NRC Research Press

ARTICLE

Wildfire risk adaptation: propensity of forestland owners to purchase wildfire insurance in the southern United States

Jianbang Gan, Adam Jarrett, and Cassandra Johnson Gaither

Abstract: The economic and ecological damages caused by wildfires are alarming. Because such damages are expected to increase with changes in wildfire regimes, this calls for more effective wildfire mitigation and adaptation strategies. Wildfire adaptation options for forestland owners include purchasing wildfire insurance, which provides compensation to those insured if a wildfire damages their properties. We attempt to (*i*) identify factors that influence the decision of family forestland owners in the southern United States to purchase wildfire insurance for their forestlands via logistic regression using landowner survey data and (*ii*) examine the propensity of these landowners to purchase wildfire insurance under climate change. We find that landowners are much more likely to purchase wildfire insurance if they are female or well educated or if their land is not classed as heirs' property, has been hit by a hurricane, or has not been burned by wildfire previously. Because climate change is likely to alter future wildfire and hurricane activity in the region, more forestland owners are predicted to purchase wildfire insurance, although the magnitude of such an increase appears moderate under current market institutions. These results would be helpful for developing new wildfire insurance programs and increasing the participation of forestland owners in the wildfire insurance market.

Key words: wildfire, adaptation, insurance, family forestland owner, climate change.

Résumé : Les dommages écologiques et économiques causés par les feux de forêt sont inquiétants et on s'attend à ce que ces dommages augmentent avec les changements dans les régimes des feux, demandant l'adoption de stratégies plus efficaces d'atténuation et d'adaptation à l'égard des feux de forêt. Parmi les mesures d'adaptation aux feux de forêt dans le cas des propriétaires de terrains forestiers, il y a l'achat d'une assurance contre les feux de forêt qui procure une compensation à ceux qui sont assurés si un feu de forêt cause des dommages à leurs propriétés. Nous avons essayé : (*i*) d'identifier les facteurs qui influencent la décision des propriétaires de terres forestières familiales du sud des États-Unis d'acheter une assurance contre les feux de forêt pour leurs boisés en utilisant la régression logistique avec des données d'enquêtes auprès des propriétaires, et (*ii*) d'étudier la propension de ces propriétaires à acheter une assurance contre les feux de forêt dans le contexte des changements climatiques. Nous avons trouvé que les propriétaires sont nettement plus susceptibles d'acheter une assurance contre les feux de forêt s'il s'agit d'une femme ou d'une personne instruite, ou si leurs terrains ne font pas partie des biens destinés aux héritiers, ont été frappés par un ouragan ou n'ont pas déjà été brûlés par un feu de forêt. Étant donné que les changements climatiques sont susceptibles de modifier l'activité future des feux de forêt et des ouragans dans la région, on prédit que davantage de propriétaires de terrains forestiers achèteront une assurance contre les feux de forêt bien que l'ampleur d'une telle augmentation semble modérée compte tenu des institutions œuvrant actuellement dans ce marché. Ces résultats seraient utiles pour élaborer de nouveaux programmes d'assurance contre les feux de forêt et augmenter la participation des propriétaires de terrains forestiers dans le marché de l'assurance contre les feux de forêt. [Traduit par la Rédaction]

Mots-clés : feu de forêt, adaptation, assurance, propriétaire de terres forestières familiales, changements climatiques.

Introduction

Wildfire has become an increasing threat to ecosystems, properties, and even human life in recent years in the United States (US) and many other parts of the world. According to the National Interagency Fire Center (2014), the area burned in the US, although variable from year to year, has shown an upward trend since 2000 (Fig. 1*a*). As the threat becomes more pressing, demand for fire suppression has also risen. Wildfire suppression costs by US federal agencies alone have steadily increased over the past few years, reaching an average US$1.46 billion annually from 2000 to 2012 (Fig. 1*b*) and reflecting the severity of the growing wildfire threat.

This threat is attributable to several factors, including increased human migration into natural areas (e.g., the wildland–urban interface), wildfire suppression policy, and climate variability. These factors interact with one another creating a vicious cycle of wildfire phenomena. On the one hand, the immediate need to protect natural resources, property, and human life entail more frequent and intensive wildfire suppression (US Department of Agriculture (USDA) and US Department of Interior (USDI) 2000; Stephens and Ruth 2005). On the other hand, increased wildfire suppression efforts lead to greater accumulation of vegetation fuels on the ground, increasing wildfire intensity if it occurs (USDA and USDI 2000; Schoennagel et al. 2004). Climate variability may also directly and indirectly alter wildfire regimes through its impact on heat and vegetation fuels (Clark 1990; Swetnam 1993; Whitlock et al. 2003).

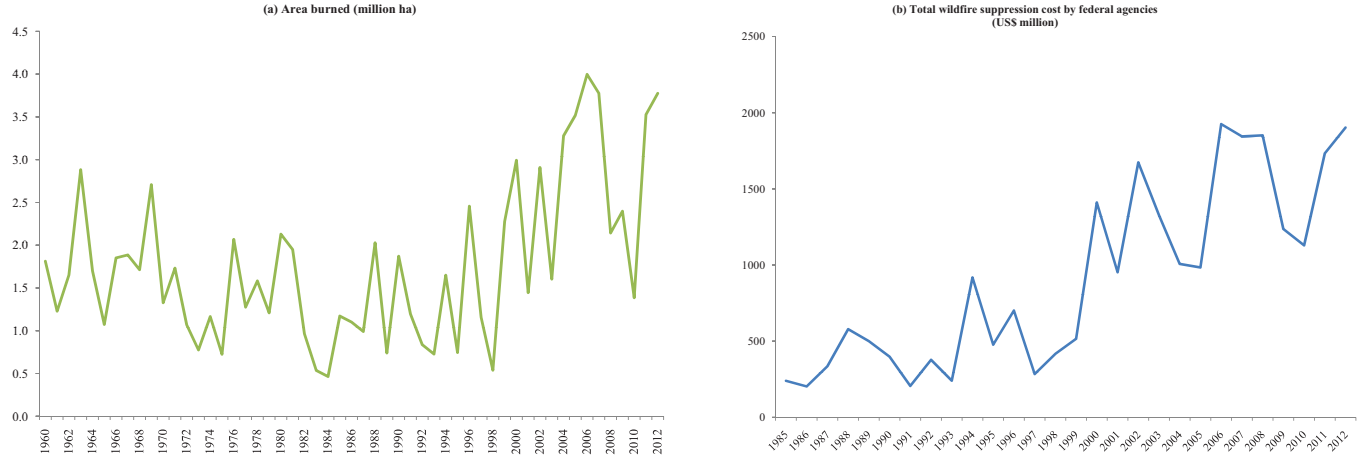
There are several wildfire mitigation and adaptation options. Mitigation aims to reduce wildfire risk, whereas adaptation is intended to lessen the burden of loss on individuals impacted by

Received 1 July 2014. Accepted 17 August 2014.

J. Gan. Department of Ecosystem Science and Management, Texas A&M University, College Station, TX 77843, USA.
A. Jarrett. Texas Department of Wildlife and Parks Service, Tyler, TX 75701, USA.
C.J. Gaither. USDA Forest Service, Athens, GA 36602, USA.
Corresponding author: Jianbang Gan (e-mail: j-gan@tamu.edu).

Published at www.nrcresearchpress.com/cjfr on 18 August 2014.

Fig. 1. (*a*) Area burned by wildfire and (*b*) federal wildfire suppression cost (data source: National Interagency Fire Center 2014).



wildfire. Among wildfire mitigation options are vegetation fuel treatments (e.g., thinning and prescribed burning) and the construction of fire lines. Fuel treatment and fire line construction aim to reduce wildfire risk directly. Extensive work has been done in this area in recent years (e.g., Graham et al. 2004; Agee and Skinner 2005; Reinhardt et al. 2008). Several studies have also explored the economic aspects of wildfire prevention and fuel treatments, especially focusing on willingness to pay for wildfire prevention in general (Kaval 2009) and fuel treatments in particular (Kaval et al. 2007; Walker et al. 2007). Fuel treatments, however, are costly (Rummer 2008), reducing the motivation of private landowners to adopt these practices. Additionally, effective mitigation of wildfire risk via fire prevention and fuel treatments requires broad and coordinated efforts of many adjacent landowners, which is not an easy task in areas such as the southern US where forests are primarily owned by small private landowners (Butler et al. 2004). In addition to the complexity of coordination, the public good nature of wildfire risk mitigation, which often leads to externalities and free riding in terms of benefits derived from wildfire risk reduction efforts, creates an additional challenge in wildfire prevention and fuel treatments. Finally, wildfire cannot be completely prevented or mitigated. Hence, adaptation could be a viable option to reduce wildfire loss, particularly for small family forestland owners. One loss-reduction adaptation option is wildfire insurance.

Insurance has long been considered an adaptation-based mechanism to reduce losses resulting from natural disasters (Kunreuther and Roth 1998), with examples ranging from crop insurance (Glauber et al. 2002) to recently proposed insurance against climate change (Gurenko 2006). Wildfire insurance was proposed decades ago (Yatagai 1933; Shepard 1935, 1937), yet there are few such insurance programs available and few forestland owners have taken advantage of existing insurance programs (Chen et al. 2014). Currently, assistance to wildfire victims in the US is primarily provided by nonprofit organizations (e.g., the American Red Cross) and governments. Nonprofit organizations primarily focus on helping the affected individuals meet immediate personal needs. Government assistance is usually in the form of tax relief and subsidized loans to help hard-hit communities and individuals, which may both address personal needs and partially compensate for property losses or restoration costs (USDA and USDI 2000; State of Georgia 2008; US Department of the Treasury Internal Revenue Service 2009). These current wildfire disaster relief programs operated by governments have several shortcomings. First, they can only partially compensate for the losses of hard-hit individuals in government-declaimed disaster areas. As such, many impacted individuals or landowners are not covered or inadequately covered by these programs. Second, these relief programs are constrained by continuing reductions in federal government budgets while wildfire activity and damage are on the increase. Given the limited impact of government-run relief programs, landowners would derive benefits from the additional support provided by privately operated wildfire insurance.

Although insurance could be an effective mechanism for responding to wildfire risk, studies in wildfire insurance are limited. Recently, several studies have looked into the supply side of wildfire insurance, primarily the determination of wildfire insurance premiums (Holecy and Hanewinkel 2006; Chen et al. 2014). Work on the demand side of wildfire insurance (e.g., the behavior of forestland owners in purchasing wildfire insurance) is even rarer. Via model simulations, Barreal et al. (2014) demonstrated that buying wildfire insurance is beneficial to forestland owners, particularly those facing high wildfire risk. Collins (2008) addressed wildfire insurance coverage from a class perspective in his political ecological argument about risk exposure. He maintained that market institutions such as local fire protection services and fire risk insurance help insulate upper income individuals from property losses resulting from wildfire. Lower income homeowners in the same communities, however, are typically less able than their better-off neighbors to command or pay for such services. This situation results in poorer households bearing a disproportionate amount of the losses from wildfire because of their inability to marshal the level of protection afforded by those with higher incomes.

This study focuses on the propensity of family forestland owners to purchase wildfire insurance in the southern US. The study region included 13 states: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. This region is one of the most important forest regions in the US and the world. The volume of roundwood harvested in this region in 2006 accounted for 57% of total US roundwood production and 14.2% of total world industrial roundwood production, respectively (Smith et al. 2009; United Nations Food and Agriculture Organization 2014). Additionally, forests in this region provide a variety of ecosystem services, including carbon storage, water regulation, biodiversity, and others, to the residents of the region and beyond (USDA Forest Service 2012). Approximately 60% of timberlands in the region are owned by family forestland owners (Smith et al. 2009), who have diverse ownership objectives, forest tract sizes, and socioeconomic characteristics (Butler et al. 2004).

Like other regions in the US, wildfire has become a big concern in the southern US (Stanturf et al. 2002) and the issue could be worsened due to expanding urbanization and presumed climate

change. In addition to changes in temperature and precipitation that affect vegetation (fuel) growth and fire ignition conditions, future hurricane activity in this region is anticipated to intensify under climate change scenarios (Knutson et al. 2013). There is strong evidence of the linkage between wildfires and hurricanes (especially large hurricanes) in the southern US (Myers and Van Lear 1997; Liu et al. 2008). Insurance is considered an effective and more affordable response to climate change (Hoeppe and Gurenko 2006).

The main objectives of this study were to (*i*) identify the factors that influence the decision of family forestland owners in the southern US to purchase wildfire insurance and (*ii*) estimate the impact of climate change on the propensity of these landowners to purchase wildfire insurance. The findings from this study will provide not only insights into the behavior of these landowners in purchasing wildfire insurance, but also guidelines for encouraging forestland owners to use insurance as a wildfire adaptation option and for developing more effective and affordable wildfire insurance programs to attract the patrons of these landowners.

Methods

Identifying factors influencing landowners' decisions to purchase wildfire insurance

This study is drawn on random utility models that have been widely adopted in analyzing consumer choices of products including insurance products (Manski 1977; Baltas and Doyle 2001). Suppose that a landowner makes his (her) decision on whether or not to purchase wildfire insurance based on the difference in the utilities derived from buying and not buying the insurance. That is, a landowner will purchase wildfire insurance if $U_1 - U_0 > 0$, where U_1 and U_0 are his (her) utility derived from buying and not buying the insurance, respectively; otherwise, the landowner will not purchase the insurance. For simplicity and without loss of generality, we can set $U_0 = 0$. Then, $U_1 - U_0 > 0$ becomes $U_1 > 0$. We can write $U_1 = v + \varepsilon$, where v and ε are the deterministic and stochastic components of the utility function, respectively (ε is also called random utility). $U_1 = v + \varepsilon > 0$ gives rise to $\varepsilon > -v$.

Hence, the probability of buying wildfire insurance can be measured by the probability of the random utility (ε). That is, Pr(buying insurance) = Pr($U_1 > 0$) = Pr($\varepsilon > -v$) = Pr($\varepsilon < v$). The last equality holds for any symmetric probability density function. Following the conventional practice in applying random utility models (Manski 1977; Baltas and Doyle 2001), we further assume that v is a linear function of a set of variables ($\boldsymbol{X}$) describing the attributes of wildfire risk and consequences, the landowner, and the insurance program (i.e., $v = \boldsymbol{X}'\boldsymbol{\beta}$ with $\boldsymbol{\beta}$ being the vector of coefficients corresponding to $\boldsymbol{X}$). These attributes also echo the determinants of consumer demand for risk insurance (Desrosiers 2012). Several probability distribution functions can be used to portray ε. In this study, the logistic probability distribution was adopted because it is a canonical link function for a binary response variable. Compared with a noncanonical link function (e.g., probit), a canonical link function possesses some desirable statistic properties, including minimum sufficiency in addition to its computational and interpretational convenience.

Because a landowner either purchases or does not purchase wildfire insurance, his (her) decision variable (y) takes only two values. For example, if the landowner purchases wildfire insurance, then $y = 1$, otherwise, $y = 0$. Thus, binary logistic regression was employed to determine the factors that determine landowners' decisions. The logit function on which the regression model is based can be written as follows (Greene 2008):

$$\text{(1)} \qquad \text{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \boldsymbol{X}'\boldsymbol{\beta}$$

where p is the probability that the landowner will purchase wildfire insurance, $p/(1 - p)$ is the odds ratio, and ln is the natural logarithm operator. Rearranging eq. 1, we can derive

$$\text{(2)} \qquad p = \Pr(y = 1) = \frac{\exp(\alpha + \boldsymbol{X}'\boldsymbol{\beta})}{1 + \exp(\alpha + \boldsymbol{X}'\boldsymbol{\beta})}$$

Data used to estimate the regression model were drawn from 585 valid responses received from a mail survey of 2500 family forestland owners (households) in the study region. The survey sample was selected via cluster sampling from the population of landowners who owned at least 10 acres of forestland. Excluding 127 undeliverable mails, the survey yielded a 24.7% response rate.

The survey was designed and administrated using the methods devised by Dillman et al. (2009). The questionnaire consisted of a series of questions pertinent to landowners' perception of wildfire risk, wildfire mitigation and adaptation strategies, forest tract features, and demographic and socioeconomic characteristics. Some of these survey questions are presented in Table 1. More detailed descriptions of the survey design, implementation, and responses can be found in Jarrett et al. (2009).

Empirical specification of the binary logistic regression model involved two steps. First, we selected independent variables that were likely to influence landowners' decision to purchase wildfire insurance. A set of independent variables was initially included in the regression model. The descriptions of these variables and their descriptive statistics are shown in Table 1. These variables portray the characteristics of forestlands and their owners, as well as landowners' perception of and experience with wildfire and other natural disturbances; together they represent wildfire risk, potential consequences associated with the risk, and the attitudes of landowners toward the risk.

Because information about existing wildfire insurance programs was unavailable, no independent variable describing insurance programs was incorporated in modeling. The benefit of using the random utility model is that it allows for omitting unobservable variables, including unobserved product heterogeneity, because these unobservable variables are represented by the stochastic utility component (ε) (Manski 1977; Baltas and Doyle 2001). Additionally (or in the worst case), omitting the insurance program variable is equivalent to assuming that all wildfire insurance programs available to these landowners were the same. This assumption also seems reasonable given that only few wildfire insurance programs were on market and that we intended to focus on landowners' participation in the overall wildfire insurance program without distinguishing individual insurance programs.

With the inclusion of these independent variables in the initial model, the stepwise backward (Wald) method was then used to eliminate statistically insignificant independent variables one by one and to estimate the final regression model. In this stepwise backward approach, independent variables were eliminated from the model based on the Wald statistic, which follows a chi-square distribution, and its associated p value. All independent variables with a p value greater than a predetermined significance level (10% in our case) were eliminated to derive the final model. The final model was validated using several statistical tests in addition to the Wald test for significance of individual variables, including the log-likelihood and Hosmer–Lemeshow tests for overall goodness of fit. There was no evidence of multicollinearity among the independent variables in the final model according to the variance inflation factor and simple correlation coefficients. SAS version 9.3 (SAS Institute Inc. 2011) was used in the regression analysis.

Predicting climate change impact on landowners' propensity to purchase wildfire insurance

Climatic conditions have played an important role in wildfire activity in the southern US (Stanturf et al. 2002; Gan 2005*a*). To

Table 1. Independent variables initially included in regression analysis.

Independent variable (survey question)	Value	Frequency or mean
Has a wildfire been present on your land in the last 10 years?	Yes = 1, no = 0	1: 0.246
Has anyone you know lost property due to wildfire in the last 10 years?	Yes = 1, no = 0	1: 0.214
Do you believe your land could be damaged by wildfire?	Yes = 1, no = 0	1: 0.921
Do you use the information received from a state agency to protect your land from wildfire?	Yes = 1, no = 0	1: 0.500
What is your gender?	Female = 1, male = 0	1: 0.276
What is your age?	≤40 years = 0	0: 0.023
	40–49 years = 1	1: 0.125
	50–59 years = 2	2: 0.320
	≥60 years = 3	3: 0.532
What is your race?	White = 1, nonwhite = 0	1: 0.913
Do you personally manage your land?	Yes = 1, no = 0	1: 0.874
Do you live on the land?	Yes = 1, no = 0	1: 0.520
Is this land heirs' property?	Yes = 1, no = 0	1: 0.443
Is this land used for timber production?	Yes = 1, no = 0	1: 0.699
Do you have a forest management plan for this land?	Yes = 1, no = 0	1: 0.515
Has this land been hit by bark beetles?	Yes = 1, no = 0	1: 0.363
Has this land been hit by hurricane?	Yes = 1, no = 0	1: 0.247
What is your highest level of education?	<High school = 0	0: 0.023
	High school graduate = 1	1: 0.285
	College or technical school graduate = 2	2: 0.397
	>4-year degree = 3	3: 0.294
What is your annual household income	≤$30k = 0	0: 0.141
	$30k–49k = 1	1: 0.131
	$50k–69k = 2	2: 0.167
	$70k–89k = 3	3: 0.129
	$90k–119k = 4	4: 0.167
	≥$120k = 5	5: 0.265
What percent of your household income is from rural land?	0–100	11.41 (22.19)[a]
Do you have internet access?	Yes = 1, no = 0	1: 0.730

[a]Mean with standard deviation in parentheses.

estimate the impact of climate change on the behavior of forestland owners in purchasing wildfire insurance, we needed to connect climate change to eq. 1. Based on the estimated logistic regression model (to be described in the next section), only two significant independent variables were associated with climate change. They were the past wildfire occurrence (denoted by x_f henceforth) and hurricane hit (denoted by x_h henceforth) on forestlands. Because these two independent variables were treated as discrete (dichotomous) variables, we could not take partial derivatives of eq. 1 to derive their marginal effect on the dependent variable. Instead, we took the expectation (E) of eq. 1 first, yielding

$$(3) \qquad E\left[\ln\left(\frac{p}{1-p}\right)\right] = \ln\left(\frac{p}{1-p}\right) = E(\boldsymbol{X}'\boldsymbol{\beta}) = E(\boldsymbol{X}')\boldsymbol{\beta}$$

$E(x_f) = 1p_f + 0(1 - p_f) = p_f$, where p_f is the probability of forestland being burned by a wildfire, which is continuous. Similarly, $E(x_h) = 1p_h + 0(1 - p_h) = p_h$, where p_h is the probability of forestland being hit by a hurricane. Then, taking the partial derivative of eq. 3 with respect to $E(x_f)$ and $E(x_h)$, respectively, we derive

$$(4) \qquad \beta_f = \partial \ln\left(\frac{p}{1-p}\right) \Big/ \partial E(x_f)$$

and

$$(5) \qquad \beta_h = \partial \ln\left(\frac{p}{1-p}\right) \Big/ \partial E(x_h)$$

where β_f and β_h are the regression coefficients associated with x_f and x_h, respectively. Thus, β_f and β_h can be interpreted as percentage change in the log odds ratio of buying wildfire insurance due to a unitary change in p_f and p_h, respectively.

Then, the change in $\ln[p/(1-p)]$ due to changes in $E(x_f)$ and $E(x_h)$, ceteris paribus, can be written as follows (with Δ denoting change):

$$(6) \qquad \Delta \ln\left(\frac{p}{1-p}\right) \cong \Delta E(\boldsymbol{X}')\boldsymbol{\beta} = \beta_f \Delta E(x_f) + \beta_h \Delta E(x_h) = \beta_f \Delta p_f + \beta_h \Delta p_h$$

Let R_1 be the odds ratio of buying wildfire insurance under future climate change and R_0 be the current odds ratio. Thus, eq. 6 can be rewritten as

$$(7) \qquad \ln\left(\frac{R_1}{R_0}\right) \cong \beta_f \Delta p_f + \beta_h \Delta p_h$$

Rearranging eq. 7 yields

$$(8) \qquad R_1 \cong R_0 e^{\beta_f \Delta p_f + \beta_h \Delta p_h}$$

where e is the base of the natural logarithm. As climate change is likely to alter the probabilities of wildfire and hurricane activities, eqs. 6 or 7 and 8 can be used to estimate climate change impact on landowners' willingness to purchase wildfire insurance.

Data on the projected risk of future wildfire and hurricanes in the study region under climate change were derived from the existing literature. The occurrence of human-caused wildfire, the dominant wildfire in the southern US (Stanturf et al. 2002), would

Table 2. Logistic regression results of landowners' decision to purchase wildfire insurance for their forestlands.

Variable	Estimated coefficient	Odds ratio	Wald chi-square (df = 1)	*p*
Intercept	–9.5752		15.8312	<0.0001
Wildfire occurrence in the last 10 years	–1.4028	4.067	4.9482	0.0261
Female	3.0152	20.393	14.4043	0.0001
Heirs' property	–1.7316	5.650	4.6497	0.0311
Hurricane hit	1.5225	4.584	5.2481	0.0220
Highest education of the landowner	2.0288	7.605	9.7371	0.0018
–2 log likelihood (intercept and covariates)	66.94			
Hosmer and Lemeshow test (*p* value)	0.7971			
Percentage correct prediction	87.4			

change by a range between –7% and 37% under the projected climate change (Gan 2005*b*). These projections of wildfire risk are based on the projected seasonal temperatures and annual precipitation in the region in the late part of the 21st century under a moderate greenhouse gas (GHG) emissions scenario.

Although the projected change in the frequency of all hurricanes in the 21st century varies and is generally insignificant, the frequency of intense (categories 4 and 5) hurricanes would increase significantly (Emanuel et al. 2008; Villarini et al. 2011; Villarini and Vecchi 2013). It is predicted that the frequency of category 4 and 5 hurricanes in the Atlantic basin would increase by approximately 39% to 87% in the 21st century under the A1B scenario described in the Special Report on Emissions Scenario (SRES) (Knutson et al. 2013). The global GHG emissions under A1B reflect the central part of the wide range of emissions predicted under all the emissions scenarios considered by the Intergovernmental Panel on Climate Change (2000). Our study region is located in the impact zone of hurricanes from the Atlantic basin. Given that most hurricane damage is caused by category 4 and 5 hurricanes (Pielke et al. 2008), we used the above projected range of change in hurricane activity to infer the impact of hurricane risk on landowner purchase of wildfire insurance in the southern US.

Results and discussion

Propensity to purchase wildfire insurance and its influencing factors

Of the survey respondents, only 9.4% purchased wildfire insurance for their forestlands. The majority of forestland owners in the region did not purchase wildfire insurance as a wildfire adaptation strategy. The low participation of these landowners in wildfire insurance markets may be partly due to limited availability of wildfire insurance programs (Chen et al. 2014) and partly due to government-run relief programs. Individuals tend to be reluctant to buy disaster insurance when they perceive that these low-probability events would not happen to them and that governments will help them out if a disaster happens (Kunreuther 1996).

The final logistic regression model (Table 2) passed several statistical tests, including the log-likelihood and Hosmer–Lemeshow tests. More than 87% of actual observations can be accurately predicted by the model. These suggest that the final model is a good fit to the data.

According to the logistic regression results, five independent variables have a statistically significant impact on landowners' decision to purchase wildfire insurance for their lands. Landowners who had experienced wildfire on their lands were less likely to purchase wildfire insurance than those who had not, with an odds ratio greater than four. This unexpected result may be attributable to the fact that a previous fire reduces the probability of fire reoccurrence in the near future because vegetation will take some time to regrow to accumulate fuel as evidenced by the wildfire cycle in the region (Stanturf et al. 2002); hence, the landowner may not see an immediate need to purchase wildfire insurance.

The gender of landowners shows a huge difference in insurance purchasing. Female landowners were much more likely to buy wildfire insurance than males, with an odds ratio greater than 20. This may be partly because women are arguably more risk averse than men (Jianakoplos and Bernasek 1998; Eckel and Grossman 2008).

Landowners whose land was heirs' property were less likely to buy wildfire insurance than those whose land was not heirs' property. The ownership of heirs' property is less clear or more complex and thus more vulnerable (easier to lose) (Graber 1978), reducing the incentive of the landowner to protect the land resource.

Landowners whose land had been hit by a hurricane had a higher propensity to buy wildfire insurance than those who had not experienced hurricane damage on their land. Hurricanes often alter fuel patterns on forestlands, which could become a fire hazard. The probability and intensity of wildfire would increase after a major hurricane (Myers and Van Lear 1997; Liu et al. 2008). As such, the damage caused by a hurricane could prompt the landowner to take action to protect the land from further damage.

Education also shows a large significant impact on landowners' decision to buy wildfire insurance. On average, the odds ratio between buying and not buying wildfire insurance was 7.6 when the landowner's education increased by one category, echoing that more educated people are more risk averse (Hersch 1996).

Interestingly, other demographic and socioeconomic characteristics of landowners such as age, race, and household income did not show a significant impact on the purchase of wildfire insurance. We are cautious about the racial impact because only a small portion (8.7%) of our survey respondents were minorities. The ambiguity of income effect on wildfire insurance purchase may be partially attributable to the complex relation between income and the demand for insurance, which also depends on risk aversion and income elasticity of demand among other factors (Cleeton and Zellner 1993). Surprisingly, landowners' belief in wildfire threat did not translate into their action to buy wildfire insurance (Tables 1 and 2), although approximately 92% of landowners surveyed stated that they believed that their lands could be damaged by wildfire.

Impact of climate change on landowners' propensity to purchase wildfire insurance

The impact of climate change on landowners' propensity to purchase wildfire insurance will be primarily through its impact on future wildfire and hurricane risk. Approximately one-quarter (24.61%) of survey respondents stated that they had experienced wildfire on their lands and 24.69% of respondents said that their lands had been hit by a hurricane (Table 3).

Climate change is likely to alter wildfire regimes and hurricane risk on forestlands in the southern US. According to Gan (2005*b*) and Knutson et al. (2013), if the projected climate change takes place, wildfire and hurricane activity would change by approxi-

Table 3. Climate change impact on landowners' propensity to purchase wildfire insurance.

Item	Low	Average	High
(*i*) Percentage of landowners whose land has been burned by wildfire[a]	24.61	24.61	24.61
(*ii*) Percentage of landowners whose land has been hit by hurricane[a]	24.69	24.69	24.69
(*iii*) Predicted percentage change in wildfire occurrence under climate change[b]	37	15	–7
(*iv*) Predicted percentage change in occurrence of category 4 and 5 hurricanes under climate change[c]	39	63	87
(*v*) Predicted percentage of landowners whose land would be burned by wildfire under climate change[d]	33.72	28.30	22.89
(*vi*) Predicted percentage of landowners whose land would be hit by hurricane under climate change[e]	34.32	40.24	46.17
(*vii*) Change in ln(odds ratio of buying wildfire insurance) due to climate change[f]	1.88	18.50	35.12
(*viii*) Change in the ratio of odds ratios of buying wildfire insurance due to climate change[g]	1.01	1.15	1.31

[a]Data (percentages) for item (*i*) was drawn from the landowner survey reported in Jarrett et al. (2009).
[b]Data for item (*iii*) was derived from the paper by Gan (2005*b*). The low and high values are reverse because the occurrence of past wildfire has a negative impact on the likelihood of the landowner to purchase wildfire insurance.
[c]Data for item (*iv*) was obtained from the paper by Knutson et al. (2013).
[d]Calculated based on (*i*) and (*iii*).
[e]Calculated based on (*ii*) and (*iv*).
[f]Calculated based on eq. 6.
[g]Calculated based on eq. 8.

mately –7% to 37% and approximately 39% to 87%, respectively. This would lead to a nearly 2% to 35% change in the log odds ratio of buying wildfire insurance, with its exponential value (or the ratio of odds ratios) ranging from 1.01 to 1.31 (Table 3). In other words, the predicted climate change would increase the odds ratio of the landowners to purchase wildfire insurance by approximately 1% to 31%. Hence, if the projected climate change occurs, family forestland owners in the southern US would be more likely to purchase wildfire insurance for their forestlands. Yet, the impact of climate change on landowners' behavior in purchasing wildfire insurance would be moderate, in general.

Conclusion

We used landowner survey data and logistic regression to identify the determinants of landowners' decision to purchase wildfire insurance for forestlands in the southern US. Five factors were identified to have statistically significant impacts on the propensity of these landowners to purchase wildfire insurance as an adaptation option to wildfire risk. Past hurricane damage on their properties would encourage landowners to purchase wildfire insurance, whereas previous wildfire incidents on their lands would discourage them to do so. Female or more educated landowners have much higher propensity to buy wildfire insurance. Yet, landowners of heirs' properties are less likely to participate in the wildfire insurance market. Additionally, climate variability is likely to intensify hurricane activities and alter wildfire regimes, which would lead to only a moderate increase in landowners' propensity to purchase wildfire insurance.

These results have several useful implications for adapting to wildfire risk by family forestland owners and for expanding wildfire insurance markets in the southern US. First, there is great potential to expand wildfire insurance markets in the region because only a small fraction of landowners have bought wildfire insurance. Yet, fully realizing this market potential could be challenging because landowners' beliefs in wildfire threat do not necessarily lead to their purchase of wildfire insurance. Second, to increase the participation of family forestland owners in wildfire insurance programs in the region, insurance providers should target those who are well educated or female or whose lands are not heirs' properties. Third, there is a lower fire risk associated with lands burned recently and owners of these lands are less likely to purchase wildfire insurance. On the other hand, landowners whose lands have been hit by a hurricane are more willing to buy wildfire insurance because hurricane-damaged forests represent a higher fire risk. This could lead to adverse selection in the wildfire insurance market, a phenomenon in which only the landowners with high wildfire risk buy insurance, thus creating a potential challenge for wildfire insurers. Finally, the low propensity of family forestland owners to purchase wildfire insurance (even with intensified hurricane activity under climate change) engenders private–public partnerships in developing and offering wildfire insurance programs. Government-assisted insurance programs would be feasible and more affordable as demonstrated by crop insurance programs (Glauber et al. 2002), thus encouraging landowners' participation in the insurance programs and reducing taxpayers' burden in funding disaster relief programs.

This study can be expanded in several fronts. There are multiple wildfire mitigation and adaptation options for forestland owners. Future studies can explore landowners' decisions to adopt other options and the interactions between different wildfire mitigation and adaptation options, including new options. This is important particularly because the random utility model assumes the independence of irrelevant alternatives. Additionally, the features of wildfire insurance programs are not incorporated in this study. As a result, their impact on landowners' purchases of wildfire insurance remains to be explored. Finally, this paper focuses only on family forestland owners in the southern US. Because wildfire is also a concern for other types of lands such as rangelands and in other regions, this study can be extended to these landowner groups and regions.

Acknowledgements

This study was financially supported in part by the Joint Fire Science Program, US Department of Agriculture (NIFA and AFRI), and Texas A&M AgriLife Research. The opinions expressed here, however, are the authors' own.

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