{S}\pi_{k=1})^{1/\alpha}} \tag{1.9}$$

Equation (1.9) highlights the difference between the model we propose in this study and the traditional monocentric city model. Traditionally, the land price does not reflect any associated risk. Based on a non-risk-involved land bid rent function, residents tend to overbid on land in the fire-hazardous area and land is overdeveloped. Alternatively, the land bid rent in our model reflects the willingness to pay under uncertainty. Facing possible wildfire hazards, households would move into fire-prone areas only if they can achieve the same (expected) utility level at the residency within the fire-zone as they did outside the fire-zone.

2.2 Government service level and tax rate determination

There also exists a public decision sector in this economics model. The main objectives for the local government include maximizing her local tax base, the total land value in development (TLV), and providing government services for local residents. This allows her to levy local property tax and provide corresponding government services as laid out in the local balanced budget.

To make our model rigorous enough, additional assumptions are imposed on the timing of the public decision. The local budget is stipulated at the beginning of the year and is comprised of two parts, the expenditure and the revenue. The expenditure focuses on the government services (g) to her local residents (N). At the same time, an *ex ante* property tax rate (τ) is promulgated and local tax is collected. It is a lump-sum tax[4] and no adjustment is made afterwards throughout the year. The sole purpose of the local tax is for funding the local government service provision.[5] Households can also predict the impact of change of government services on the housing/land price; their willingness to bid on land reflects the changes of local tax and government service level immediately. The timing assumption of local tax collection and budget compilation is critical for our model.

To achieve the goal, the local government needs to select the locus of (g,τ) to maximize the total land value as well as keep the budget balanced ($TC \equiv TR$). The total revenue (TR) of the government comes solely from the property tax levied on residents' housing expenditures or the total land value in development,

$$(1.10) \qquad TLV = \int_{x\in\aleph_k} 2\mathrm{Pi}\cdot p_k(x)xdx \;\; ; \; TR = \tau\cdot TLV = \tau\cdot \int_{x\in\aleph_k} 2\mathrm{Pi}\cdot p_k(x)xdx$$

, with $\aleph_k$ defining the domains of x. The cost of government services (TC) in the city is assumed to take the following form in Borcherding and Deacon (1972) as

$$(1.11) \qquad TC = gN^{\lambda} \qquad \lambda\in[0,1]$$

λ is the economy of scale parameter, with $\lambda = 1$ indicating no economy of scale and $\lambda = 0$ infinite economy of scale. It determines the efficiency level that the local government can achieve when providing local services to her residents. The number of households is given as

[4] This is a single tax payment for the amount due at the beginning of the year, as opposed to a series of periodic payments.
[5] This is also consistent with the facts that local governments take a small share of the financial responsibility of the fire suppression cost overall and almost nothing for major fires and disaster fires.

(1.12) $$N = \int_{x \in \aleph_k} \frac{2\mathrm{Pi}x}{h_k} dx = \int_{x \in \aleph_k} \frac{2\mathrm{Pi}(1+\tau)}{\alpha} \frac{p_k^*(x)x}{y - tx} dx$$

With these setups, Wu (forthcoming)[6] suggests that the optimization of the local tax base subject to the community's budget constraint is equivalent to the maximization of $g^{\frac{\mu}{\alpha}} \big/ (1+\tau)$ to the same constraint[7]. As a result, the optimization of the total land value based on homogeneous-preference households yields a fixed tax rate of $\tau = \dfrac{1}{\frac{\alpha}{\mu} + (1-\lambda)}$ and reduces itself to the optimization of government services to the same budget constraint. This enables the local government to narrow down her focus to the changes of government service level with a fixed tax rate. These results are verified in our simulation studies.

2.3 Equilibrium conditions

After characterizing the behavior functions of the households and the local government, we need determine the spatial equilibriums in the city. Spatial equilibrium is achieved when three conditions are satisfied. First, households choose their location and have no intention to move. Second, land owners will allocate the land to achieve the highest possible land value. Third, the tax base is optimized and the budget of the local government is strictly balanced.

One direct outcome of the spatial equilibrium requires that land be allocated to the highest bidders

(1.13) $$p(x) = \max[p_k(x), \overline{p}_{ag}]$$

[6] See the assumptions and proofs in Wu (forthcoming) for details.

[7] In this paper, we assume that the natural amenity level is exogenously determined. The results may not be true, especially if natural amenity level is endogenously affected by residents' location choices and included in the objective function from the local government. Instead, simulation studies will be conducted to maximize the total land value in development.

Equation (1.13) allows land to be allocated in order to generate optimal land value. With the continuity of the land bid rent function, the development boundary (r_c) in the city is defined as follows:

Definition 1

A development boundary (r_c) is defined as the point where the bid price offered by residents equals land reservation price, as in

$$p_k(r_c) = \overline{p}_{ag} \quad (1.14)$$

r_c separates land in development from reserved land. It is noticeable that income mix and heterogeneous amenity level make the determination of community development boundaries complicated: land bid curve either intersects with the land reservation price at r_c, where the higher bid price offered by residents equals the land reservation price either inside ($p_{h,k=1}(r_c) = \overline{p}_{ag}$) or outside the fire-zone ($p_{h,k=0}(r_c) = \overline{p}_{ag}$), or is intercepted at jurisdictional/fire-zone boundaries, or both; no other possibilities exist.[8] This definition determines the existence condition for the urban development boundary.

Another possible outcome in equilibrium is leap-frog development. As wildfire uncertainty lowers households' intention to move into fire-prone areas, the land bid price that reflects this risk might be considerably lower than its counterparts outside the fire-prone area. With the land allocated to generate optimal land value, it is highly possible that land within the fire-zones may not be developed at all. However, outside fire-zones, land development reappears. The leap-frog

[8] See Fig. 1 for more details.

development may be reinforced or weakened by income mix and heterogeneous natural amenity levels across the region, and we will discuss possible results in the simulation section.

The spatial equilibrium also requires determining the community development boundary when facing multiple income groups. For example, we may have a situation with both high and low-income groups living in the city. They have different income levels and different commuting costs. Accordingly, their consumption bundles, including housing expenditures, non-housing goods, government services and locational amenities, will be different and so will their land bid functions. This leads us to define a point (x_0) at which the two income groups may offer the same land bid price and prove its existence as follows:

Definition 2

A price indifference point (x_0) is defined as the point where the bid price offered by both income groups is equals, as in

(1.15) $$p_{hk}(x_0) = p_{lk}(x_0)$$

x_0 separates both income groups; it exists even if the land bid price is lower than the land reservation price. Definition 2 also implies that income mix coexists with the price indifference curve (x_0); otherwise, there is only one income group in the city.

2.4 The effects of fire-zone designations

It is important to realize that fire-prone areas are changing over time and across the region. The dynamics in fire regimes, including the changes of fire occurrence probability, fire-zone area, income mix and government disaster assistance level, will change the government service level and the optimal land bid rent as well. This section will mainly focus on an exploration of these effects.

Before we proceed, it is necessary to have the definitions of the share of the total residents in the fire-zone (η_c), the share of the total tax revenue from residents in the fire-zone (η_r) and the relative burden of property tax for residents in the fire-zones as follows:

Definition 3

The share of the total residents in the fire-zone (η_c) is defined as

$$\eta_c = \frac{N_{k=1}}{N} = \frac{1}{N} \int_{x \in \aleph_{k=1}} \frac{2\text{Pi}x}{h_{k=1}} dx$$

The share of the total tax revenue from residents in the fire-zone (η_r) is defined as

$$\eta_r = \frac{TR_{k=1}}{TR} = \frac{1}{TR} \int_{x \in \aleph_{k=1}} 2\text{Pi}\,\tau\, p_{k=1}(x) x dx$$

The ratio of tax revenue per household in the fire-zone to that in the city (β_R) is defined as

$$\beta_R = \frac{TR_{k=1}}{N_{k=1}} \Big/ \frac{TR}{N} = \frac{TR_{k=1}}{TR} \Big/ \frac{N_{k=1}}{N} = \frac{\eta_r}{\eta_c}$$

If $\beta_R > \lambda$, then property tax per household is relatively more burdensome for residents in the fire-zone than for residents in the city; if $\beta_R < \lambda$, then property tax per household is relatively less burdensome for residents in the fire-zone than for residents in the city.[9]

a. The effects on government service level

1) The effects of fire occurrence probability and government disaster assistance

Proposition 1

Given an economy of scale (λ) and imposed domains of households' preferences ($\frac{\alpha}{\mu} > 1$), if property tax per household is relatively more burdensome for residents in the fire-zone than for residents in the city ($\beta_R > \lambda$), a designation with lower wildfire risk ($\pi_{k=1}$) tends to improve government service level (e.g., $\frac{\partial g}{\partial \pi_{k=1}} < 0$), while a designation with lower levels of government disaster assistance tends to lower government service level, (e.g., $\frac{\partial g}{\partial \overline{S}} > 0$). If property tax per household is relatively less burdensome for residents in the fire-zone than for residents in the city ($\beta_R < \lambda$), the effects are reversed.

(Proof is attached in Appendix.)

Proposition 1 states how the changes of wildfire occurrence probability and government assistance affect the government service levels. The results here are central to our arguments in this paper, simply because they disclose the binary feature of the effects based on $\beta_R - \lambda \lessgtr 0$. It is

[9] This is because with $TR = TC = g_c N^{\lambda}$, as it is always relatively cheaper to provide government service for residents in the whole city than for individual residents.

also noticeable that the bench mark value of judging the relative burden of local property tax depends on the economy of scale of the government service provision (λ). The impacts on β_R itself are too complicated to derive. Simulation studies may provide possible clues.

2) **The effects of fire occurrence probability and government disaster assistance with income mix**

Proposition 2

Given a fixed economy of scale (λ) and the same level of government disaster assistance ($\overline{S}$) for both income groups, if $\beta_{R2} = \dfrac{(\omega_l \eta_{l,r} + \omega_h \eta_{h,r})}{(\omega_l \eta_{l,c} + \omega_h \eta_{h,c})} > \lambda$ [10], then a designation with lower fire risk ($\pi_{k=1}$) tends to improve government service level (e.g., $\dfrac{\partial g}{\partial \pi_{k=1}} < 0$); otherwise, the effect is reversed. Similarly, if $\beta'_{R2} = \dfrac{(\omega'_l \eta_{l,r} + \omega'_h \eta_{h,r})}{(\omega'_l \eta_{l,c} + \omega'_h \eta_{h,c})} > \lambda$ [11], then a designation with lower government disaster assistance ($\overline{S}$) tends to lower government service level, (e.g., $\dfrac{\partial g}{\partial \overline{S}} > 0$); otherwise, the effects are reversed. [12]

(The proof is attached in the Appendix.)

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[10] β_{R2} is defined analogously as β_R. ω_i / ω_j stands for the relative ratio of the income-groups i and j of the fire occurrence elasticity ($\pi_{k=1}$) of the risk measure function $\theta_{i,1}$, with $\theta_{i,1} = \left[\dfrac{(1-\pi_{k=1})}{(\overline{V}_i - \pi_{k=1}\overline{S}_i)} \right]^{1/\alpha}$. See proof in the Appendix for more detail.

[11] β'_{R2} is defined analogously as β_R. ω'_i / ω'_j stands for the relative ratio of the income-groups i and j of the government assistance ($\overline{S}$) elasticity of the same risk measure $\theta_{i,1}$. See proof in the Appendix for more detail.

[12] Please note that the weights (ω_i / ω_j and ω'_i / ω'_j) are different if $\overline{S} > 0$; if $\overline{S} = 0$, both β_{R2} and β'_{R2} equal β_R.

As we see in the results of Proposition 2, income mix changes the expression of β_R in Proposition 1. The outcome is rooted in the difference in incomes, commuting costs and expected utility levels of the two income groups. As a consequence, different magnitudes (ω_i) are observed as households respond to the wildfire characteristics differently. However, it does not change the binary nature of the effects on the government services. In particular, if $\overline{S} = 0$, results in Proposition 2 will be reduced to those in Proposition 1 respectively. From this point of view, Proposition 2 generalizes the results of Proposition 1 in the presence of income mixing.

3) The effects of changing fire-zone size

Proposition 3

Suppose there is no undeveloped land within the fire-zone.[13] Given a fixed economy of scale (λ), and a given lower boundary of the fire-zone (r_{fl}), if $\beta_{R3} = \dfrac{\tau p(r_{fl} + w_f)h}{TR/N} > \lambda$, then a smaller fire-zone (w_f) tends to improve government service level (e.g., $\dfrac{\partial g}{\partial w_f} < 0$); otherwise, the effect is reversed.

(The proof is analogous to that of Proposition 1 or Proposition 2.)

Proposition 3 reflects the fact that the change in the upper boundary of the fire-zone caused by the wildfire-regime dynamics also has binary effects on the optimal government service level. Its results share similarities with the results in Proposition 1 and Proposition 2.

[13] The results remain valid on the occasion when there is a combination of undeveloped land within the fire-zone and development beyond the fire-zone. However, when there is no development beyond the fire-zone, changing the size of the fire-zone will have no effect.

In brief, our theoretical results can be summarized as follows. First of all, designations of fire-zone that signals different fire occurrence probabilities, as the fire hazard severity zone classifications by the CDF, may have binary effects on the optimal government service level that a local government can provide. The effect depends on the value of a ratio indicator (β_R) compared with the bench mark value (λ).The binary nature also applies to the effects of government disaster assistance and the size of the designated fire-zone. This binary nature is pivotal to understand the unintended consequences with the implementation of California laws including Sec. 1103. Second, income mix may change the magnitude of the effects of fire-zone characteristics on government service level, because different income groups respond differently to wildfire characteristics. Third, heterogeneous amenity levels may strengthen or weaken the effects on government service level by changing the magnitude or even reversing the effects.

b. The effects on land bid rent

Of all the characteristics that describe housing development patterns, land bid rent function characterizes the behaviors of residents better than others. It represents the willingness to bid on land by households and directly determines urban development patterns. Without local property tax and government services, the land bid price outside the fire-zone will not be affected by fire-zone designations; however, if local property tax is levied to fund government services provision, households outside the fire-zone will also be affected by fire-zone designations. In other words, one household’s location choice inside fire-zone impacts that of others across the city. In this section, we focus on the effects of major fire-zone characteristics on the land bid rent inside and outside fire-zones to understand the behavior of households across the city.

First, we examine how these fire-zone characteristics impact on the optimal land bid rent inside the fire-zone ($p^*_{k=1}(x)$). Suppose the values of the ratios[14] suggest that property tax is relatively more burdensome in the fire-zone ($\frac{\partial g}{\partial \pi_{k=1}} < 0$, $\frac{\partial g}{\partial \overline{S}} > 0$, and $\frac{\partial g}{\partial w_f} < 0$), we apply the Implicit Function Theorem to equation (1.9) and derive the first order derivatives of $p^*_{k=1}(x)$

(1.16) $$\frac{\partial p^*_{k=1}(x)}{\partial \pi_{k=1}} < 0\ ; \frac{\partial p^*_{k=1}(x)}{\partial \overline{S}} > 0\ ; \frac{\partial p^*_{k=1}(x)}{\partial w_f} < 0\ .$$

On the other hand, suppose tax is relatively less burdensome in the fire-zone. $\frac{\partial p^*_{k=1}(x)}{\partial w_f} > 0$, but $\frac{\partial p^*_{k=1}(x)}{\partial \pi_{k=1}}$ and $\frac{\partial p^*_{k=1}(x)}{\partial \overline{S}}$ are generally undetermined because of counteracting effects involved.

Next, we examine the effects on the optimal bid rent outside the fire-zone ($p^*_{k=0}(x)$). As equation (1.8) shows, let $k = 0$

(1.17) $$\frac{\partial p^*_{k=0}(x)}{\partial \pi_{k=1}} \underset{>}{<} 0;\ \frac{\partial p^*_{k=0}(x)}{\partial \overline{S}} \underset{<}{>} 0;\ \frac{\partial p^*_{k=0}(x)}{\partial w_f} \underset{>}{<} 0.$$

If property tax is relatively more burdensome for residents in the fire-zone, fire-zone designation with lower fire risk, higher government assistance and smaller area result in a higher bid price outside fire-zone due to improved government services; otherwise, the effects will be the opposite. And income mix and heterogeneous natural amenity levels play similar roles in the optimal bid price as seen in our analysis of the effects on government services.

[14] We must notice that these indicators (β_R) are different from each other in the previous proofs.

In summary, there are several points worth noticing. First, wildland fire hazard will lower household's intention to move into fire-prone areas. In the presence of government services and local property tax, designation of fire-zone signaling potential wildland fire hazard not only impacts residents within the fire-zones, but influence residents outside. Second, these effects are conditionally binary: they depend on values of some indicators (β_R) relative to the bench mark one (λ). If these indicators suggest property tax per household is relatively more burdensome than average, then any changes that might make residents move out of fire-prone areas, e.g. higher fire occurrence probability, lower government disaster assistance, and expansion of the fire-zone area will decrease government service levels and optimal land bid price outside fire-zones; otherwise, the effects are opposite. Third, income mix may influence the magnitude of the effects on housing bid rent, simply because that different income groups have different level of income, expected utility level and commuting cost; they respond differently to the changes in wildland fire hazard and government disaster assistance. Fourth, heterogeneous natural amenity levels may magnify or weaken these effects, or completely alter the sign of these effects. Some of these effects are shown in the following Figures 1 and Figure 2.

3. Simulation Studies

In this section, we conduct a simulation analysis in Mathematica 6.2 to verify our theoretical findings in the previous section. In our analysis, we explore how wildfire occurrence, fire-zone area, income mix, and heterogeneous natural amenity levels affect the households' location choices and government services. The results in the simulation studies reveal the changing urban development patterns in response to the wildfire-regime dynamics. The parameters values for the simulation studies chosen are shown in Table 1. Our sources of data include the U.S. Census

Bureau (USCB), the Bureau of Labor Statistics (USDL\BLS), the California State Government, the San Diego County, and the San Diego City. Some sensitivity analysis is also conducted to test whether or not our simulation results are prone to changing with different parameter setups.

To be explicit, our simulation studies are conducted in two different setups: the simulations with one income group and the ones with mixed income groups. In our first setup, we assume only high-income residents in the city. The income of households in this group is set at $75,000, which is within the fifth 20% quantile[15] of the block level household's income statistics in the San Diego County from the U.S. Census 2000. Their yearly commuting cost is set at $1,500 per mile, which is consistent with the fact that transportation cost accounts for 10-15% of households' total expenditure from the Consumer Expenditure Survey. According to the population and housing characteristics of U.S. Census 2000, the property tax rate is generally less than 2% of median home value and less than 7% of households' income across the United States. Also, for a land share around 25% in a real property value (Epple and Romer, 1991), we set households' preference for housing at 0.125 and preference for government services at 0.015. Due to little knowledge about households' preference for natural amenities, its value is set at 0.125 for technical convenience. Land reservation price is estimated at $1,000 per acre, close to the U.S. average farm real estate value in 2000 by the National Agricultural Statistics Service Information (USDA/NASS). The fire-zone is located far away from the CBD; its location is consistent with the fact that the wildland areas usually have low development density, high vegetation coverage and high wildfire risk. In three different scenarios, we examine the effects of wildland fire occurrence, designated fire-zone area (width) and heterogeneous natural amenity levels on urban development patterns. The level of locational natural amenity takes the

[15]This is equivalent to households with income less than or equal to $75,000/year, which account for around 84.27% of households in the San Diego County.

exponential form as in the early section with parameters specified in Table 1. In another setup, we add low-income residents to this area. Their income level is set at $35,000, which is within the third quantile[16] of the households' income of the same statistics that we use for high-income households. Low income households' commuting cost is set at $1,000 per mile, which is also consistent with the Consumer Expenditure Survey. To be consistent with our theoretical results, we assume two income groups share the same preferences over consumption bundles. Our simulation results are shown in Table 2 and Table 3 respectively.

(Table 2 and Table 3 are attached in Appendix)

Table 2 shows the simulation results with high-income residents only. The first column lists parameters that characterize the urban development patterns, e.g. total land value in development, housing price, development density, lot size, government service levels, and property tax per household. The second column shows our base case urban profiles with no fire-zone designation and uniform natural amenity level. All other columns show how the urban development patterns change in response to the changes of the fire-zone characteristics. Besides, we calculate the average land bid price in a 2-mile-in-width area around the CBD to study the impact of land bid price change outside the fire-zone; we also calculate the total land value in development and the ratio β_R's. Simulations are conducted under three main scenarios, including changes in the fire occurrence probability and fire-zone area and locational amenity changes (both the level and the relative location). We compare the results within each scenario with those in the base case.

The results in Table 2 consistently verify our theoretical results in the early sections of this study. In general, when natural amenity level is exogenously determined and not affected by the fire-zone characteristics, fire-zone designations will not change the optimal property tax rate.

[16] This is equivalent to households with income less than or equal to $35,000/year, which account for around 42.36% of households in the San Diego County.

$\beta_R > \lambda$ is our general assumption and β_R's change consistently with that of average property tax per household but in the opposite direction.

In the first scenario, rising wildfire occurrence lower households' willingness to bid consistently. There are several characteristics reflecting this: the optimal land bid price falls both inside and outside the fire-zone; the total land value in the city is greatly reduced; the total housing development areas shrink; and undeveloped areas appear in the designated fire-prone area. The combination of low density and discontinuity in spatial development patterns constitutes the leap-frog development as predicted in our model; when the fire risk is high enough, as shown with the fire occurrence at 0.2, housing development disappears from fire-zone entirely. As our theoretical results predict, when property tax is relatively more burdensome in the fire-zone than average ($\beta_R > \lambda$), inducing residents to move out of fire-zone by signaling higher fire hazard decreases the government service levels and increases the average tax burden per household for residents in the city. The average land price near the CBD also drops consistently, whereas the average land bid price does not, partly because the changing developed area counteracts it.

The second scenario shows the urban development patterns facing a changing fire-prone area. There are some similarities in simulation results compared with the first one: with the designated fire-zone expanding its horizon, undeveloped land begins to appear between housing developments and total development in the city decreases. On this occasion, average land bid price increases, and so do the average tax burden and optimal government service levels. The reason lies in the fact that a larger fire-zone designation lowers residents' willingness to pay and keeps more land from development. However, this impact has its limits. When little or no development is located beyond the fire-zone, the effects on land bid rent and government services may be negligible.

In the third scenario, natural amenity is assumed to be heterogeneous both in levels and in locations, compared to unity natural amenity level in the previous two scenarios. The natural amenity function takes an exponential form; it decreases from its center which is located in the fire-zone. We first fix the center of the amenity, and raise the natural amenity levels; then we locate the center of natural amenity in different places. Simulation results confirm that heterogeneous locational amenity levels play an important role of influencing the development patterns in the city. Especially, when natural amenity level is high in the fire-prone area, high amenity level offsets the negative impact of fire-zone designation. Higher amenity levels attract more residents to live within the fire-zone, which increases the average land bid price across the region, improves the government services and lowers the tax burdens. Results imply that high natural amenity level may be accountable for overdevelopment in the fire-prone area. Results also suggest that the distance of the amenity center to the CBD affects development patterns as well: the increase on this distance decreases the overall effects on the spatial development patterns in the city.

Table 3 shows the simulations conducted in the presence of mixed income groups with the same scenarios in Table 2. Besides the results in Table 3 that consistently verify our theoretical results as those in Table 2, they provide additional insights. First, income mix brings benefits and cost differently for different income groups and they may have to sacrifice some benefits while enjoying additional ones. For high-income households, the government service level is much lower at the same tax rate than that in the comparable cases in Table 2 but tax burden for them is lowered significantly. For low-income households, tax burden is much higher, but a higher level of government service is achieved, which cannot be achieved when low-income households alone live in the city. Households from both income groups need to deal with smaller affordable lot size. Even with similar preferences, residents from different income groups still responded differently to the changes of wildfire characteristics; this is expected in our theoretical results as well.

Second, income mix also changes the relative burden of property tax in the fire zone. In our simulations, income mix significantly raises the value of indicators (β_R's), as opposite to the comparable cases in Table 2. It suggests that the relative property tax burden in the fire-zone is heavier although the tax burden per household is much lower. As opposite to the results above, higher tax burden per household and lower relative property tax burden in the fire zone are anticipated if all the residents are all from low-income group in the first setup. However, the effects on average tax burden and government services may be quite the opposite when $\beta_R < \lambda$.

Third, the income mix changes itself as well. From the results in Table 3, the ratio of low to high-income households within the fire-zone changes, because they respond differently to potential wildland fire hazard as predicted in our theoretical results. The ratio of low to high-income residents does not change very much with either the wildfire occurrence probability or the level of the amenity; but it does change drastically with the change in the location of the fire-zone and natural amenity center. From this point of view, income mix is both the premise and the outcome.

In summary, our simulation results from both setups consistently verify our theoretical results in this study. We found out that major fire-zone characteristics have significant impacts on the urban development patterns in the city. These impacts are a binary, which depends on the value of indicators (β_R's): if property tax is relatively more burdensome in the fire-zone, any change in the characteristics that induces residents to move out of the fire-zone will lower government service level, which results in smaller tax base and lower average land/housing value; any change of the characteristics that attracts residents to move in will do the opposite. If property tax is relatively less burdensome in the fire-zone, the effects will be the opposite.

4. Understanding the policies of Sec. 1103 with our model

In this section, we go back to review Sec. 1103 and its related laws. We combine some issues in Troy and Romm (2004, 2006, and 2007) with our results in this paper. We focus on the fire-zone designation flaws and analyze the behaviors of local government and residents. The analysis would be useful to provide policy suggestions.

As suggested in Troy and Romm (2004), serious flaws are associated with California's local fire-zone (VHFHSZ) designation. As required by the Natural Hazard Disclosure Law (Sec. 1103), the fire-zone designation mapping falls into two separate categories, the State Responsibility Area (SRA) and the Local Responsibility Area (LRA). The wildland fire area (SRA) is designated by the California Department of Forestry (CDF) and the LRA is mapped by the California Department of Forestry in cooperation with local government. Local governments may exempt land within their jurisdictions from any VHFHSZ status.[17] This is flawed in Sec. 1103, because it enables local government and residents to challenge the designation status even though wildland fire hazard prevails. According to Troy and Romm (2004), some parcels of land in the close vicinity of the SRAs with very high fire-hazard severity classification have been successfully exempted from any designation status. This inconsistency in the LRAs will not

[17] "A local agency may, at its discretion, exclude from the requirements of Section 51182 an area identified as a very high fire hazard severity zone by the director within the jurisdiction of the local agency, following a finding supported by substantial evidence in the record that the requirements of Section 51182 are not necessary for effective fire protection within the area." (California Government Code , Section 51179 (b))

bridge the information gap for local residents; market failure continues to dominate in the appearance of overbidding and overdevelopment on fire-hazardous areas.

Another policy-related flaw exists in current budget structure on fire protection costs. Historical data in the current California Fire Plan suggests that local governments take less than a third of the financial burden of fire suppression of initial attacks. All other funds come from the California State government and federal agencies, and most of the major fire suppression costs and disaster relief efforts are taken care of by the state and federal governments. This gives rise to the issue that the development on fire-hazardous areas is at the cost the all other areas that is not prone to wildfires. With these premises, we explore behaviors of the local government and fire-zone residents and provide our explanation.

a. Local government

At little or no cost of wildland fire suppression, the local governments face two choices. The first one is to fully adopt the state mapping of the VHFHSZ in LRAs. As predicted from our results, land bid rent drops significantly, especially when affluent residents are the majority in these areas. As a consequence, local governments might face revenue shortage with shrinking tax base for local property tax. What is worse, they might lose other tax bases (such as sales tax); it would be extremely cumbersome for local governments since the passage of Proposition 13 in 1978, which capped the local property tax rate and shifted the financial power to the state. Alternatively, they could exempt from all CDF designations as laid out in the Government Code 51179. As the wildfire occurrence is random, residents might be totally unaware of potential wildland fire damages without previous knowledge about wildland fire. On this occasion, households overbid on land, which expands the tax base for the local government. Accordingly, the local government can provide higher levels of government services and attract more residents to move into fire-prone areas. As a result, more life and properties are located in wildfire hazardous areas. Even when wildfire breaks out, the fire suppression cost at the local government level is considerably low. From this point of view, local governments will be better off in this way, although the cost of damages and casualties might be extremely high.

At the same time, it is still possible that local governments may benefit from fire-zone designation. Considering the situation that property tax is relatively less burdensome in the fire-zone than average, adopting the VHFHSZ mapping will induce residents out of fire-prone area and improve government services. There has been some evidence to support our claim with the fact that some jurisdictions did not challenge the designation. However, the real intention could not be simply inferred without additional knowledge.

b. Households

Now we analyze the behavior of households in the fire-zone. Troy and Romm (2004) found that fire-zone homes near the site of a recent fire (within 5 years) are worth considerably less than they would have been had they not been near the site of a recent fire. Their results disclose the fact that residents may have limited knowledge or resources of wildfire hazard: since fire ignition and spreading is very complicated, the knowledge about fire might be beyond the understanding of residents. Short-sightedness is another possibility; they may simply ignore wildland fire hazard. Plus, other factors, such as affordable fire insurance coverage, may also contribute.

As predicted, the designation of very high fire-hazard severity zone (VHFHSZ) may bring more direct negative impacts than potential benefits for residents. Timing is a critical issue. The VHFHSZs are mapped after most residents have moved into the proposed fire-zones and been locked in mortgages. A huge loss in housing value after the disclosure of fire hazard severity classification is wildly anticipated for residents. Although wildfire will cause severe damages and casualties when it breaks out, the benefits of risk-signaling designations are not directly visible, and wildfire occurrence is considerably small and random. Plus, affordable wildfire insurance may cover a lot of damage and loss. This offsets the benefits brought about by fire-zone designations even further. Outflow of affluent residents and tax base loss in the fire-prone area also degrades government service levels; this leads to residents outside the fire-zone suffering from housing value depreciation as well. With little liability or cost for fire suppression, households can also do better to challenge the VHFHSZs designation by CDF. So, there is no surprise that they will not support fire-zone designations within and surrounding their property.

Due to the combined efforts of the residents and local government, LRAs by Sec. 1103 are not consistently designated. As of 1999, 52 local jurisdictions with VHFHSZs mapped by the CDF claimed that they “meet or exceed” the minimums and 58 jurisdictions exempted themselves from any fire-zone designations, even though many of these jurisdictions contain extremely flammable landscapes.

c. Some policy suggestions

The theoretical findings in our study have confirmed some empirical finding in Troy and Romm (2004, 2006 and 2007). Although in-depth research is needed to fully understand any policy impacts, there are some apparent flaws that await revamping.

First, the inconsistent designation in the LRAs needs to be corrected. It is widely accepted that the wildfire behavior is very complicated, and wildfire-regime dynamics are largely impacted by human activities. As more research efforts need to be devoted to the wildland fire issue, it is quite possible that residents may have information gaps. With limited knowledge about fire or with the hope that the chance of wildland fire is small, market failure is characterized as land overbidding and overdevelopment in fire-hazardous areas. From our point of view, both the LRAs and SRAs should be remapped and a uniform standard should be made to the general public. With evidence supporting the impacts of human activities on wildfire occurrence, the mapping of fire-zones should be frequently updated. This also helps to cushion the impacts of fire-zone designation changes by allocating the fluctuations to smaller time slots.

Second, policies should be addressed to change the fire suppression budget. In terms of California Fire Plan (1996), the financial responsibility is inadequately portioned among local, state and federal agencies. With little or no financial responsibilities, local governments intend to exempt from any VHFHSZs mapping and encourage fire-zone housing development to maximize local tax base at the cost of all jurisdictions. Future policies should be designed to balance the financial responsibilities and tax revenue for local governments as well.

5. Conclusion

In this study, we did a formal analysis of the impacts of fire-zone designations on urban development patterns. Recognizing the dynamic nature of fire regimes, we focus on the effects of major fire-zone characteristics on urban development profiles. We have shown that fire-zone designation has strong impacts on urban development patterns both inside and outside of fire-zones. But these effects are binary: they depend on the indicator of the relative burden of the property tax and that of the bench mark. In other words, fire-zone designations may significantly improve government services and housing value across the whole area if property tax is relatively less burdensome in the fire-zone than average; if the above condition has changed, housing value and local government services will be lowered with a shrinking tax base. Based on the theoretical framework, simulations are conducted with parameters estimated from real economic statistics. The simulation studies confirm the theoretical results and reveal the mechanism that leads to the changes in urban development patterns.

Based on the theoretical findings and simulation results, we review the information disclosure required by Sec. 1103 and its related laws; and we focus on the behavior of residents and local governments. Such information disclosure mandated by Sec.1103 should enhance the efficiency of market allocation of land, in the efforts to make land price and development patterns better reflect the benefits and risks of living in the wildfire hazardous areas. However, policy flaws induce unintended consequences and make the information disclosure dysfunctional: the inconsistent designation in the LRAs might not effectively bridge the information gap of wildfire hazard for local residents. Even though local government services can be improved, and housing values enhanced, this inconsistency has caused market failures, such as overbidding on land for housing development and over-development in wildfire hazardous areas. With heterogeneous amenity levels and income mixing condition across fire-prone area, this leads to more residents and higher-valued properties exposed to highly flammable landscapes. From this point of view, the inconsistency in LRAs violates the initial objective of Sec. 1103. At the same time, we found out the asymmetric structure of financial responsibility in the favor of local jurisdictional governments is another problem that needs to be solved. In this budget framework, local jurisdictions intend to exempt themselves from the VHFHSZs mapped by the CDF within the framework of Sec. 1103 and its related laws. As a consequence, Sec. 1103 and its related laws unintentionally promote overdevelopment in fire-hazardous areas and fail to protect residents from wildfires.

Our study also lends adequate theoretical supports for previous research, such as Troy and Rumm (2004, 2006 and 2007) and Donovan et al. (2007). Different from empirical studies, our results have shown fire-zone designation will impact urban development patterns and spatial profiles outside the designated fire-prone areas; the impacts help us to characterize the behaviors of residents across the whole region. Our results have predicted that under certain conditions, the designations will improve government services and strength housing values. This result offers one way to explain why some local government did not challenge the CDF VHFHSZs mapping as mentioned in Troy and Rumm (2006). However, there are still issues yet to be studied, which call for more research efforts devoted to fully understand policy impacts and find solutions aimed at the maximization of the net total social benefits.

Appendix

Proof of Proposition 1

Given $\theta_1 = \frac{(1-\pi_{k=1})^{\frac{1}{\alpha}}}{(\overline{V}-\pi_{k=1}\overline{S})^{\frac{1}{\alpha}}}$, we derive the first order conditions of θ_1 with respect to the change in parameters of $\pi_{k=1}$ and $\overline{S}$ as

$$\frac{\partial\theta_1}{\partial\pi_{k=1}} = \frac{1}{\alpha}\theta_1^{\frac{1}{\alpha}-1}\frac{(-1)(\overline{V}-\pi_{k=1}\overline{S})-(-\overline{S})(1-\pi_{k=1})}{(\overline{V}_i-\pi_{k=1}\overline{S})^2} = -\frac{1}{\alpha}\theta_1^{\frac{1}{\alpha}-1}\frac{(\overline{V}-\overline{S})}{(\overline{V}-\pi_{k=1}\overline{S})^2} < 0$$

$$\frac{\partial\theta_1}{\partial\overline{S}} = -\frac{1}{\alpha}\theta_1^{\frac{1}{\alpha}-1}\frac{(1-\pi_{k=1})}{(\overline{V}-\pi_{k=1}\overline{S})^2}(-\pi_{k=1}) = \frac{1}{\alpha}\theta_1^{\frac{1}{\alpha}-1}\frac{(1-\pi_{k=1})}{(\overline{V}-\pi_{k=1}\overline{S})^2}\pi_{k=1} > 0$$

Let $F = TC - TR = g^{\frac{\mu\lambda}{\alpha}+1}(\theta_0 C_0 + \theta_1 C_1)^{\lambda} - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\theta_0 R_0 + \theta_1 R_1) = 0$

F. O. C. of F with respect to g

$$\frac{\partial F}{\partial g} = (\frac{\mu\lambda}{\alpha}+1)g^{\frac{\mu\lambda}{\alpha}+1}(\theta_0 C_0 + \theta_1 C_1)^{\lambda} g^{-1} - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\theta_0 R_0 + \theta_1 R_1)\frac{\mu}{\alpha}g^{-1} = \frac{\mu}{\alpha}\tau^{-1}g^{-1}TR > 0$$

F. O. C. of F with respect to $\pi_{k=1}$

$$\frac{\partial F}{\partial\pi_{k=1}} = g^{\frac{\mu\lambda}{\alpha}+1}(\theta_0 C_0 + \theta_1 C_1)^{\lambda-1}\lambda(\frac{\partial\theta_1}{\partial\pi_{k=1}}C_1) - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\frac{\partial\theta_1}{\partial\pi_{k=1}}R_1)$$

By definition $\eta_r = \frac{\theta_1 R_1}{\theta_0 R_0 + \theta_1 R_1}$ and $\eta_c = \frac{\theta_1 C_1}{\theta_0 C_0 + \theta_1 C_1}$

$$\frac{\partial F}{\partial\pi_{k=1}} = TR\left[\lambda\frac{1}{\theta_1}\frac{\partial\theta_1}{\partial\pi_{k=1}}\eta_c - \frac{1}{\theta_1}\frac{\partial\theta_1}{\partial\pi_{k=1}}\eta_r\right] = \pi_{k=1}TR\cdot\left[\xi_\pi(\lambda\eta_c - \eta_r)\right] = \pi_{k=1}\eta_c TR\cdot\left[\xi_\pi(\lambda - \frac{\eta_r}{\eta_c})\right]$$

where ξ_π is the risk elasticity of the expected utility level (ξ_π).

Substitute $\frac{\partial\theta_1}{\partial\pi_{k=1}}$ to $\frac{\partial F}{\partial\pi_{k=1}}$, $\frac{\partial F}{\partial\pi_{k=1}} = \frac{-TR\cdot\eta_c}{\alpha(1-\pi_{k=1})}\left[\frac{(\overline{V_l}-\overline{S})}{(\overline{V_l}-\pi_{k=1}\overline{S})}(\lambda-\frac{\eta_r}{\eta_c})\right]$

By applying the Chain rule, F. O. C. of F with respect to $\overline{S}$

$$\frac{\partial F}{\partial\overline{S}} = g^{\frac{\mu\lambda}{\alpha}+1}(\theta_0 C_0+\theta_0 C_0)^{\lambda-1}\lambda(\frac{\partial\theta_1}{\partial\overline{S}}C_1) - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\frac{\partial\theta_1}{\partial\overline{S}}R_1) = TR\eta_c\left[\frac{1}{\theta_1}\frac{\partial\theta_1}{\partial\overline{S}}(\lambda-\frac{\eta_r}{\eta_c})\right]$$

Substitute $\frac{\partial\theta_1}{\partial\overline{S}}$ to the above result and get $\frac{\partial F}{\partial\overline{S}} = \frac{\pi_{k=1}}{\alpha}TR\left[\frac{(\lambda\eta_c-\eta_r)}{(\overline{V}-\pi_{k=1}\overline{S})}\right] = \frac{\pi_{k=1}TR\cdot\eta_c}{\alpha(\overline{V}-\pi_{k=1}\overline{S})}(\lambda-\frac{\eta_r}{\eta_c})$

Apply the Envelope Theorem and let $\beta_R = \frac{\eta_r}{\eta_c}$

$$\frac{\partial g}{\partial\pi_{k=1}} = -\frac{\partial F/\partial\pi_{k=1}}{\partial F/\partial g} = \frac{\tau g\eta_c(\overline{V_l}-\overline{S})}{\mu(1-\pi_{k=1})(\overline{V_l}-\pi_{k=1}\overline{S})}(\lambda-\beta_R)$$

$$\frac{\partial g}{\partial\overline{S}} = -\frac{\partial F/\partial\overline{S}}{\partial F/\partial g} = -\frac{\pi_{k=1}\tau g\eta_c}{\mu(\overline{V_l}-\pi_{k=1}\overline{S})}(\lambda-\beta_R)$$

The above expressions state that if the ratio β_R indicates that property tax is relatively more burdensome for residents in the fire-zone than the average level in the city ($\beta_R > \lambda$), then lower wildfire occurrence or higher government disaster relief assistance tends to improve government service level; otherwise, the effects are the opposite.

(QED)

Proposition 2 Proof

Assume that income mix also exists in the fire-zone designation. Proofs in other scenarios can be conducted analogously.

Given $\theta_{i,1} = \frac{(1-\pi_{k=1})^{\frac{1}{\alpha}}}{(\overline{V}_i - \pi_{k=1}\overline{S})^{\frac{1}{\alpha}}}$, the first order conditions of $\theta_{i,1}$ with respect to $\pi_{k=1}$ and $\overline{S}_i$

$$\frac{\partial\theta_{i,1}}{\partial\pi_{k=1}} = \frac{1}{\alpha}\theta_{i,1}^{\frac{1}{\alpha}-1}\frac{(-1)(\overline{V}_i - \pi_{k=1}\overline{S}_i) - (-\overline{S}_i)(1-\pi_{k=1})}{(\overline{V}_i - \pi_{k=1}\overline{S}_i)^2} = -\frac{1}{\alpha}\theta_{i,1}^{\frac{1}{\alpha}-1}\frac{(\overline{V}_i - \overline{S}_i)}{(\overline{V}_i - \pi_{k=1}\overline{S}_i)^2} < 0$$

$$\frac{\partial\theta_{i,1}}{\partial\overline{S}_i} = -\frac{1}{\alpha}\theta_{i,1}^{\frac{1}{\alpha}-1}\frac{(1-\pi_{k=1})}{(\overline{V}_i - \pi_{k=1}\overline{S}_i)^2}(-\pi_{k=1}) = \frac{1}{\alpha}\theta_{i,1}^{\frac{1}{\alpha}-1}\frac{(1-\pi_{k=1})}{(\overline{V}_i - \pi_{k=1}\overline{S}_i)^2}\pi_{k=1} > 0$$

Let $F = TC - TR = g^{\frac{\mu\lambda}{\alpha}+1}(\theta_{l,0}C_{l,0} + \theta_{h,0}C_{h,0} + \overline{\theta_1 C_1})^{\lambda} - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\theta_{l,0}R_{l,0} + \theta_{h,0}R_{h,0} + \overline{\theta_1 R_1}) = 0$

(Define $\overline{\theta_0 C_0} = \theta_{l,0}C_{l,0} + \theta_{h,0}C_{h,0}$, $\overline{\theta_0 R_0} = \theta_{l,0}R_{l,0} + \theta_{h,0}R_{h,0}$, $\overline{\theta_1 C_1} = \theta_{l,1}C_{l,1} + \theta_{h,1}C_{h,1}$,

$\overline{\theta_1 R_1} = \theta_{l,1}R_{l,1} + \theta_{h,1}R_{h,1}$)

F. O. C.s of F with respect to g

$$\frac{\partial F}{\partial g} = (\frac{\mu\lambda}{\alpha}+1)g^{\frac{\mu\lambda}{\alpha}}(\overline{\theta_0 C_0} + \overline{\theta_1 C_1})^{\lambda} - \frac{\tau}{(1+\tau)}g^{\frac{\mu}{\alpha}}(\overline{\theta_0 R_0} + \overline{\theta_1 R_1})\frac{\mu}{\alpha}g^{-1} = \frac{\mu}{\alpha}\tau^{-1}g^{-1}TR > 0$$

Given $\theta_{l,0} = \frac{1}{\overline{V}_l^{1/\alpha}}$; $\theta_{h,0} = \frac{1}{\overline{V}_h^{1/\alpha}}$; $\theta_{l,1} = \left[\frac{(1-\pi_{k=1})}{(\overline{V}_l - \pi_{k=1}\overline{S}_l)}\right]^{1/\alpha}$; $\theta_{h,1} = \left[\frac{(1-\pi_{k=1})}{(\overline{V}_h - \pi_{k=1}\overline{S}_h)}\right]^{1/\alpha}$

F. O. C.s of F with respect to $\pi_{k=1}$

$$\frac{\partial F}{\partial\pi_{k=1}} = TR(\overline{\theta_0 C_0} + \overline{\theta_1 C_1})^{-1}\lambda(\frac{\partial\theta_{l,1}}{\partial\pi_{k=1}}C_{l,1} + \frac{\partial\theta_{h,1}}{\partial\pi_{k=1}}C_{h,1}) - TR(\overline{\theta_0 R_0} + \overline{\theta_1 R_1})^{-1}(\frac{\partial\theta_{l,1}}{\partial\pi_{k=1}}R_{l,1} + \frac{\partial\theta_{h,1}}{\partial\pi_{k=1}}R_{h,1})$$

Let $\eta_{l,c} = \frac{\theta_{l,1}C_{l,1}}{(\overline{\theta_0 C_0} + \overline{\theta_1 C_1})}$, $\eta_{l,r} = \frac{\theta_{l,1}R_{l,1}}{(\overline{\theta_0 R_0} + \overline{\theta_1 R_1})}$, $\eta_{h,c} = \frac{\theta_{h,1}C_{h,1}}{(\overline{\theta_0 C_0} + \overline{\theta_1 C_1})}$, $\eta_{h,r} = \frac{\theta_{h,1}R_{h,1}}{(\overline{\theta_0 R_0} + \overline{\theta_1 R_1})}$,

$$\frac{\partial F}{\partial\pi_{k=1}} = TR\left[\lambda(\frac{1}{\theta_{l,1}}\frac{\partial\theta_{l,1}}{\partial\pi_{k=1}}\eta_{l,c} + \frac{1}{\theta_{h,1}}\frac{\partial\theta_{h,1}}{\partial\pi_{k=1}}\eta_{h,c}) - (\frac{1}{\theta_{l,1}}\frac{\partial\theta_{l,1}}{\partial\pi_{k=1}}\eta_{l,r} + \frac{1}{\theta_{h,1}}\frac{\partial\theta_{h,1}}{\partial\pi_{k=1}}\eta_{h,r})\right]$$

Let $\omega_l = \frac{(\overline{V_l} - \overline{S}_l)}{(\overline{V_l} - \pi_{k=1}\overline{S}_l)}$ and $\omega_h = \frac{(\overline{V_h} - \overline{S}_h)}{(\overline{V_h} - \pi_{k=1}\overline{S}_h)}$ and substitute $\frac{\partial \theta_{i,1}}{\partial \pi_{k=1}}$ to $\frac{\partial F}{\partial \pi_{k=1}}$

$$\frac{\partial F}{\partial \pi_{k=1}} = \frac{-1}{\alpha(1-\pi_{k=1})} TR(\omega_l \eta_{l,c} + \omega_h \eta_{h,c}) \left[\lambda - \frac{(\omega_l \eta_{l,r} + \omega_h \eta_{h,r})}{(\omega_l \eta_{l,c} + \omega_h \eta_{h,c})} \right]$$

F. O. C.s of F with respect to $\overline{S}$ [18]

$$\frac{\partial F}{\partial \overline{S}} = TR \left[\frac{1}{\theta_{l,1}} \frac{\partial \theta_{l,1}}{\partial \overline{S}} (\lambda \eta_{l,c} - \eta_{l,r}) + \frac{1}{\theta_{h,1}} \frac{\partial \theta_{h,1}}{\partial \overline{S}} (\lambda \eta_{h,c} - \eta_{h,r}) \right]$$

Let $\omega_l' = \frac{1}{(\overline{V_l} - \pi_{k=1}\overline{S})}$ and $\omega_h' = \frac{1}{(\overline{V_h} - \pi_{k=1}\overline{S})}$, and substitute $\frac{\partial \theta_{i,1}}{\partial \overline{S}} = \frac{1}{\alpha} \frac{\pi_{k=1}}{(\overline{V_i} - \pi_{k=1}\overline{S})}$ to $\frac{\partial F}{\partial \overline{S}}$

$$\frac{\partial F}{\partial \overline{S}} = \frac{\pi_{k=1}}{\alpha} TR(\omega_l' \eta_{l,c} + \omega_h' \eta_{h,c}) \left[\lambda - \frac{(\omega_l' \eta_{l,r} + \omega_h' \eta_{h,r})}{(\omega_l' \eta_{l,c} + \omega_h' \eta_{h,c})} \right]$$

Apply the Envelope Theorem

$$\frac{\partial g}{\partial \pi_{k=1}} = -\frac{\partial F / \partial \pi_{k=1}}{\partial F / \partial g} = \frac{\tau g(\omega_l' \eta_{l,c} + \omega_h' \eta_{h,c})}{\mu(1-\pi_{k=1})} \left[\lambda - \frac{(\omega_l' \eta_{l,r} + \omega_h' \eta_{h,r})}{(\omega_l' \eta_{l,c} + \omega_h' \eta_{h,c})} \right]$$

This expression states that if the weighted average indicates that property tax is relatively more burdensome for residents ($\frac{(\omega_l' \eta_{l,r} + \omega_h' \eta_{h,r})}{(\omega_l' \eta_{l,c} + \omega_h' \eta_{h,c})} > \lambda$), then lower wildland fire hazard tends to improve government service level; otherwise, the effects are the opposite.

[18] If $\overline{S}_l \neq \overline{S}_h$, then we can directly apply chain rule and we can show that the impacts of different income groups depends only on the ratio of that group. In the following proof, we further suppose that $\overline{S}_l = \overline{S}_h = \overline{S}$ and show the composite effects.

Similarly, $\frac{\partial g}{\partial \overline{S}} = -\frac{\partial F / \partial \overline{S}}{\partial F / \partial g} = -\frac{1}{\frac{\mu}{\alpha}\tau^{-1}g^{-1}TR}\frac{\pi_{k=1}}{\alpha}TR(\omega_l'\eta_{l,c} + \omega_h'\eta_{h,c})\left[\lambda - \frac{(\omega_l'\eta_{l,r} + \omega_h'\eta_{h,r})}{(\omega_l'\eta_{l,r} + \omega_h'\eta_{h,r})}\right]$

This expression states that property tax is relatively more burdensome for residents ($\frac{(\omega_l'\eta_{l,r} + \omega_h'\eta_{h,r})}{(\omega_l'\eta_{l,c} + \omega_h'\eta_{h,c})} > \lambda$), then rising government disaster relief efforts tend to increase government service level; otherwise, the effects are the opposite.

In particular, when $\overline{S} = 0$, then $\omega_l = \omega_h = 1$; the above results will be reduced to that in Proposition 1

(QED)

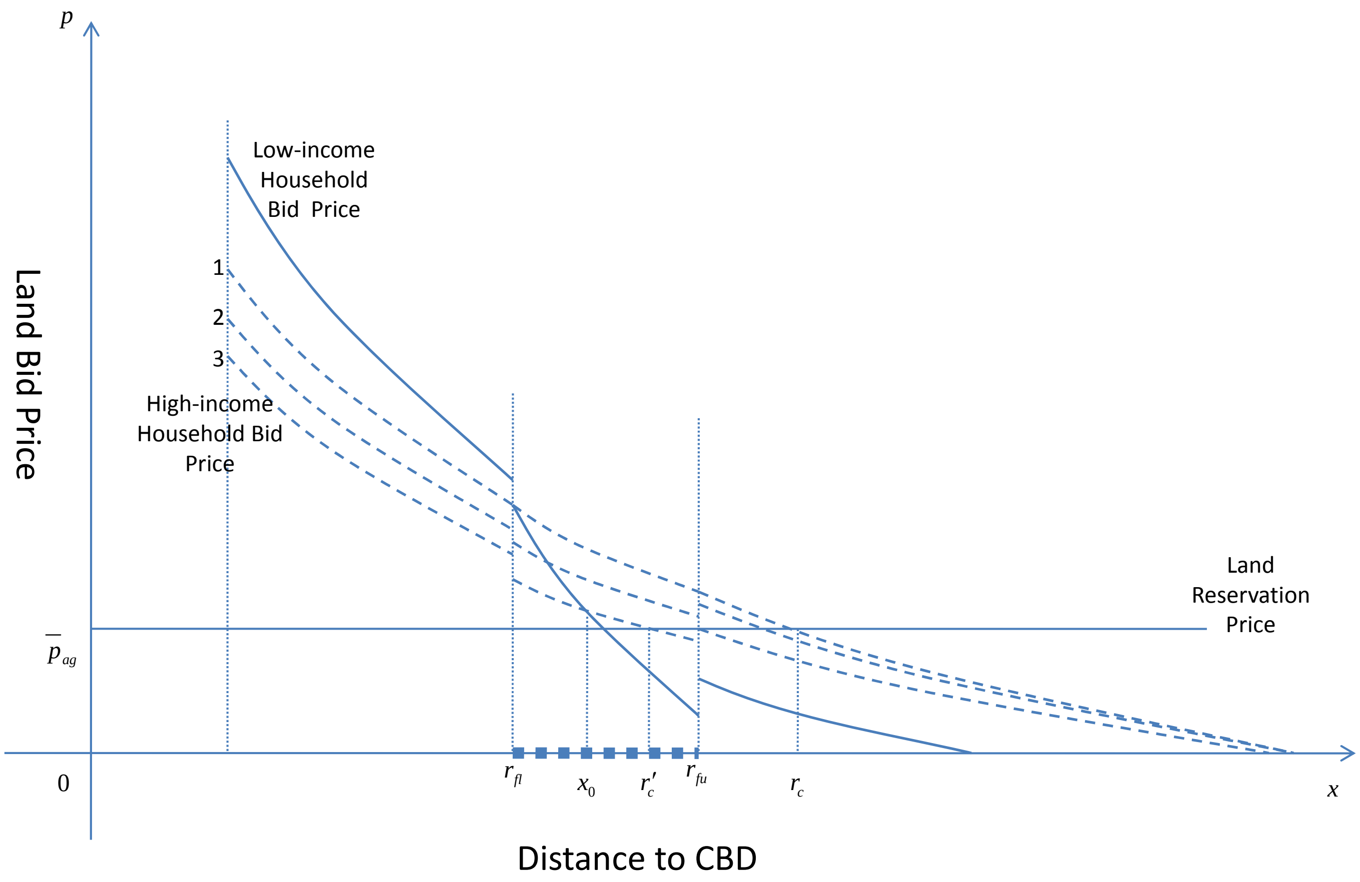

Fig. 1. Optimal Bid Price under the Impact of Fire-zone Designation and Uniform Natural Amenity with Tax.

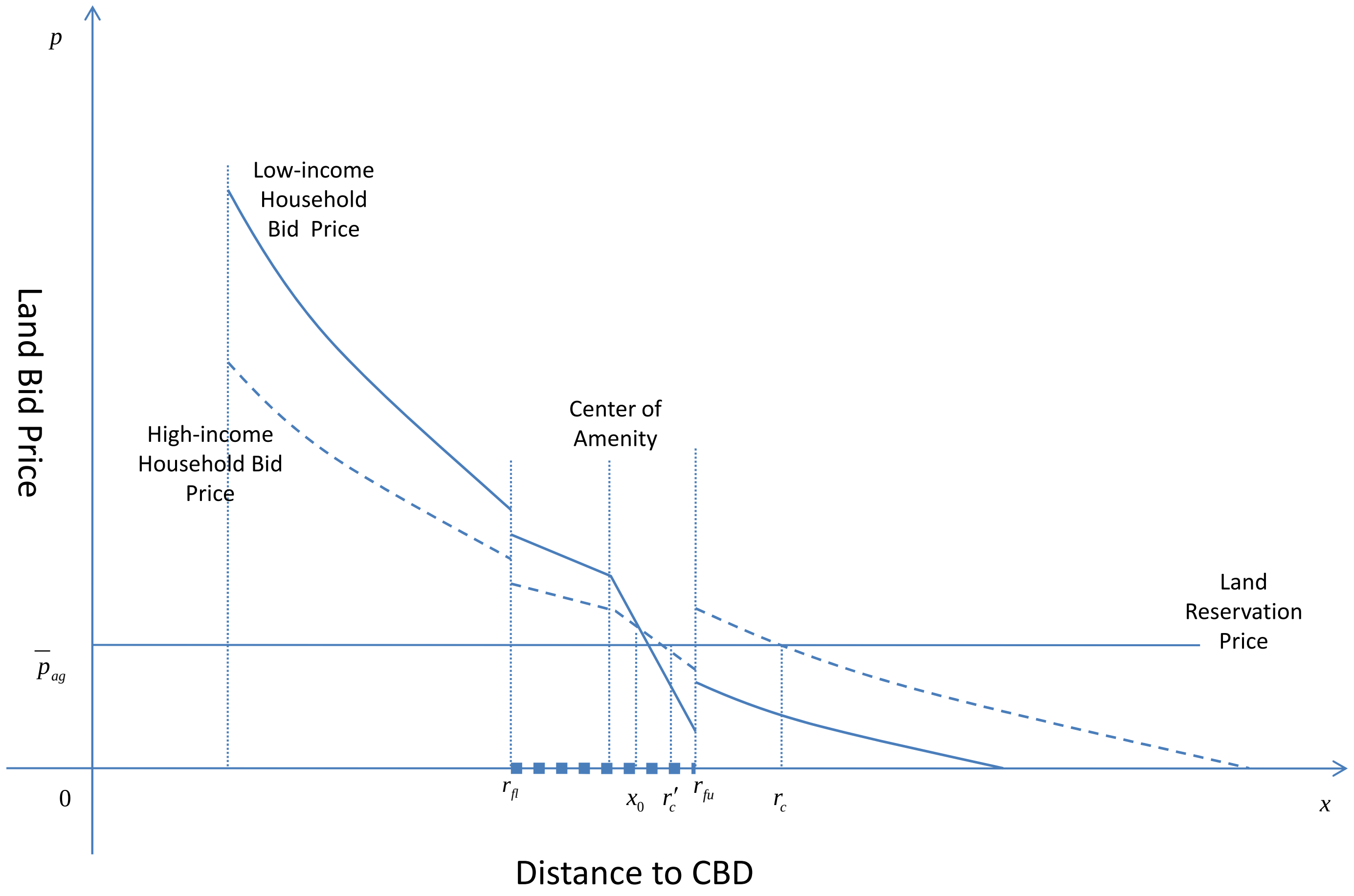

Fig. 2. Optimal Bid Price under the Impact of Fire-zone Designation and Heterogeneous Exogenous Natural Amenities with Tax.

Table 1

Parameter Values for Simulation Studies

Exogenous Parameters of Characteristics across the City		
Households Characteristics		
Low-income Household Income	y_l	35,000
High-income Household Income	y_h	75,000
Low-income Household Expected Utility	$\overline{V}_l$	2,920
High-income Household Expected Utility	$\overline{V}_h$	7,123
Government Disaster Assistance for Low-income Household	$\overline{S}_l$	0
Government Disaster Assistance for High-income Household	$\overline{S}_h$	0
Low-income Household Unit Commuting Cost	t_l	1,000
High-income Household Unit Commuting Cost	t_h	1,500
Low-income Household Preference for Housing Consumption	α_l	0.125
High-income Household Preference for Housing Consumption	α_h	0.125
Low-income Household Preference for Government Service	μ_l	0.015
High-income Household Preference for Government Service	μ_h	0.015
Low-income Household Preference for Natural Amenities	γ_l	0.125
High-income Household Preference for Natural Amenities	γ_h	0.125
City Characteristics		
City Jurisdictional Boundary	b_c	20
Economy of Scale	λ	0.85
Land Reservation Price	$\overline{p}_{ag}$	1,000
Natural Amenity and Fire-zone Characteristics		
Amenities Function Parameters	a_d	1/1.5/2
Amenities Function Parameters	δ	0.5
Amenities Function Parameters	w_{os}	1.0
Fire-zone Area (Width)	w_f	2/3/4
Wildland Fire Occurrence Probability	$\pi_{k=1}$	0.05/0.1/0.2

Table 2

Fire-zone Characteristics and Urban Development Patterns (One Income Group)

Community Characteristics	Baseline	Fire Occurrence Probability			Fize-zone Area (Width)			Natural Amenity (Level)			Natural Amenity (Location)		
		0.05	0.1	0.2	2-mile	4-mile	6-mile	2	3	4	10-mile	11-mile	12-mile
City													
Total Land Value (Million Dollars)	2,969.74	2,848.89	2,765.30	2,610.97	2,765.30	2,584.94	2,382.05	3,316.74	3,868.33	4,420.30	3,088.21	3,041.03	3,024.64
Community Development Boundary (Miles)	17.216	17.214	17.213	17.211	17.213	17.212	17.213	17.387	17.531	17.655	17.273	17.304	17.355
Average Land Price ($/Acre)	4,983	4,782	4,642	5,149	4,642	4,521	5,278	5,457	6,260	7,054	5,148	5,051	4,995
Average Land Price Around CBD ($/Acre)	23,644	23,634	23,626	23,612	23,626	23,620	23,628	23,870	24,110	24,346	23,822	23,749	23,703
Number of Households	426,519	407,996	395,185	371,530	395,185	365,967	331,292	478,666	562,133	645,646	442,848	436,933	435,597
Lot Size (Acre/ Household)	1.40	1.46	1.51	1.36	1.51	1.56	1.36	1.27	1.10	0.97	1.35	1.38	1.39
Density (Units/Acre)	458	438	425	469	425	410	470	504	582	659	472	464	460
Government Service Level (Index)	5,948	5,925	5,909	5,880	5,909	5,897	5,913	6,022	6,126	6,224	5,990	5,967	5,950
Average Property Tax Payment ($/Household)	850.85	853.28	855.09	858.77	855.09	863.13	878.64	846.71	840.86	836.63	852.16	850.50	848.51
Property Tax Rate	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%
Fire-zone													
Start Location (Mile)	-	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
End Location (Mile)	-	12.00	12.00	12.00	12.00	14.00	16.00	12.00	12.00	12.00	12.00	12.00	12.00
Width (Mile)	-	2.00	2.00	2.00	2.00	4.00	6.00	2.00	2.00	2.00	2.00	2.00	2.00
Community Development Boundary (Miles)	-	12.00	12.00	10.00	12.00	13.57	13.57	12.00	12.00	12.00	12.00	12.00	12.00
Total Development (Acre)	-	88,467	88,467	-	88,467	169,119	169,204	88,467	88,467	88,467	88,467	88,467	88,467
Average Land Price ($/Acre)	-	2,109	1,369	-	1,725	1,468	1,468	3,090	4,459	5,834	2,284	2,407	2,262
Number of Households	-	111,073	23,403	-	23,403	38,778	38,806	41,916	60,500	79,148	30,957	32,650	30,717
Average Lot Size in Fire-zone (Acre/ Household)	-	2.45	3.78	-	3.78	4.36	4.36	2.11	1.46	1.12	2.86	2.71	2.88
Development Density (Units/Acre)	-	261	169	-	169	147	147	303	438	573	224	236	222
Indicator* (β_R)	0.850	0.934	0.932	-	0.932	0.906	0.890	0.941	0.948	0.952	0.936	0.937	0.938

*Note. * Indicator in scenario 2 is calculated based on residnets in the whole fire-zone instead of residnets at the boundary, considering there is no resident at the boundary.*

Table 3

Fire-zone Characteristics and Urban Development Patterns (Mixed Income Groups)

Community Characteristics	Baseline	Fire Occurrence Probability			Fize-zone Area (Width)		
		0.05	0.1	0.2	2-mile	4-mile	6-mile
City							
Total Land Value (Million Dollars)	4,379.82	4,260.66	4,178.23	4,025.50	4,178.23	3,981.63	3,777.45
Community Development Boundary (Miles)	16.960	16.958	16.956	16.950	16.956	16.944	16.931
Average Land Price ($/Acre)							
Low-income group	15,114	14,835	14,642	14,412	14,642	14,600	14,556
High-income group	2,017	1,865	1,760	2,007	1,760	1,368	1,214
Around CBD	57,164	57,131	57,108	57,029	57,108	56,944	56,771
Number of Households							
Low-income group	1,130,250	1,105,330	1,088,090	1,055,600	1,088,090	1,084,970	1,081,660
High-income group	110,581	102,672	97,201	82,350	97,201	66,965	33,957
Lot Size (Acre/ Household)							
Low-income group	0.22	0.22	0.23	0.23	0.23	0.23	0.23
High-income group	3.01	3.24	3.42	2.96	3.42	4.36	5.00
Density (Units/Acre)							
Low-income group	2,948	3,522	2,838	2,753	2,838	2,830	2,821
High-income group	212.55	197	187	216	187	147	128
Level of Government Service (Index)	3,539	3,510	3,510	3,470	3,510	3,427	3,341
Average Property Tax Payment ($/Household)	431.33	431.00	430.76	427.74	430.76	422.38	413.76
Property Tax Rate	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%
Fire-zone							
Start Location (Mile)	-	10.00	10.00	10.00	10.00	10.00	10.00
End Location (Mile)	-	12.00	12.00	12.00	12.00	14.00	16.00
Width (Mile)	-	2.00	2.00	2.00	2.00	4.00	6.00
Community Development Boundary in Fire-zone (Miles)	-	12.00	12.00	10.00	12.00	13.27	13.26
Total Development Acre	-	88,467.20	88,467.20	-	88,467.20	153,050.00	169,204.00
Average Land Price in Fire-zone ($/Acre)	-	2,595	1,683	-	1,683	1,454	1,452
Number of Households in Fire-zone	-	63,244	41,020	-	41,020	52,769	52,487
Low and High-income Mix Ratio	-	3.1050	3.1050	-	3.1050	1.4172	1.4251
Average Lot Size (Acre/ Household)	-	1.40	2.16	-	2.16	2.90	2.90
Density (Units/Acre)	-	458	297	-	297	221	221
Indicator* (β_R)	0.850	1.029	1.030	-	1.030	1.220	1.244

*Note. * Indicator in scenario 2 is calculated based on residnets in the whole fire-zone instead of residnets at the boundary, considering there is no resident at the boundary.*

Table 3 (Cont.)

Fire-zone Characteristics and Urban Development Patterns (Mixed Income Groups)

Community Characteristics	Baseline	Natural Amenity (Level)			Natural Amenity (Location)		
		2	3	4	10-mile	11-mile	12-mile
City							
Total Land Value (Million Dollars)	4,379.82	4,817.00	5,455.28	6,093.58	4,573.83	4,497.73	4,464.63
Community Development Boundary (Miles)	16.960	17.153	17.312	17.447	17.021	17.060	17.121
Average Land Price ($/Acre)							
Low-income group	15,114	16,431	18,222	20,017	16,007	15,536	15,203
High-income group	2,017	2,269	2,755	3,224	1,918	2,018	2,135
Around CBD	57,164	57,718	58,309	58,887	57,535	57,416	57,365
Number of Households							
Low-income group	1,130,250	1,235,190	1,382,560	1,530,220	1,199,700	1,161,620	1,134,060
High-income group	110,581	129,719	162,013	194,185	107,102	113,500	121,532
Lot Size (Acre/ Household)							
Low-income group	0.22	0.20	0.18	0.16	0.20	0.21	0.22
High-income group	3.01	2.67	2.21	1.89	3.15	2.99	2.83
Density (Units/Acre)							
Low-income group	2,948	3,222	3,606	3,991	3,129	3,030	2,958
High-income group	212.55	240	290	339	203	214	226
Level of Government Service (Index)	3,539	3,589	3,659	3,722	3,536	3,551	3,571
Average Property Tax Payment ($/Household)	431.33	431.26	421.13	431.84	427.68	431.10	434.52
Property Tax Rate	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%	12.22%
Fire-zone							
Start Location (Mile)	-	10.00	10.00	10.00	10.00	10.00	10.00
End Location (Mile)	-	12.00	12.00	12.00	12.00	12.00	12.00
Width (Mile)	-	2.00	2.00	2.00	2.00	2.00	2.00
Community Development Boundary in Fire-zone (Miles)	-	12.00	12.00	12.00	12.00	12.00	12.00
Total Development Acre	-	88,467	88,467	88,467	88,467	88,467	88,467
Average Land Price in Fire-zone ($/Acre)	-	3,012	4,346	5,685	2,234	2,347	2,204
Number of Households in Fire-zone	-	73,494	106,104	138,828	55,616	57,239	52,523
Low and High-income Mix Ratio	-	3.0825	3.0704	3.0624	3.4973	3.1152	2.7566
Average Lot Size (Acre/ Household)	-	1.20	0.83	0.64	1.59	1.55	1.68
Density (Units/Acre)	-	532	768	1,004	402	414	380
Indicator (β_R)	0.850	1.027	1.026	1.025	1.015	1.028	1.044

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