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Optimal wildfire insurance in the wildland-urban interface in the presence of a government subsidy for fire risk mitigation

By

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Abstract

We investigate the effectiveness of a government subsidy and mitigation based insurance contracts at discouraging migration into the wildland interface and at inducing incentives for risk mitigation. We construct a model of the individual migration decision, where the individual maximizes expected utility defined over attributes of locations including cost of insurance and mitigation, wildfire damage, and the availability of a subsidy for reducing wildfire risks through fuel management. Our analysis shows that standard insurance policies provide inefficiently weak incentive for wildfire risk mitigation by offering a low insurance premium to high-risk landowners. We find on the other hand that in the presence of optimal government subsidy, contingent contracts provide an efficient solution where a homeowner chooses a mitigation level that maximizes social benefit and insurers provide actuarially fair contracts such that each individual is offered a premium of the exact value of her wildfire risk.

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1. Introduction

Changing demographics in fire-prone areas, coupled with rising fire expenditures and externalities associated with little fire risk mitigation make wildfire risk management a growing policy concern. Today, roughly 38.6 millions of people live in fire-prone environments, resulting in an average of 900 structures destroyed each year, escalating fire suppression expenditures, and increasing threats to public safety (ISO, 1997, Sampson et al, 2000, Cleaves, 2001).

Migration decisions to rural areas are influenced by various factors including amenities values, privacy, etc (Mckee et al, 2004). Homeowners are drawn to these areas by their preferences for natural settings, spectacular views and location amenities values. However, these new owners of property in wildland-urban interfaces often pay little attention to the natural hazard surrounding their homes, or the risks of financial losses they and the entire taxpaying population might incur from wildfires (Kovacs, 2001). The literature provides evidence that fire risk mitigation generates private risk reduction benefits as well as positive externalities in terms of fire damage risks. Yet, homeowners' preferences for natural settings, financial and labor costs, and lack of experience represent serious barriers to the adoption and implementation of fire risk mitigation measures (Hodgson 1995, Kovacs 2001, Brenkert et al, 2005). With weak private incentives for fire prevention, suppression becomes the main tool for wildlife damage reduction. Currently, more than two billion dollars are spent annually on public wildfire suppression and risk mitigation efforts (Ingalsbee, 2000).

Financial loss from wildfire also affects property owner insurance companies, since standard homeowner policies usually cover wildfire damage (Brillinger, 2003). In 1991, roughly $1.7 billion was disbursed in insured losses caused by the Oakland/Berkeley Tunnel Fire (ISO, 1997). More recently, more than $3 billions were paid by the industry following the large wildfires in California in the 1990's (Kovacs, 2001 (ISO report (1997)). Arguably, the misalignment of homeowners' incentives with risky choice is encouraged by the current type of insurance contract, which provides a wildfire coverage that is not contingent upon individuals' risk mitigation effort. Studies have criticized the shortcomings of the current situation and suggested that insurance companies design insurance so that high premiums are correlated with high fire risk in order to discourage people from building in areas with high risk (Reice, 2003). Recognizing that wildfire risk mitigation could be instrumental in reducing average insurance claims, private insurance companies are taking steps towards mitigation-based insurance for communities in fire-prone areas (e.g. in the states of Colorado, Arizona, New Mexico and Nevada). Homeowners' non-compliance with the insurance program' requirements might result in either the non-renewal of the coverage policy or a higher premium (USDA, 2003). Hence, the contingent insurance increases the homeowners' opportunity cost of not taking risk protective measures.

Also in response to increasing wildfire risks in wildland-urban interfaces, state and federal agencies including the U.S. Forest Service are promoting a variety of programs for strengthening risk mitigation incentives (McKee et al, 2004). Cost-sharing programs (CSP) for risk mitigation in the wildland-urban interface are one important part of this incentive policy approach in several states in the Western US. These programs make funding available to counties and communities to subsidize the creation of defensible space around structures, fuel breaks, and the disposal of slash (Steelman et al, 2004). For instance, New Mexico pays up to 75 percent of the total cost of certain risk mitigation measures, and Colorado and Arizona have a 50/50 cost-share program. By reducing the cost of mitigation to homeowners, the subsidy is expected to strengthen incentives for investments in fire protection measures, which in principle will translate into fire damage reduction to participants and their neighbors.

While contingent insurance contracts are expected to realign individuals' incentives for risk mitigation, and cost share subsidies may offer a solution to the problem of under-provision of mitigation, the effectiveness of these programs at deterring migration to fire prone environments and inducing incentives for mitigation is yet unknown. For instance, the effectiveness of contingent contracts for homeowner policy coverage at discouraging settlements in fire prone environments and inducing more investment in risk mitigation in wildland urban interfaces is yet to be determined. Also, while government subsidy may promote risk mitigation efforts for residents of the urban-wildland interface, it can be criticized on the ground that it might have the unintended effect of encouraging migration into urban/wildland interfaces (Wright and Rossi 1981, Gardner and El-Abd 1984).

The combination and implementation of government subsidy and mitigation-contingent insurance policies is a new trend that has tended to occur concurrently in the same vicinities.[1] The economic interactions between these two contractual mechanisms are not well understood. For example, it is unclear the extent to which economies of scope are driving the simultaneous development of these programs, or if it is simply because these areas face exceptionally imperfect insurance markets that are independent of potential positive externalities from private wildfire risk mitigation. Furthermore, although it seems relatively obvious that both subsidies and mitigation-contingent contracts will induce more private risk mitigation, it is unclear whether taken together these programs will promote or reduce incentives to migrate to high-risk areas.

These new developments provide an unprecedented setting to examine this interaction. We construct a model of individual migration decision where individuals maximize expected utility defined over attributes of locations. Attributes may include cost of insurance, cost of wildfire risk mitigation, resource damage from wildfire, and the availability of a subsidy for mitigation. We use this model (1) to discuss individuals' incentives for 'moving to the hazard', (2) to examine individuals' incentives for risk mitigation and (3) to discuss economic efficiency of contingent contracts in the presence of a subsidy for risk mitigation.

Our analysis shows that standard insurance policies provide inefficiently weak incentive for wildfire risk mitigation by offering a low insurance premium to high-risk landowners. We find on the other hand that insurance contracts contingent upon mitigation effort provide a second best optimum in the sense that homeowners choose a

[1] For instance, in the states of Colorado, Arizona, New Mexico, cost share programs are available and the mitigation against insurance program is also underway since 2003 (USDA, 2003).

positive level of mitigation that maximizes their private benefit and insurers provide actuarially fair contracts such that each individual is offered a premium of the exact value of her wildfire risk. The analysis shows that an efficient solution is obtained under contingent insurance contract, when government subsidy is chosen such that it covers the external benefits from mitigation.

The next section describes a model of the current standard practice in wildfire insurance in which the same insurance contract is offered to all individuals regardless of their risk level. We discuss the implications of this contract on individuals' incentive structure. This model is then modified and extended in section 3 to show that, when contingent contracts are offered in the presence of an optimal subsidy, individuals' incentives are properly aligned with their risky choices. In section 4, we discuss policy implications of our findings.

2. Wildfire insurance contracts: the current setting

The economy consists of N risk-averse households who make the decision (1) to move to location *j,* and if they choose to move to a high-risk area, (2) they decide whether or not to invest in wildfire risk mitigation. Both decisions are made at once, based on the outcome of households' utility maximization. Let V_j be the household initial endowment, which represents the location amenity value. Because the relocation area can either be a wildland-urban interface *(w)* or urban vicinity *(u)*, households' expected utility is affected by the risk of wildfire and other costs and losses associated with this risk.

Given that individuals are risk averse, we suppose that they account for the cost of insurance and the expected costs for fire risk mitigation in their decision process.

Let r be the fixed cost per unit of mitigation effort e when the homeowner decides to move into a urban/wildland area, so that the total cost of risk mitigation is $C(e) = r\,e$. *De*note by $\pi_j(e)$ be the probability of wildfire in location $j = (w, u)$. In the event of a fire, each individual in urban population (N_u) incurs a loss $\beta_u D \leq V_u$ with probability $\pi_u(e)$, and each individual in the urban/wildland population (N_w) incurs a loss $\beta_w D \leq V_w$ with probability $\pi_w(e)$, such that $0 \leq \pi_u(e) < \pi_w(e) < 1$. The total loss is $D = (\beta_u + \beta_w)D$, and the total population is $N = N_u + N_w$.

2.1. Standard insurance (pooling contract) with no subsidy for risk mitigation

Standard homeowners' insurance policies include coverage for wildfire damage **(**Insurance Information Institute**,** Insurance Services Office).[2] Yet, these policies are not contingent upon mitigation effort. Insurers offer the same contract (pooling contract) (P, Q) to all households, with average premium P and compensation (net amount) Q in case of fire.[3] Following Laffont (1990), calculation of the premium P for a pooling contract is based on the following weighted average probability of fire occurrence:

$$\pi = \pi_u \frac{N_u}{N} + \pi_w \frac{N_w}{N}$$

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[2] http://www.iii.org/, http://www.iso.com/.

[3] As we shall see later in the paper, contingent contracts can improve efficiency by strengthening policyholder incentives for risk mitigation. A fundamental question that arises from this is: why aren't all insurance policies contingent on risk mitigation? We will make the implicit assumption here that contingent contracts require monitoring by the insurance agency, and that monitoring is costly. If monitoring costs a fixed value per contract, then this assumption does not change the marginal results discussed in this paper in substantive qualitative ways.

Where $\pi_u(e) < \pi_u < \pi < \pi_w(e) < \pi_w$, and $\frac{N_u}{N}$, $\frac{N_w}{N}$ are the proportions of people in urban and wildland-urban interfaces.[4] The expected profit of the insurer is:

$$\Pi = \pi(-Q) + (1-\pi)P \tag{1}$$

Competition drives profit to zero, which implies the premium

$$P = \frac{\pi}{(1-\pi)}Q \tag{2}$$

Assume that a homeowner buys insurance contract *(P, Q)*. Then, she gets x_1 if fire occurs and x_2 if no fire such that

$$x_1 = V_j - re - \beta_j D + Q$$

And $$x_2 = V_j - P$$

Recalling that unlike insurers, homeowners know and account for the fact that their mitigating behavior affects their wildfire risk such that an individual N_j is subject to wildfire risk $\pi_j(e)$, the homeowners' problem is then to choose the mitigation level e and contract *(P,Q)* such as to maximize the following expected utility:

$$\underset{e,(P,Q)}{Max}\ EU = \pi_j(e)U[x_1] + (1-\pi_j(e))U[x_2] \tag{3}$$

To derive the first order condition with respect to mitigation level and compensation, we explicitly write expected utility (3) as a function of e and Q by substituting insurance premium P, and compensation Q by their respective values and rearranging.

[4] Note that we consider a risk level contingent upon mitigation $\pi_j(e)$ and a risk level non-contingent upon mitigation π_j. This is because the insurers do not factor in mitigation effort, and in determining expected profit, consider that a homeowner in area $j = u, w$ is subject to risk of wildfire risk π_j (non contingent upon mitigation effort); while homeowners know their real exposure to wildfire, also know how their mitigating behavior may affect their wildfire risk, and consider a risk exposure $\pi_j(e)$ (contingent on mitigation).

First, since we assume that the homeowner buys the contract *(P, Q)*, we can substitute the value of the premium *P* (from equation 2) in her expected gain, x_2 such that:

$$x_2 = V_j - \frac{\pi}{(1-\pi)} Q \quad (4)$$

Then, since $x_1 = V_j - re - \beta_j D + Q$, we can derive the compensation $Q = x_1 - V_j + re + \beta_j D$, which is then substituted in equation (4) as:

$$x_2 = V_j - \frac{\pi}{(1-\pi)} (x_1 - V_j + re + \beta_j D)$$

Rearranging, we obtain:

$$x_2 = \frac{V_j - re - \beta_j D \pi}{(1-\pi)} - \frac{\pi}{(1-\pi)} x_1 \quad (5)$$

Then, substituting x_1 and x_2 by their respective values, expected utility (3) can be written as:

$$\underset{e,\,(P,Q)}{Max} EU = \pi_j(e) U\left[V_j - re - \beta_j D + Q\right] + (1-\pi_j(e)) U\left[\frac{V_j - re - \beta_j D\pi}{(1-\pi)} - \frac{\pi}{(1-\pi)}(x_1)\right] \quad (6)$$

First order condition with respect to *e* is:

$$\frac{\partial EU}{\partial e} = \pi'_j(e) U(x_1) - r\pi_j(e) U'(x_1) - \pi'_j(e) U(x_2) - \frac{r}{1-\pi}(1-\pi_j(e)) U'(x_2) \leq 0 \quad if \quad e = 0$$
$$= 0 \quad if \quad e > 0$$

Since we assume that actuarially fair contracts are available, risk averse agents always insure themselves completely to obtain the same utility regardless of the event that occurs

(Laffont, 1990). Following Laffont (1990), complete insurance means u'(x_1) = u'(x_2). This implies that the first order condition with respect to *e* can be written:

$$\frac{\partial EU}{\partial e} = -r\pi_j(e)U'(x_1) - \frac{r}{1-\pi}U'(x_2) + \frac{r}{1-\pi}\pi_j(e)U'(x_2)$$

$$\frac{\partial EU}{\partial e} = \left(-\pi_j(e) - \frac{1}{1-\pi} + \frac{1}{1-\pi}\pi_j(e)\right)rU'(x_2)$$

$$-\left(1-\pi\pi_j(e)\right)rU'(x_2) < 0 \quad if \quad e^* = 0 \qquad (7)$$
$$= 0 \quad if \quad e^* > 0$$

Since $U'(x_2) > 0$, $1-\pi\pi_j(e) > 0$, $r > 0$; we must have that the level of mitigation is zero (*e**=*0*) regardless of the location chosen: urban or urban/wildland. [5] Our first, perhaps most obvious result is:

Proposition 1: *Standard insurance is ineffective at inducing incentive for wildfire risk mitigation.*

Given the chosen level of mitigation e^*, the optimality condition for *Q* is:[6]

$$\frac{\partial EU}{\partial Q} = \pi_j(e^*)U'(x_1) - (1-\pi_j(e^*))\frac{\pi}{(1-\pi)}U'(x_2)$$

$$= \frac{\pi_j(e^*)}{(1-\pi_j(e^*))}\frac{U'(x_1)}{U'(x_2)} - \frac{\pi}{(1-\pi)} \qquad (8)$$

Because $\pi_u(e^*) < \pi_u < \pi$, relation [8] implies

$$\frac{\pi_u(e^*)}{1-\pi_u(e^*)}\frac{U'(x_1)}{U'(x_2)} < \frac{\pi}{1-\pi} \qquad \Rightarrow \qquad MRS^{u}_{x_1x_2} < \frac{\pi}{1-\pi}$$

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[5] Note that the absence of incentive for mitigation (i.e. e^*=0) is a reasonable result here because we assume that homeowners insure themselves completely (no deductible).

[6] Recall that $x_1 = V_j - re - \beta_j D + Q$ is a function of Q so that the second element of expected utility (6) can also be derived with respect to Q

which can also be written as:

$$\frac{\pi_u(e^*)}{1-\pi_u(e^*)}Q < \frac{\pi}{1-\pi}Q \qquad \Leftrightarrow \qquad P_u < P \qquad (9)$$

Similarly, for high-risk group $\pi_w > \pi_w(e^*) > \pi$, equation [8] implies

$$\frac{\pi_w(e^*)}{1-\pi_w(e^*)}\frac{U'(x_1)}{U'(x_2)} > \frac{\pi}{1-\pi} \qquad \Rightarrow \qquad MRS^{w}_{x_1x_2} > \frac{\pi}{1-\pi}$$

Or $$P_w > P \qquad (10)$$

Results [9] and [10] show that the pooling contract *(P, Q)* is not an optimal choice for residents or prospective residents of the wildland- urban interface.

Proposition 2: *Standard insurance promotes building in fire-prone environment by offering high-risk individuals (defined as those living in the urban-wildland interface) a premium (P) smaller than their wildfire risk (P_w).*

Propositions 1-2 highlight two important issues arising under the standard insurance policy coverage. First, we find that since the contracts offered do not factor in homeowners' mitigation efforts and yet provide coverage for wildfire damage, homeowners have little incentive for investing in risk mitigation. Second, we find that under the standard policy coverage, insurers offer high-risk households a premium lower than their wildfire probability, thus promoting further building in fire-prone environments. A company offering such contract risks losing low-risk policyholders, which is a common adverse selection result given non-contingent contracts.

An additional issue that relates to social optimality concerns the externalities resulting from little or no mitigation where it would be appropriate. When the homeowner mitigates wildfire risk on her land, she is likely to mitigate fire risk on her neighbors' land. And because some benefits of wildfire risk mitigation are extended to neighboring landowners, cost-sharing programs could be justified to effectively induce landowners to internalize these benefits to neighbors. Next, we discuss the introduction of a subsidy in the context of a standard contract.

2.2. Standard pooling insurance contract with subsidy for wildfire risk reduction

One common government intervention approach to encourage positive external benefits is the use of subsidies. Suppose that the cost of mitigating is shared by a government agency such that homeowners pay a percentage α for of the total cost such that their expected cost is $(\alpha\ r\ e)$, where α can take values ($\alpha = 0$, $0 < \alpha < 1$, $\alpha = 1$). Let $(1-\alpha)$ be the subsidy provided by the agency. If $\alpha = 0$, then the full cost of fire risk mitigation is covered by the CSP subsidy, and households pay nothing. If $0 < \alpha < 1$, then the cost of fire risk mitigation is partially covered by the CSP subsidy, in which case only a partial externalization of the costs exists. Finally, if $\alpha = 1$, the full cost of fire risk mitigation is borne by households. Given this specification, homeowner gets x_3 if a fire occurs and x_4 is no fire occurs, such that

$$x_3 = V_j - \alpha re - \beta_j D + Q$$

And $$x_4 = V_j - P = \frac{V_j - \alpha re - \beta_j D\pi}{(1-\pi)} - \frac{\pi}{(1-\pi)}(x_1).$$

The household chooses the optimal contract to maximize the expected utility:

$$\underset{e,\,Q,P}{Max} \quad EU = \pi_j(e)U\left[V_j - \alpha re - \beta_j D + Q\right] + (1-\pi_j(e))U\left[\frac{V_j - \alpha re - \beta_j D\pi}{(1-\pi)} - \frac{\pi}{(1-\pi)}(x_1)\right] \quad (11)$$

The optimal mitigation level and insurance contract are identical to the previous case, with first order conditions shown by equations 7, 9, 10. Homeowners choose to exert zero mitigation (e*=0) with the subsidy. This suggests that making a subsidy available in the standard insurance contract context is not an effective approach to creating incentives for fire prone environment residents (or prospective residents) to mitigate the risk of wildfire. For a subsidy to have any effect in this framework, we would need to relax our assumption of full insurance to make the homeowner liable for covering some of her expected loss from wildfire. In fact, if there is a deductible, that is, if landowners have to pay say, $X, of the damage to their property in the event of a fire under a standard contract, then they will have some limited incentive to mitigate the risk.

Proposition 3: *Subsidies are likely to be ineffective at inducing private wildfire risk mitigation under standard pooling contracts.*

As summarized in propositions 1-3 standard insurance policies present some challenging issues in terms of incentive for wildfire risk mitigation. Yet, the insurance industry has the potential, by working closely with governments and individuals, to properly align individuals' incentives with risky choices. Insurances companies are acting upon the limitations of the standard insurance policy by moving towards insurance contracts that are contingent on policyholder risk mitigation.

3. Efficient wildfire insurance in the presence of government intervention through a subsidy for risk mitigation

In this section, we analyze the implications of insurance contracts contingent upon investment in fire risk mitigation in terms of incentives for mitigation and disincentives for ‘moving to the hazard’. We discuss the efficiency of this type of contract with and without subsidy programs.

3.1. Contingent insurance contracts for wildfire risk

The economy consists of the same group of N agents introduced previously. Insurers offer a contract contingent on effort *e*, $(P_j(e), Q_j(e))$ with premium $P_j(e)$, and compensation $Q_j(e)$ in case of fire. The expected profit of the insurer is:

$$\Pi = \pi_j(e)(-Q_j(e)) + (1 - \pi_j(e))\, P_j(e) \qquad (12)$$

Competition drives profit to zero, which implies the actuarially fair premium

$$P_j(e) = \frac{\pi_j(e)}{(1 - \pi_j(e))} Q_j(e) \qquad (13)$$

Given that homeowners buy contracts $(P_j(e), Q_j(e))$, they get x_5 if a fire occurs and x_6 is no fire such that:

$$x_5 = V_j - re - \beta_j D + Q_j(e)$$

$$x_6 = V_j - re - P_j(e)$$

Following the same reasoning as before, we substituting premium $P_j(e)$ and compensation $Q_j(e)$ by their respective values, x_6 is written as:

$$x_6 = V_j - \frac{\pi_j(e)}{(1-\pi_j(e))} Q_j(e) \qquad (14)$$
$$= V_j - \frac{\pi_j(e)}{(1-\pi_j(e))}(x_5 - V_j + re + \beta_j D)$$
$$= \frac{V_j - re - \beta_j D \pi_j(e)}{(1-\pi_j(e))} - \frac{\pi_j(e)}{(1-\pi_j(e))} x_5 .$$

This time, both insurers and homeowners account for wildfire risks contingent upon mitigation in their respective objective functions. In this case, the homeowner's problem is to find the optimal contract $\left(P_j(e), Q_j(e)\right)$ given the mitigation level *e* that they choose to maximize the following expected utility:

$$\underset{e,\, Q_w(e), P_w(e)}{Max} \; EU = \pi_j(e) U\left[V_j - r \;\; e - \beta_j D + Q_j(e)\right] + (1-\pi_j(e)) U\left[\frac{V_j - re - \beta_j D \pi_j(e)}{(1-\pi_j(e))} - \frac{\pi_j(e)}{(1-\pi_j(e))} x_5\right] \qquad (15)$$

First order condition with respect to e is:

$$\frac{\partial EU}{\partial e} = \pi_j'(e) U(x_5) - \pi_j(e)\left[r + Q_j'(e)\right] U'(x_5)$$
$$- \pi_j'(e) U(x_6) - (1-\pi_j(e))(r + P'_j(e))\, U'(x_6) = 0 \quad if \quad e^p > 0$$
$$< 0 \quad if \quad e^p = 0$$

The contingent insurance contract allows $u'(x_5) = u'(x_6)$ and therefore the first condition with respect to e is:

$$\frac{\partial EU}{\partial e} = -\pi_j(e)\left[Q_j'(e)\right] U'(x_5) - (r + P'_j(e))\, U'(x_6) + \pi_j(e)(P'_j(e))\, U'(x_6) = 0 \quad if \quad e^p > 0$$
$$< 0 \quad if \quad e^p = 0$$

$$r + \pi_j(e^p) Q_j'(e^p) + (1-\pi_j(e^p))(P'_j(e^p)) = 0 \quad if \quad e^p > 0 \qquad (16)$$
$$< 0 \quad if \quad e^p = 0$$

Because all elements on the left hand side of equation [16] are non-negative, we must have that the optimal level of mitigation is non-zero ($e^p > 0$). In other words, homeowners choose non negative level of mitigation $e^p > 0$, such that their marginal cost for risk mitigation equals their marginal benefit:

$$r = -\pi_j(e^p)Q_j'(e^p) - (1-\pi_j(e^p))(P'_j(e^p)) \quad (17)$$

Given the optimal private mitigation level e^p >0, the compensation $Q_j(e^p)$ is derived from the following first order condition:

$$\frac{\partial EU}{\partial Q_j(e^p)} = \pi_j(e^p)U'(x_5) - (1-\pi_j(e^p))\frac{\pi_j(e^p)}{(1-\pi_j(e^p))}U'(x_6) = 0$$

$$\Rightarrow U'(x_5) = U'(x_6)$$

$$\Rightarrow x_5 = x_6$$

$$\Rightarrow V_j - re^p - \beta_j D + Q_j(e^p) = V_j - re^p - \frac{\pi_j(e^p)}{(1-\pi_j(e^p))}Q_j(e^p)$$

$$\Rightarrow Q_j^p(e^p) = \left(1-\pi_j(e^p)\right)\beta_j D \quad (18)$$

Substituting optimal compensation $Q_j^p(e^p)$ from equation [17] in equation [13], we get

$$P_j^p(e^p) = \pi_j(e^p)\beta_j D \quad (19)$$

Combination of results [18] and [19] constitute the following optimal insurance contract for households

$$\left(P_j^p(e^p), Q_j^p(e^p)\right) = \left(\pi_j(e^p)\beta_j D, (1-\pi_j(e^p))\beta_j D\right) \quad (20)$$

Substituting the optimal contract in the first order condition [18], we can rewrite it as:

$$-r = \pi_j(e^p)Q_j'(e^p) + (1-\pi_j(e^p))(P'_j(e^p))$$

$$r = -\pi_j'(e^p)\beta_j D. \quad (21)$$

Proposition 4: *Under a contingent contract, a homeowner chooses mitigation level e^p >0 and insurers offer a premium of the exact value of her private wildfire risk.*

Keys findings from the implementation of contingent contracts are the induction of incentives for mitigation and the realignment of incentive with risky choices by the provision of a contract that reflect individuals' risk. For instance, assuming that the risk of *wildfire* is zero in urban area, a homeowner in such vicinity suffers a loss $\beta_u D$ with probability $\pi_u\ (e^p) = 0$ and therefore does not need a wildfire coverage included in her policy.[7] A wildland-urban interface resident on the other hand suffers a loss $\beta_w D$ with probability $\pi_w(e^p)>0$. Such homeowner chooses to mitigate until her private marginal benefit in terms of damage reduction equals the unit cost of mitigation at the margin

$$r = -\pi_w'(e^p)\beta_w D.$$

The following contract is offered $\left(P_w^p(e^p), Q_w^p(e^p)\right) = \left(\pi_w(e^p)\beta_w D, (1-\pi_w(e^p))\beta_w D\right)$, which reflects the landowner's mitigation level.

Results [20] and [21] show that implementation of contingent contracts strengthen private incentive for investments in fire protection measures and deter new developments in fire hazard areas. However, this result corresponds to a second best optimum. A homeowner in the urban/wildland interface chooses the level of mitigation that optimizes her private benefits without consideration for risk reduction provided to her neighbors. In her expected utility, the homeowner only tries to reduce privately born resource damage $(\beta_j D)$ in the case of a fire, while a higher level of mitigation could reduce not only privately born damage $(\beta_j D)$, but also damage to others $(1-\beta_j)\ D$.

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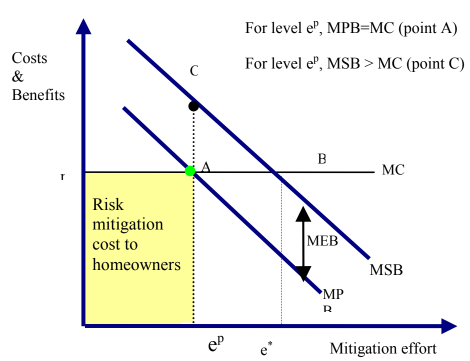
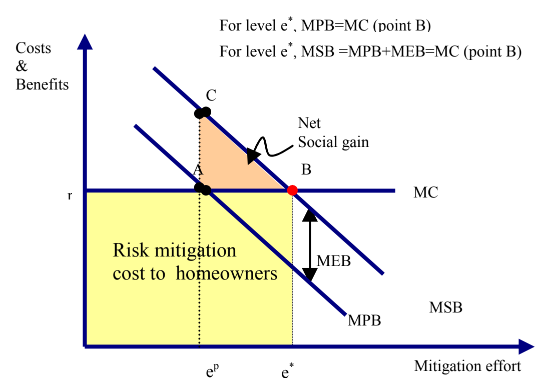
[7] Here we are discussing specifically the part of the insurance premium that covers wildfire damage. Note that a complete policy would offer a total premium TP which include not only the premium $P_j^p(e)$ for wildfire coverage but also a premium (I) for coverage of other elements that the homeowners chooses to include in her policy such that total premium could be written $TP = P_j^p(e) + I$.

In figure 3-1.A, we represent the optimal private level of mitigation obtained in condition [21]. Since the homeowner does not account for the benefit of her mitigating action on the others, she chooses a level of mitigation e^p such that private net benefit are maximized, that is when marginal private benefits equals marginal cost, MPB = MC (point A). For the same level of mitigation, figure 3-1.A shows that social efficiency is not achieved because marginal social benefit is higher than the marginal cost, MSB>MC, (point C).

Figure 3-1: Optimal private and social mitigation level in the presence of positive externalities provided by fire risk mitigation

Figure 3-1.A: Optimal private solution   **Figure 3-1.B:** Optimal social solution





Social efficiency can be obtained by choosing a level $e^* > e^p$ of mitigation such that the marginal external benefits from risk mitigation (MEB) are privately internalized and the socially efficient solution is in point B (figure 3-1.B). Mathematically, the social optimization problem is:

$$\underset{e,Q_W(e),P_W(e)}{Max} \quad EU = \quad \{\text{E [Net Private Benefits (e)]}\} \quad + \{\text{E [External Benefits (e)]}\}$$

$$= \left\{ \begin{array}{l} \pi_j(e) U\left[V_j - r\,e - \beta_j D + Q_j(e)\right] \\ + (1-\pi_j(e)) U\left[V_j - r\,e - P_j(e)\right] \end{array} \right\} + \left\{ \pi_j(e) U\left[-(1-\beta_j)D\right] \right\} \tag{22}$$

First order conditions show that the socially optimal solution is to choose level of mitigation e^* is such that:

$$r = \left\{-\pi_j'(e^*)\beta_j D\right\} + \left\{-\pi_j'(e^*)(1-\beta_j)D\right\} = -\pi_j'(e^*)D \tag{23}$$

or MC = MPB+MEB = MSB as displayed in figure 3-1.B

Given the mitigation level e^*, the following contingent contracts are available

$$\left(P_j^*(e^*), Q_j^*(e^*)\right) = \left(\pi_j(e^*)D, (1-\pi_j(e^*))D\right) \tag{24}$$

Note that at the socially optimal level of mitigation e^*, private costs are higher than benefits (MC>MPB at point B in figure 3-1.B) suggesting that homeowners need more incentives to move from the competitive level of mitigation, e^p, to the desired level of mitigation, e^*.

Proposition 5: *Contingent insurance contracts strengthen homeowner incentives for fire risk mitigation. However, private mitigation effort is still suboptimal.*

Proposition 5 suggests that economic efficiency can be improved by encouraging more risk mitigation. This can be done through the use of the cost share program subsidy that reduces the cost of fire risk mitigation to homeowners. The question we address next is from a policymaker perspective to calculate the subsidy level such that homeowners choose the socially optimal level of mitigation e^*.

3.2-Optimal subsidy for efficient contingent insurance contract

Government interventions through subsidies are often justified by the presence of market failure. In the present context, wildfire risk mitigation provides positive externalities in terms of expected damage reduction to neighbors. But, because homeowners fail to account for these benefits in their objective function, a free market results in under-provision of risk mitigation. Economic theory suggests that the choice of a subsidy that amounts to the size of the externality can restore efficiency. Let *(1-α)* be the subsidy such that the homeowner now pays *αr* and the subsidy covers *(1-α) r*. Homeowners get x_7 and x_8 respectively in cases of fire and no fire such that $x_7 = V_j - \alpha r e - \beta_j D + Q_j(e)$ and $x_8 = V_j - \alpha r e - P_j(e)$.

The private optimization problem is:

$$\underset{e, Q_w(e), P_w(e)}{Max} EU = \pi_j(e) U[x_7] + (1 - \pi_j(e)) U[x_8] \qquad (25)$$

Optimality conditions show that the level of mitigation e^* is chosen such that:

$$\alpha r = -\pi_j'(e^*)\beta_j D \qquad (26)$$

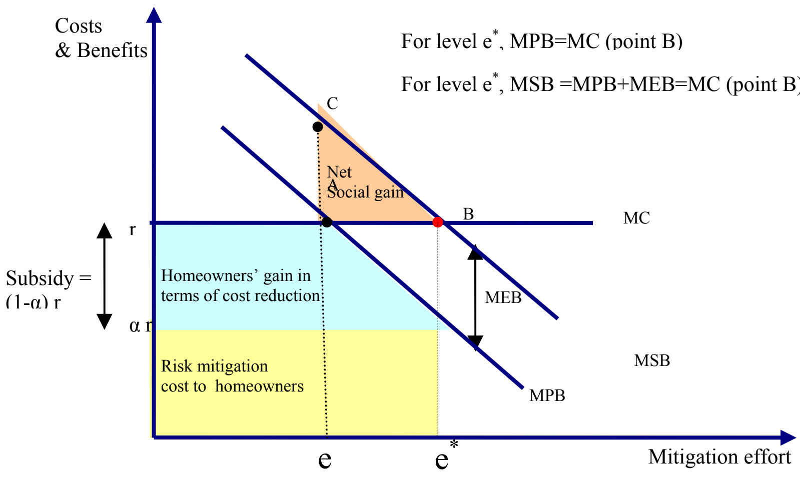
Substituting external benefits from condition [23] into [26], we get the optimal subsidy:

$$(1-\alpha) r = -\{\pi_j'(e^*)(1-\beta_j)D\} \qquad (27)$$

Condition [27] shows that for the homeowner to exert socially efficient mitigation level e^*, the optimal subsidy should equal the external benefit to society from additional mitigation effort as illustrated in figure 3-2.

Proposition 6: *When the subsidy for fire risk mitigation is set to equal the net social gain from fire risk reduction, homeowners exert the socially efficient level of mitigation e^* and insurers offer insurance contracts that reflect individuals' risks.*

Figure 3-2: Socially efficient solution with optimal subsidy



4. Discussion

Wildfire risk in the WUI is a growing problem with high social and economical consequences, and affects a variety of stakeholders including fire protection agencies, homeowners, governments, and insurance companies. Barriers to the effective implementation of risk management policies range from free-riding behavior related to risk mitigation, to underinsurance in fire prone areas. In response, some local governments and insurance companies are moving toward using incentive-based approaches to promote private wildfire risk mitigation efforts. Insurers are implementing insurance contracts contingent upon mitigation effort, and various government agencies are providing cost-share programs for wildfire risk mitigation.

In this paper, we investigate the effect of standard and contingent insurance contracts and government subsidies on incentives for risk mitigation by WUI residents, and the incentives for settlement in fire prone areas. We construct a model of migration decisions, where individuals choose the location that provides the highest expected utility given a range of location specific attributes including insurance contracts, and cost sharing program subsidies for fire risk mitigation. The effectiveness of non-contingent and contingent insurance contracts is examined in the presence (or not) of government cost share subsidy.

Our analysis shows that offering mitigation-contingent insurance contracts to residents (or prospective residents) in the wildland-urban interface improves incentives for mitigation as well as incentive related to development in fire-prone areas. Residents of urban vicinities do not share the burden of wildfire risk. Contingent contracts increase the sum of mitigation costs and premiums to owners of fire-prone property, thereby inducing fewer people to move into fire prone areas and increasing the risk mitigation efforts of those who do. Because wildfire ignores property boundaries, risk mitigation by one property owner can reduce the wildfire risk faced by neighbors. The fact that investments in risk mitigation generate positive externalities can be viewed as a justification for public support of mitigation efforts on private land. Our analysis shows that in the presence of standard insurance contracts, subsidies are ineffective for inducing private risk mitigation efforts, whereas they are more effective under contingent contracts. Furthermore, whereas standard contracts in conjunction with subsidies induce too much development in fire-prone areas, the combination of contingent contracts and subsidies of the appropriate size correct this problem.

References

Brenkert Hannah, Champ Patricia, Flores Nicholas. 2005. "Mitigation of Wildfire Risk by Homeowners". USDA Forest Service. *Rocky Mountain Research Station. Research Note RMRS-RN-25WWW*

Brillinger, R. David. 2003. "Three Environmental Probabilistic Risk Problems". *Statistical Sciences, Vol. 18, N0 4, 412-421*

Cleaves Dave. "Fires in the Wildland Urban Interface: Dilemmas of Duality and the Role of National Science Leadership". Presented to: Natural Disasters Roundtable Friday, January 26, 2001 Washington, DC. By National Program Leader, *Fire Systems Research USDA Forest Service.*

Gardner, G. T., and P. Stern. 1996. "Environmental problems and human behavior". *Boston, MA: Allyn & Bacon*

Hodgson W. Ronald, 1995. "Strategies for and Barriers to Public Adoption of Fire Safe Behavior". *The Biswell Symposium: Fire Issues and Solutions in Urban Interface and Wildland Ecosystems*

Ingalsbee Timothy, 2000. "Money to burn: The Economics of Fire and Fuels

Management" http://www.fire-ecology.org/research/money_to_burn.html

Insurance Information Institute, http://www.iii.org/,

Insurance Services Office, http://www.iso.com/

ISO, Insurance Issues Series, 1997. "The Wildland/Urban Fire Hazard". Insurance Services Office.

Laffont, Jean-Jacques. 1990. "The Economics of Uncertainty and Information". The MIT Press Cambridge, Massachusetts London, England.

Kovacs, P. 2001. "Wildfires and insurance". Toronto, Ontario, Canada: Institute for Catastrophic Loss Reduction Research. *Paper Series No.11*.

Mckee Michael, Berrens P. Robert, Jones Michael, Helton Ryan, Talberth John. 2004. "Using Experimental Economics to Examine Wildfire Insurance and Averting Decisions in the Wildland-Urban Interface". *Society and Natural Resources, 17:491–507, 2004*

Reice, Seth R. 2003. "Silver Lining: The Benefits of Natural Disasters". *Princeton University Press.*

Sampson, Neil. 2000. "Wildland/Urban Interface Mapping Project". *Final report to U.S. Department of Agriculture Forest Service.*

Steelman Toddi A., Ginger Kunkel, and Devona Bell. 2004. "Federal and State Influence on Community Responses to Wildfire Threats: Arizona, Colorado, and New Mexico" *Journal of Forestry. Bethesda. Vol. 102, Iss. 6; p. 21 (7 pages)*

Steelman Toddi A., Ginger Kunkel. 2004. "Effective Community Responses to Wildfire

Threats: Lessons From New Mexico”. *Society and Natural Resources, 17:679–699, 2004*

USDA Forest Service Fire and Aviation Management Briefing Paper. 2003. “U.S. insurance companies target wildfire preparedness in the wildland/urban interface”

Wright D. James, Rossi, H. Peter. 1981.“Social Science & Natural Hazards”. *Abt Books* /Cambridge, Massachusetts.