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WILDFIRES IN GALICIA: CAUSALITY, FOREST POLICY AND RISK IN FOREST MANAGEMENT

A thesis submitted to the University of Santiago de Compostela, in fulfillment of the requirements for the Degree of Doctor of Philosophy

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WILDFIRES IN GALICIA: CAUSALITY, FOREST POLICY AND RISK IN FOREST MANAGEMENT
Los incendios forestales en Galicia: causalidad, política forestal y riesgo en la gestión forestal

This scientific report was elaborated by Jesús Barreal Pernas and constitutes the Dissertation to obtain the Doctorate degree by the University of Santiago de Compostela.
Esta memoria científica ha sido realizada por Jesús Barreal Pernas y constituye la tesis que presenta para optar al grado de Doctor por la Universidad de Santiago de Compostela.

Santiago de Compostela, 8th June 2014
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the scientific report titled "Wildfires in Galicia: causality, forest policy and risk in forest management" was conducted by Jesús Barreal Pernas under my supervision and contributes to obtain the Doctorate Degree by the University of Santiago de Compostela. I consider that the PhD candidate fulfils with Article 34 of the Law regulating PhD studies and I am not affected by any incompatibility according to RD 30/1992.

La memoria científica titulada "Los incendios forestales en Galicia: causalidad, política forestal y riesgo en la gestión forestal" fue realizada por Jesús Barreal Pernas bajo mi supervisión y supone una contribución para optar al grado de Doctor por la Universidad de Santiago de Compostela. Considero que el candidato cumple con los requisitos del Artículo 34 de los Estudios de Doctorado, y que no incurro en ninguna causa de abstención establecidas en el RD 30/1992.

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ABSTRACT

Forestlands are one of the most important environmental resources. If a better conservation and management was achieved, then the social welfare and economic wealth would be higher. To obtain a better forest conservation, wildfires can be prevented by public policies. The first chapter of this thesis is focused on providing suggestions to improve the current public policies in order to reduce the wildfire occurrence. In this chapter spatial econometric models are developed in order to analyse the relations between socioeconomics, environmental and climatic variables with wildfires occurrence. In particular, Chap. I studies the heterogeneous behaviour of wildfire patterns within the Galician Forest Districts. The main results of this chapter highlight the importance of the role of socioeconomic factors in explaining wildfire occurrence. Based on these results, some policy guidelines are suggested.

Chaps. II and III study the forest insurance as a tool for reducing the economic risk and guarantee the production of environmental services. The proposed insurance model includes the coverage of restoration costs and timber damages after wildfires. Hence, the production of environmental services will be guaranteed and the forest investment will reduce their volatility. Thus, in Chap. II the influence of forest insurance is analysed by employing Net Present Value model (NPV). In the Chap. III, forest insurance is studied as a tool to incentive the landowner to produce environmental services. Therefore, private and social forest valuation is conditioned by this incentive; so that the optimal forest rotation considers the valuation of environmental goods and services.

In the last chapter, Chapter IV, the demand for forest insurance contracts is studied. A survey is conducted among 210 landowners and forest managers. A choice experiment of some possible insurance policies is included in this survey. The proposed insurance attributes contain both timber and restoration cost coverage; and forest certification, included as a requirement. The insurance demand according to landowners or forest managers' preferences and their socioeconomic features is estimated. From these results, the willingness to pay for the forest insurance program is obtained (3.64 €/Ha). Finally, it can be concluded that the insurance demand is affected by both, insurance attributes and socioeconomic features of the forest managers.

Keywords: environmental services, forest insurance, public policy, risk, wildfires.

RESUMEN

Los recursos forestales son uno de los principales activos ambientales. De esta manera, una mejora en su conservación y explotación redundará en un mayor bienestar social y un incremento de la riqueza económica. Para una mejor conservación forestal, los incendios se pueden prevenir mediante políticas públicas. El primer capítulo de esta tesis tiene por objetivo favorecer el diseño de políticas públicas que reduzcan los incendios. Para ello se estiman una serie de análisis econométricos en los que se incluyen variables socioeconómicas, ambientales y climatológicas para explicar la ocurrencia de incendio. Sus resultados sirven para estudiar el comportamiento de los incendios en los Distritos forestales gallegos. Los principales resultados de este capítulo demuestran la importancia de los factores socioeconómicos para explicar los incendios en Galicia. Asimismo, en este capítulo se ofrecen una serie de recomendaciones enfocadas en mejorar las políticas públicas.

Los Capítulos II y III inciden en el estudio del seguro forestal como un mecanismo para reducir el riesgo económico de la explotación forestal y garantizar la producción de servicios ambientales. El seguro propuesto puede cubrir tanto la recuperación forestal como los daños en la madera tras un incendio. Esto provoca que la producción de servicios medioambientales se vea garantizada y que la inversión forestal reduzca su volatilidad. Así, en el Capítulo II se analiza su influencia del seguro forestal en la rotación forestal al incluir este factor en el modelo de Valor Actualizado Neto (VAN). No obstante, en el Capítulo III se analiza el empleo del seguro como un incentivo con el que se motive al propietario a producir servicios medioambientales. Por lo tanto, la valoración forestal pública y privada dependerá de la aplicación de este incentivo, lo que provoca que la rotación forestal óptima tenga en cuenta ambos intereses.

En el último capítulo se estudia la demanda del seguro forestal. Para ello se realiza una encuesta a 210 propietarios y gestores forestales en la que se incluye un experimento de elección entre diversos seguros forestales. La póliza propuesta incluye tanto la cobertura de daños en la madera como los costes de recuperación del terreno forestal tras incendio. También se incluye la posible obligación de estar certificado para poder asegurar las propiedades forestales. Con esto se analiza la demanda del seguro forestal de acuerdo con las preferencias de los propietarios o gestores forestales y sus características socioeconómicas. A partir de esos datos se obtiene la disposición a pagar por el seguro forestal (3.64 €/Ha), así como por sus atributos. Con los resultados obtenidos se concluye que existe una demanda heterogénea dependiendo del tipo de seguro y de las características del propietario.

Palabras clave: Incendio forestal, política forestal, riesgo de incendio, seguro forestal, servicios ambientales.

RESUMO

Os recursos forestais son un dos principais activos ambientais. Deste xeito se producirse unha mellora na súa conservación e explotación redundará nun maior benestar social e nun incremento da riqueza económica. Para unha mellor conservación os incendios forestais poden ser previdos mediante políticas públicas. O primeiro capítulo desta tese ten por finalidade favorecer o deseño de políticas públicas que reduzan a incidencia dos incendios. Para elo neste capítulo estímanse una serie de modelos econométricos no que se inclúen variables socioeconómicas, ambientais e climáticas para explicar a ocorrencia de incendios. Os seus resultados serven para estudar o comportamento heteroxéneo dos incendios entre os Distritos forestais galegos. Os principais resultados deste capítulo demostran a importancia dos factores socioeconómicos para explicar os incendios en Galicia. Do mesmo xeito, neste capítulo ofrécense unha serie de recomendacións co obxectivo de mellorar as políticas publicas.

Nos capítulos II e III estúdase o emprego do seguro forestal como ferramenta para reducir o risco económico da explotación forestal e garantir a produción de servizos ambientais. O seguro proposto pode cubrir tanto a recuperación forestal como os danos na madeira tras un incendio. Isto provoca que a produción de servizos ambientais este garantida e que a inversión forestal reduza a súa volatilidade. Así no Cap. II analízase a influencia dos seguro forestal na rotación forestal ó engadir este factor no modelo de Valor Actualizado Neto (VAN). Non obstante, no Cap. III analizase o emprego do seguro forestal coma un incentivo que motive o propietario a producir servizos ambientais. Por tanto, as valoracións forestais públicas e privadas dependerán da aplicación deste incentivo, o que provoca que a rotación forestal óptima teña en conta ambos intereses.

O derradeiro capítulo estuda a demanda do seguro forestal. Para elo realizouse unha enquisa a 210 propietarios ou xestores forestais na que se inclúa un experimento de elección entre diversos seguros forestais. Na póliza proposta inclúense tanto a cobertura nos danos na madeira como os custes de recuperación do terreo forestal tras incendio. Tamén se inclúe a posible obriga de estar certificado para poder asegurar as propiedades forestais. Con isto analízanse a demanda do seguro forestal de acordo as preferencias dos propietarios ou xestores forestais e as súas características socioeconómicas. A partir destes datos obtense a disposición a pagar polo seguro forestal (3.64 €/Ha), así como polos seus atributos. Os resultados conclúen que existen unha demanda heteroxénea dependendo do tipo de seguro forestal e das características do propietario.

Palabras chave: Incendio forestal, política forestal, risco de incendio, seguro forestal, servizos ambientais.

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CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION

Forestry areas provide several goods and services to society, including timber, biomass energy, nuts and biodiversity preservation. Forest products are the main raw material for forest companies, and timber is transformed into furniture, energy or other intermediate and final goods. Forestry areas also offer several environmental services to society and biodiversity that influences water and air quality. The human health is also related to forest conservation (Forget and Lebel, 2001). Furthermore, forest lands provide natural panoramas and recreational areas to citizens (Ulrich, 1986), making environmental conservation very important for the society as well as for the private welfare.

Forestry areas are affected by floods, pests, wildfires and other risks that endanger timber stock and environmental areas as well as public and private economic interests. Landowners and society are concerned with reducing these risks. Landowners can reduce the probability of fire through specific forest management measures based on the characteristics of forest plantations and by contracting financial assets. In forest management, species selection and the amount and frequency of thinning or cleaning are determined according to the forestland's characteristics. Management can also involve clearing service roads or constructing preventive infrastructures such as fire-breaks or water points. Asset management by landowners could be related to forest insurance or financial derivatives as means of covering possible damages. This decreases landowners' uncertainty about forest investments and makes it possible to plan forest production according to financial criteria. These two types of measures are complementary and landowners can apply them simultaneously to forest management. To sum up, landowners can control exposure to forest damage through forest management efforts and financial decisions.

The main risks for forest production are the wildfires. Researchers such as Martínez *et al*. (2009), Lavorel *et al*. (2007) or Aguado *et al*. (2007) have analysed the relationship between socioeconomic, environmental or climatic variables and wildfire occurrence patterns. Many studies use econometric models to analyse the implication of socioeconomic and/or environment variables in wildfire occurrence. The results suggest that specific forest policies could be designed to reduce the incidence of wildfires by controlling the socioeconomic influence of risks involving anthropomorphic or economic variables (Butry, 2009).

Forest areas are subject to two main sets of interests: public and private. The first (private) are related to private land production and the second with the positive externalities of this production that the society enjoys. Social interests related to forest areas are defended by forest policies, which should be focused on preserving or increasing the well-being benefits that forest areas provide to society as a whole. Many forest policies are focused on controlling forest management by landowners.

It will be shown that private and public interests could be linked by using payments that guarantee forest production. Though many studies have looked at payments for environmental services (Pagiola *et al*., 2005; Engel *et al*., 2008; Wünscher *et al*., 2008), none of them have included the subsidy of an insurance contract as a potential payment (or partial payment) for ecosystem services. Implementing this measure would change public and private forest valuation: landowners would receive more income to produce environmental services while the society would have to subsidize it. Thus, the production of environmental services would also be included in the private valuation and the optimal forest rotation would take into consideration public and private interests. This would give landowners an economic incentive to guarantee the production of environmental services. If landowners develop specific forest management practices based on public interests; timber production and restoration costs would be guaranteed by the societal payment of the insurance policy.

Landowners try to maximize forest valuation based on expenses and forest revenues. Optimal forest rotation is the point of time when the maximum forest valuation is achieved. Faustmann was the first author to address forest production and optimal forest rotation (Faustmann, 1849). This work has since been extended by Hartman (1976), Samuelson (1976), Reed (1984) and others to include forest management costs, environmental services, and other factors in achieving optimal forest rotation. Within this framework, Barreto *et al*. (1998), Hyytiäinen and Haight (2010) or Hanewinkel *et al*. (2011), have used the Net Present Value (NPV) to calculate the optimal forest rotation. Accordingly, forest valuation models should be developed that include and link both private and public interests in order to obtain optimal forest rotation. However, private forest management decisions are currently developed according primarily to landowner criteria, while social interests remain unconsidered.

1.2. WILDFIRES IN GALICIA

Spanish forest production is mainly concentrated in Galicia (NW Spain), where wildfires stand out as the main cause of forest damage. Wildfires affect many hectares of forest and scrub lands and even threaten houses or human lives (Molano *et al*., 2007; Barrio *et al.*, 2007; González-Gómez *et al.*, 2013). Wildfire occurrence and/or affected areas are recorded in local councils or districts and described by spatial patterns (Balsa-Barreiro and Hermosilla, 2013; Fuentes-Santos *et al.*, 2013). Thus, most wildfires are concentrated in specific provinces, forest districts or municipalities. Figure 1.1 shows wildfire averages recorded in each Galician forest district from 2001 to 2010. Spatial patterns could be observed for each administrative area.

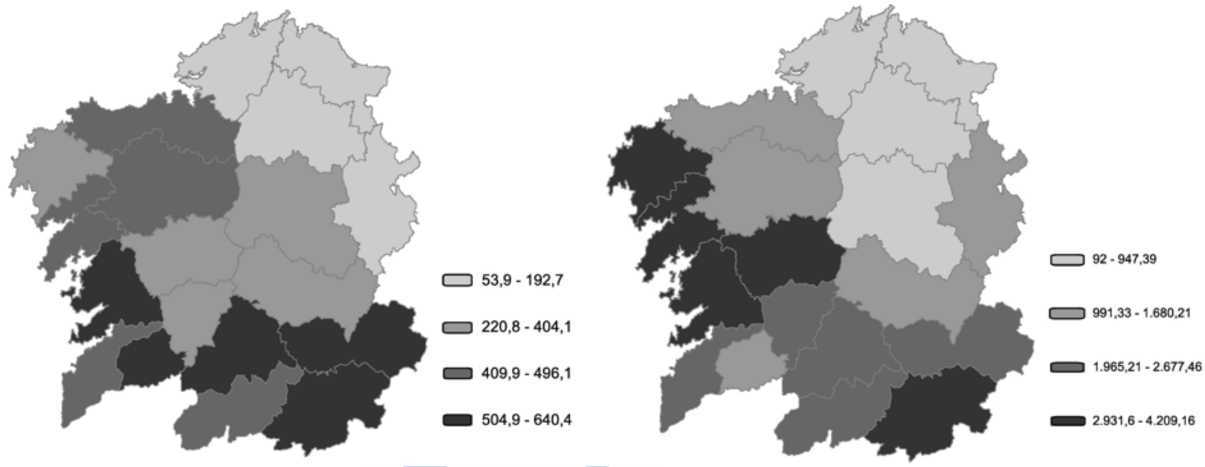

FIGURE 1.1: Wildfires in Galicia 2001-2010. a) Number of wildfires. b) Total burned area (Ha.).

Wildfire occurrence is accompanied by a high degree of human intentionality and varies from year to year. Spatial patterns also increase during these years. Among the highest years on record are 1989 and 2006, when wildfire affected 70%-100% of total area in some local councils or specific areas. Burned areas in 2006 were concentrated on the Atlantic Coast and in specific areas of the interior of Galicia, as shown in Figure 1.2.

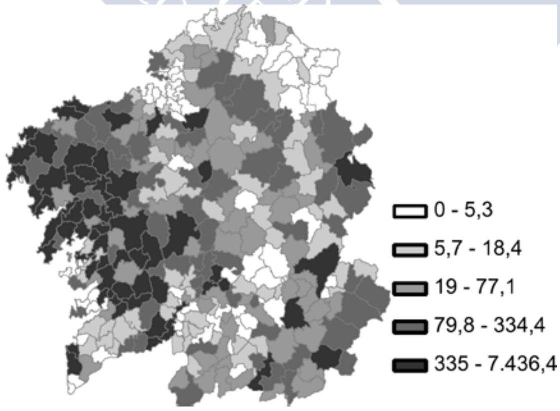

FIGURE 1.2: Burned area in 2006 (Ha).

Identifying the causes of wildfire is therefore crucial to reducing the risk of wildfire in Galician forests. According to Molano *et al.* (2007), Galician site characteristics, human resources and research criteria involve wildfire classification. Therefore, most of them are related to anthropomorphic variables, so wildfire risk could be modified through public policies and forest management efforts (Sineiro, 2006; Molano *et al.*, 2007). Galician wildfires are attributed to unavoidable or avoidable causes (Table 1.1). Unavoidable causes are those that do not associate wildfires with human behaviour. This category includes all natural hazards and lightning appears as the main cause, but it is only responsible for a small number of wildfires. In contrast, avoidable wildfires are associated with human influence and their occurrence can be prevented through public policy. Most wildfires in Galicia are due to avoidable causes, so there is room for greater development of public policy (Molano *et al.*, 2007, Balsa-Barreiro and Hermosilla, 2013; Fuentes-Santos *et al.*, 2013). This category includes wildfire occurrence due to direct or indirect human causes and is sub-divided into three categories: intentional motives, negligence and unclassified causes. Intentional wildfires are directly related to human behaviour, and this sub-section represents the cause of most Galician wildfires. However, forest research is inconclusive regarding the main reasons behind most intentional wildfires (Molano *et al.,* 2007). Neglect or negligence refers to wildfires that are indirectly conditioned by human behaviour. For example, agricultural burning is not intended to damage forest areas, but may become uncontrollable and affect other land. Finally, as the name indicates, the causes of wildfires in the third category are unidentified.

TABLE 1.1: Classification of wildfire causes.

HUMAN INFLUENCE	CAUSES	EXAMPLE OF MOTIVE
Unavoidable	Natural Hazards	Lightning
Avoidable	Intentional	Clear scrubland Regenerate pastureland Identify property Change type of crop Revenge/reprisals Hunting Unknown
	Neglect or negligence	Agricultural burning Railway Authorized burns Fireworks Sparks from machinery Wildfire reproduction
Unclassified		

Source: Molano *et al.* (2007)

Many wildfires remain unclassified because forest researchers have been unable to discover the main cause. Nevertheless, it is possible to indicate that human activity influences motive with regard to wildfires. Additionally, due to technical or human issues, it has not been possible to attribute some wildfires to either natural hazard or human intentionality.

Many Galician wildfires are classified as intentional but the precise motive is unknown. Therefore, a socioeconomic analysis should be developed to identify the hidden factors that influence wildfire risk. Identifying these variables might lead to more effective public policies against wildfires. Researchers such as Balsa-Barreiro and Hermosilla (2013) or Barreal *et al.* (2011) looked at such variables in order to identify socioeconomic influences in Galician wildfire occurrence. The spatial patterns have been also highlighted in previous research relating spatial patterns with socioeconomic, climatic or environmental variables in other study areas (Chuvieco *et al.*, 2010; Romero-Calcerrada *et al.*, 2010). Even though wildfires and socioeconomic variables are heterogeneously related, however, forest policies can be applied in situations of spatial heterogeneity by designing specific policies for different geographical areas (Balsa-Barreiro and Hermosilla, 2013).

1.3. FOREST INSURANCE IN FOREST MANAGEMENT

Landowners can contract forest insurance to cover losses from wildfires affecting their forest stands. In Spain, this financial asset is subsidized by the national and regional governments, but seldom contracted by landowners in forest management. The low level of use might be related to coverage: at the present the public subsidy only covers restoration (BOE, 2011). The Spanish forest insurance program focuses mainly on public rather than private interests. It guarantees ecosystem production services by covering wildfire restoration costs to guarantee the next forest rotation, but does not cover timber damage.

In fact, insurance companies do not usually provide coverage for possible timber damage; if it were offered, it would be expensive for the landowner. However, forest insurance coverage is an important factor in forest management and restoration coverage provides the landowner with a degree of security. If current forest production is lost to a wildfire, landowners are guaranteed resources to begin the next forest rotation. Social preferences in restoration coverage may be high due to the guarantee of environmental services production in case of wildfire.

Forest insurance could be used to introduce better forest management practices to reduce wildfires. Forest certification could be used to guarantee proper forest management by requiring landowners to comply with forest certification criteria in order to obtain eco-labelling status (Nussbaum and Simula, 2005). This certification establishes a schedule for planting, cleaning and cutting set by official foresters according to land characteristics, in order to achieve optimal forest rotation in a suitable environment. A wildfire is not desirable for the insurer, so insurance policies would be developed to dissuade it. Forest certification requirements could be included in the policy as a wildfire prevention incentive. If a wildfire occurs and the policy-holder has not fulfilled forest certification requirements, the landowner will not be eligible to receive insurance compensation. Thus, eco-labelling would guarantee a specific level of forest management in order to reduce wildfire risk.

Researchers such as Holecy and Hanewinkel (2006), Brunette and Couture (2008), or Brunette *et al.* (2012), have analysed forest insurance in forest management and included the effect of public subsidies in forest management, along with information problems. However, there is no research that analyses the importance of each type of coverage or the effect of using forest certification as an insurance requirement. Even, none of previous forest valuation models include financial assets to cover possible forest losses. As it stands now, the relationship between forest valuation and insurance models has practically not been explored.

1.4. FOREST INSURANCE DEMAND

Forest insurance is rarely used as a forest management tool in Spain (Agroseguro, 2011), or in Galicia specifically. Insurance companies do not generally offer private insurance to landowners to cover wildfire losses. Given the low rate of contracting forest insurance, public policy may need to develop and promote insurance that addresses public and private interests and increases both coverage and requirements. Insurance coverage should include total or partial timber damage while requiring landowners to increase management efforts to reduce wildfire risk. Restoration coverage should also be maintained in forest insurance policies, implying a better balance of private and public interests. Forest management efforts could be controlled through forest certification requirements and eco-labelling that ensures proper forest management and increases timber value. In the current dissertation, these ideas will be developed and incorporated into the design of a new forest insurance model.

Landowners can either contract forest insurance or assume wildfire risk according to their own forest management efforts. In order to increase contracting, demand for forest insurance and landowner preferences (Boxall *et al.*, 1996; Adamowicz *et al.*, 1998) for insurance attributes will be analysed. This will involve a survey of forest owners or managers to better determine their willingness to pay for insurance attributes. By including both private and public interests in this insurance policy, the implications of public interest can be considered to improve the analysis of private insurance demand. Other insurance attributes could be also included in the policy to improve risk sharing between the insurer and the insured. Insurance companies could consider these mechanisms to determine exposure to wildfire risk and exert control over landowners' management. This dissertation also includes a survey that was conducted in order to analyse landowner preferences regarding a proposed insurance model.

Demand for forest insurance is also very low in Galicia, suggesting that landowners do not invest in securing their forest production. This situation could be influenced by the size of property, the dimensions of forestland or ignorance about forest insurance. Approximately one in three Galicians are landowners, and those working in agriculture are generally of advanced age (Marey *et al.*, 2007). This fact complicates the forest management, because elderly forest managers usually make decisions based on tradition and long experience in the primary sector. Since financial mechanisms do not exist in traditional management, they are seldom used to reduce forest investment risk. Such behaviour might be changed with informative campaigns.

There is no research that analyses forest insurance needs; hence further research is needed to provide information about insurance in order to increase its demand. The current policy could then be adapted to incorporate landowners' preferences, making forest insurance more attractive. Research will be conducted to analyse forest insurance demand in Galicia, based on questionnaires designed to uncover landowners' preferences with regards to the forest insurance. The survey will cover questions related to knowledge about the insurance policy and the type of policy landowners find more attractive. A choice experiment model will be used to calculate the willingness to pay for insurance attributes. This model uses choice cards that represent different insurance contracts, carrying different prices and attributes. These results will provide a baseline for designing a forest insurance policy that landowners would find attractive, thereby increasing its demand. The choice experiment is often used in research to evaluate social preferences regarding a specific environmental policy (Horne, 2006; Holmes *et al.*, 2012). This model has also been used to analyse preferences for other agricultural insurances (Nganje *et al.*, 2004; Mercadé *et al.*, 2009).

The age, gender or income of landowners could affect insurance demand. These characteristics are related to their experience and risk aptitudes in forest management. Landowners might act as owners and sole forest managers; they might be co-owners, or they might assign forest management to another. The goal of forest investment might be different for each kind of landowner, and all these characteristics can influence forest insurance demand.

1.5. State of the art

This dissertation will improve the knowledge about wildfire occurrence and forest insurance as a way of reducing such economic and environmental losses. Socioeconomic factors are included to better understand their influence on wildfire occurrence. Previous studies include socioeconomic variables, but their influence on the incidence of Galician wildfires has not been analysed (Chuvieco *et al.*, 2010; Romero-Calcerrada *et al.*, 2010). Environmental and climatic variables are used to describe wildfire patterns. The combined use of spatial patterns in Galician Forest Districts with socioeconomic variables in this dissertation is fairly new; until now econometric models have rarely been employed to analyse Galician wildfire occurrence. Therefore, this dissertation provides according to previous literature an innovative analysis of Galician wildfire risk and proposes preventions through public policy.

Traditionally, forest valuation has only considered forest management and production (Hartman, 1976; Reed, 1984). However, a new insurance model will be included in forest valuation in order to analyse its influence on landowner wealth. The previous section signalled how unusual forest insurance is in Spain; this model would improve Spanish forest management and it implies a novelty in forest valuation. This study also contributes to the design of effective forest insurance that covers timber damages in addition to restoration costs. In financial terms, the forest insurance proposed in this dissertation would influence financial decisions by covering 70% of timber damage and 95-100% of forest restoration costs. Researches in this area has generally focused on landowner decisions about forest management but has not contemplated the implications of forest insurance in forest valuation.

Previous forest valuation will thereby be extended and will include public preferences or objectives. Hence, a forest valuation is subdivided into private and public objectives in order to understand forest rotation and study the difference between private and public optimal forest rotation. In the private context, forest decisions are made by each landowner without considering public preferences. To address this, an incentive to produce environmental services will be considered as a way of linking private and public forest decisions. This new forest valuation model explores incentives for improving the alignment of forest decisions and societal preferences by providing landowners with a form of payment based on ecosystem services production (PES).

Finally, insurance demand for the previous policy will be studied. The forest certification requirement will be introduced into the forest insurance policy, as a way of guaranteeing proper forest management. No prior research has included this mechanism as a guarantee of proper forest management. For this reason, a choice experiment model will be used to identify landowners' preferences to forest insurance attributes. Likewise, the use of choice experiment and other econometric models constitute a novelty to study the forest insurance demand.

1.6. RESEARCH OBJECTIVES

The goal of the current dissertation is to analyse Galician wildfire risk and the application of insurance as a forest management tool. The main objectives of current dissertation are:

- To identify the socioeconomic and forest variables that influence Galician wildfire risk to improve the public policies
- To analyse both the spatial patterns and the temporal trends in Galician wildfires.
- To incorporate both insurance models and wildfire risk into forest valuation trends in order to analyse their forest rotation influence.
- To develop a forest insurance model that incorporates both public and private interests.
- To analyse the role of forest insurance as a payment for producing ecosystem services.
- To study the forest insurance demand in Galicia.

The dissertation contains six chapters. The first and final sections are the respective introduction and conclusion. The four intermediate chapters contain the research developments. The study process initiates with the second chapter, it analyses wildfire risk and its prevention. The third and fourth following chapters propose a forest insurance model and its implication in forest management, ecosystem services and public policies. The fifth chapter studies the relation between forest insurance demand and the proposed insurance model.

Chapter II of this thesis analyses the causes of wildfire in Galicia based on climatic, environmental, socioeconomic, temporal and spatial variables for Galician Forest Districts. Moran's I and the Local Indicator of Spatial Association (LISA) statistics are used to identify the relation between wildfire occurrence and spatial patterns. Econometric models are then applied to relate wildfire occurrence with climatic, environmental, socioeconomic and temporal variables. In particular, an OLS Regression is estimated to model the ratio of wildfires to burned area with a set of explanatory variables. Since the dependent variable is the number of wildfires (counted data), a Negative Binomial Regression model is estimated, after finding statistical evidence of overdispersion. Spatial patterns are analysed using Random Effects (RE) or Fixed Effects (FE) according to the results provided by the Hausman test. These models quantify the error term effect on econometric regression.

The third chapter develops a forest insurance model with restoration coverage that involves forest management and landowner investment. The proposed forest valuation model includes forest production, forest management costs, premiums and wildfire risk. All forest investment cash-flows are discounted by a continuous factor and the optimal forest rotation is analysed including the insurance policy. An empirical simulation is also developed for *Pinus pinaster* Aiton. plantations in Galician forest districts where high, medium and lower wildfire risk have been recorded.

The fifth chapter extends the insurance model presented in the third chapter. Private and public interests are considered in this model, leading to the inclusion of environmental services in forest valuation. This section analyses both private and public forest valuation models, but no relation was included between them. To address this, a public incentive is developed to involve landowners in the production of environmental services. This incentive relates both public and private interests in this theoretical model. Information from the previous chapter as well as carbon sequestration data are used to simulate the previous forest valuation model.

The fifth chapter analyses forest insurance demand in the area known as “A Mariña Lucense” (NW, Spain). A questionnaire is developed and a choice experiment conducted to analyse landowner preferences regarding forest insurance. Insurance cost, coverage of timber damage and/or restoration costs and a forest certification requirement are included on each choice card. Socioeconomic questions are also included in the survey. This makes it possible to analyse insurance demand according to the landowners’ characteristics. The Conditional Logit Model, and the Random Parameters Logit are used to calculate the WTP for forest insurance and its attributes according to choice card and landowner characteristics. The socioeconomic variables of the landowner’s age and relation to forest management were included in previous models.

Conclusions are presented at the final chapter of this dissertation. In this section, the main results of each chapter are summarized and discussed, as well as their usefulness in achieving the goals of the current dissertation. Following this discussion, there is a section that highlights the main conclusions and outlines suggestions for future research.

1.7. DERIVED PUBLICATIONS

Some publications derived from Chapter II of the current dissertation:

- Barreal, J., Loureiro, M.L. 2015. Modelling Spatial Patterns and Temporal Trends of Wildfires in Galicia (NW Spain). Forest Systems 24 (2), e022, xx pages. http://dx.doi.org/10.5424/fs/2015242-05713.
- Barreal, J., Loureiro, M., Picos, J. 2012. Estudio de la causalidad delos incendios forestales en Galicia, Economía Agraria y Recursos Naturales 12(1), 99-114. ISSN: 1578-0732, http://recyt.fecyt.es/index.php/ECAGRN/article/view/earn.2012.01.04/10340
- Barreal, J., Loureiro, M. 2012 Análisis espacial de la ocurrencia de incendios en Galicia durante 2006, Actas del V Congreso Forestal Español, ISBN: 978, 6CFE01-323, http://www.congresoforestal.es/fichero.php?t=41725&i=5153&m=2185

Published paper from Chapter III:

- Barreal, J., Loureiro, M., Juan Picos, J. 2014. On insurance as a tool for securing forest restoration after wildfires, Forest Policy and Economics 42, 15-23. ISSN 1389-9341, http://dx.doi.org/10.1016/j.forpol.2014.02.001

The two prizes for Chapter II and III are:

- Prize "Valentín Paz Andrade" of best contribution of Galician economy research for the paper "The causality of wildfires in Galicia" published in the Economía Agraria y Recursos Naturales 12(1).
- Prize of Best Presentation in V AERNA Conference for the research "On insurance as a tool for securing forest restoration after wildfire occurrence".

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CHAPTER 2: MODELLING SPATIAL PATTERNS AND TEMPORAL TRENDS OF WILDFIRES IN GALICIA (NW SPAIN)

Abstract: The goal of this paper is to analyse the importance of the main contributing factors to the occurrence of wildfires. We employ data from the region of Galicia during 2001-2010; although the similarities shared between this area and other rural areas may allow extrapolation of the present results. To this end, we conduct an econometric analysis modelling both, the number of fires and the relative size of afflicted woodland area as dependent variables, which depend on the climatic, land cover variables, and socio-economic characteristics of the affected areas. Fixed effects and random effect models are estimated in order to control for the heterogeneity between the Forest Districts in Galicia. Based on the obtained results, we conclude that in addition to direct forest actions, other agricultural or social public plans, can help to reduce wildfires in rural areas or wildland-urban areas. Based on these conclusions, a number of guidelines are provided that may foster the development of better forest management policies in order to reduce the occurrence of wildfires in rural areas.

Keywords: Cause-effect relationship, climatology, spatial and temporal indicators, fixed effects, random effects, socio-economic factors.

2.1. INTRODUCTION

It is estimated that more than 1.3 million hectares of forest are destroyed by wildfires in Europe each year (FOREST EUROPE, UNECE and FAO, 2011). Spain is one of the five southern European countries with the highest level of damage caused by wildfires, with a yearly average of 19,705 wildfires from 1998 to 2007, affecting a total of 130,714 hectares (SECF, 2010). Within Spain, the case of Galicia is particularly relevant. While only representing 6% of national surface area, between 1991 and 2010 Galicia registered an approximate average of 46% of Spanish wildfires and 21% of the total burned surface area (Figure 2.1), according to MARM (2012) and the regional government (Xunta de Galicia, 2011). Given the geographical concentration of this problem, we limit our analysis to the wildfires occurring in this region, also due to the lack of comparable data for other Spanish regions. We believe, however, that the current paper may provide insights which are closely applicable to other European rural and wild land-urban areas.

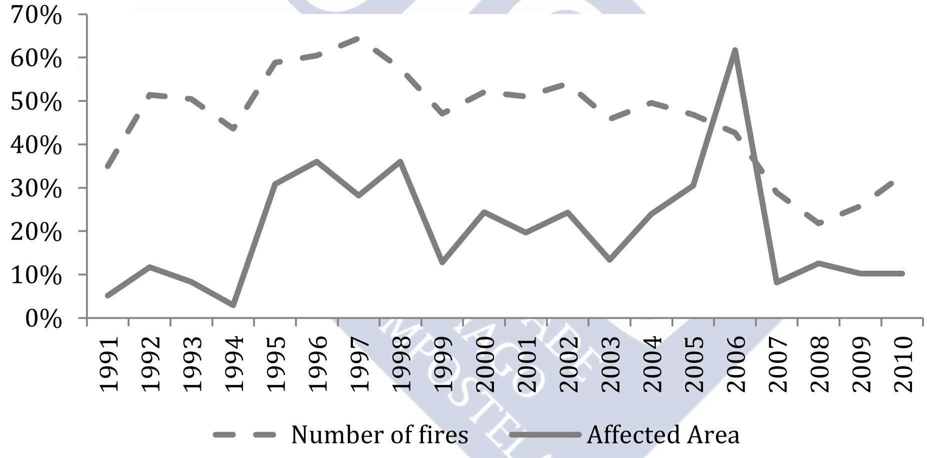

FIGURE 2.1: Galician wildfires with respect to the total number of Spanish wildfires (1991-2010).

According to data provided by the Galician Institute of Statistics (IGE, 2012a), since 2001 the number of wildfires reveals an upward trend until 2005, decreasing then in number. With regards to the affected surface area, this increased gradually from 2002 to 2006, but since then it has decreased considerably as well. It should be noted that the number of affected areas reach catastrophic levels during 2006. Furthermore, the evolution of wildfires throughout Galicia varies considerably in spatial and temporal terms (Fuentes-Santos *et al.*, 2013). Geographically, and based on the data published by the IGE (2012a), wildfires affect more severely southern districts than northern districts of Galicia, both in terms of the number of fires and forestry area affected (Figure 2.2). Also, western districts are the area in which forestry lands are the most affected in relation to their surface area, while the southern districts record the highest numbers of wildfires.

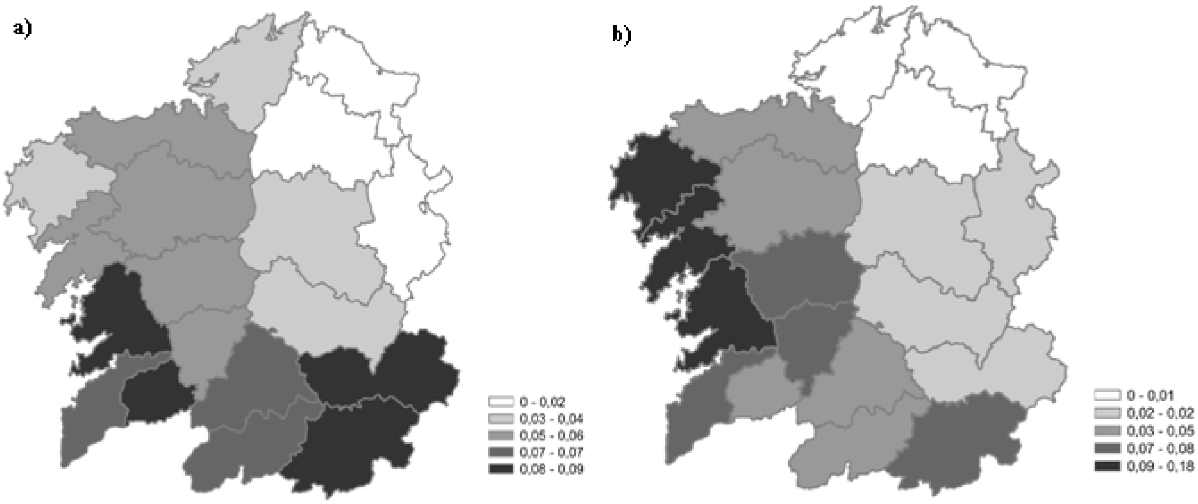

FIGURE 2.2: Geographic distribution of the occurrence of wildfires during 2001-2010. a) Representation of the number of wildfires per district with respect to the total number of Galician wildfires. b) Representation of the affected forestry area per district with respect to total affected area in Galicia.

The wildfire risk depends on several climatological, social or environmental factors, which could be modified by public policies at short or medium term. Nevertheless, decision-making is characterised by the presence of dynamic risk factors (Rogalski, 1999)[1].

In order to study wildfires in depth, it is necessary to be aware of the current situation of the agro-forestry areas in Galicia. Certain areas have scattered populations with a constant rural depopulation and continuing migration of young people to more highly populated areas (Marey *et al.*, 2007). In addition, the thinning out of the agro-forestry sector within the economy has been clear for some time now, as well as the reduction in employment in this sector. This has contributed to make much more difficult youth employment in the countryside, while at the same time, fewer farms use woodland areas to obtain productive resources (Vega, 2007; Sineiro, 2006). This trend has also caused forestry land to become increasingly neglected, allowing for an increase in the severity and spread of wildfires. Moreover, the structure of forest property is often very divided, with a high level of private

[1] Following Molano *et al.* (2007) and Martínez *et al.* (2009), the causing factors of wildfires can be divided into two main categories: avoidable and unavoidable. Unavoidable causes are considered those that cannot be foreseen or dissuaded, whereas avoidable causes are those that can be prevented through individual actions or forestry policies. This implies that there are exogenous factors, which are uncontrollable, to which other endogenous factors must be added. In general, the unavoidable category contains natural phenomena, whilst the avoidable can be divided into three possible sub-categories: intentional, negligent and unknown causes. Avoidable causes represent almost all of the causes, although the majority of these are classified as unknown, showing that the causality of wildfires is not recorded reliably and depends heavily on the criteria of investigators (Pérez and Delgado, 1995; and Molano *et al.*, 2007).

property increasingly belonging to elderly people, making it more difficult to manage the lands correctly (Sineiro, 2006).

Galicia contains different climatic areas, resulting in an uneven availability of biomass that can be burnt (Martínez *et al.*, 1999). This makes it difficult to organise the prevention and extinguishing of wildfires. Taking these circumstances into account, together with the social and environmental impacts caused by wildfires, over the last few years the government has prioritized the design of preventative policies, although most of its budget goes toward extinction activities. For these policies to work well, it is important to identify the factors that affect the occurrence of wildfires. To this end, the proposed model must be simple, structured and easy to standardise so that it can be easily updated (King and MacGregor, 2000).

Until now, several methods have been used to identify wildfire risk factors. Some studies have used various explanatory variables in order to explain the reasons why some areas are more heavily affected than others, although they do not quantify the described relationships and/or support their arguments in a quantitative way (Lavorel *et al.*, 2007). However, other papers use techniques based on Geographic Information Systems (GIS), using probability risk models and linking variables to the forest environment. (Cabrera, 1989; Vilar *et al.*, 2008; Chuvieco *et al.*, 2010; Martínez *et al.*, 2009; Romero-Calcerrada *et al.*, 2010). GIS techniques are used in several models in which geographic and other statistical variables are included (Pew and Larsen, 2001; Vega-García and Chuvieco, 2006). Relevant geographic variables include the location of roads, and industrial or recreational areas, amongst other factors (Romero-Calcerrada *et al.*, 2010). Therefore, geographical implications in the occurrence of wildfires have also been widely studied. As a result, this study focuses on assessing the geographical differences in the occurrence of wildfires.

In some earlier work, researchers have studied the error term to identify geographical and temporal trends (Disdier and Head, 2008; Prestemon *et al.*, 2002; Jones, 1991; Moulton, 1986). Testing the error term allows the researcher to control for the unobservable factors across the different entities, implying that this research can be used to determine whether differences across entities are significant. Therefore, an econometric model with random effects (RE) or fixed effects (FE) can be developed in order to account for specific local effects. Other papers explore the possible relationship between wildfires and a specific group of variables (Finney *et al.*, 2009), including forest management (Prestemon *et al.*, 2002; Butry, 2009; Wimberly *et al.*, 2009), meteorological variables (Aguado *et al.*, 2007), and socio-economic factors (Mercer and Prestemon, 2005). This research, as well as Prestemon *et al.* (2002), uses time series models to analyse temporal trends in wildfire risk. Other relevant research also includes socioeconomic variables such as income, machinery used, and/or number of livestock (Vilar *et al.*, 2008). Wildfire risk is also analysed from the perspective of the different phases in the duration of a fire, and the ignition, intensity or area affected are used as dependent variables (Genton *et al.*, 2006).

Several international studies analyze the problem of fires from a spatial context. For example, Prestemon *et al*. (2002) developed a model with fixed effects as to assess whether there is a spatial behavior in the occurrence of fires between administrative units from North Florida. Preisler *et al.* (2004) used temporal and spatial effects through a logistic regression to study the probability of fires in Oregon (USA) since 1970. Meanwhile, Brillinger *et al*. (2006) developed an empirical model for analyzing the evolution of fire risk. Their model contains both, FE and RE to analyze the fires occurrence in California (USA) during the years 2000-2003. Finally, Chen *et al.* (2014) also analyze the risks and causes of fires using spatial econometrics.

The aim of this study is to extend previous analyses using current data and taking into account the impact of socio-economic factors, land cover, and climatology using spatial analysis. Thus, econometric models have been developed to analyse the possible influence of socioeconomic factors on the risk of wildfires. The Ordinary Least Square (OLS) and econometric models for counted data are used to identify these socioeconomic factors. Random effects (RE) and Fixed Effects (FE) are also estimated to assess the presence of spatial patterns. Other methods, such as the Moran's I and LISA statistics, are included to determine whether wildfire occurrence shows spatial patterns. We expect the present results can help to improve public policy focussing on exploring spatial and temporal impacts on fire occurrence. This research starts by explaining the data and methods used. In the next section, the results are described and discussed, and then it follows a section in which the main conclusions of the research are summarized and policy implications are provided.

2.2. MATERIALS AND METHODS

2.3. DATA

Data have been gathered from 2001 to 2010. The most up-to-date data available from the 19 forest districts established by the Galician regional government were collected (Xunta de Galicia, 2011). Variability over time and between districts will be one of the desirable data properties (Cameron and Trivedi, 2009). Data have been grouped by forest districts in order to have a common geographical reference. Therefore, some variables had to be transformed prior to be included into the model by aggregating municipal data up to the district level. In the following analysis, the hectare is the unit used to measure the surface area.

The explanatory variables are shown in Table 2.1, and these can be grouped into seven main categories, including: the population structure, weather variables, territorial features, economic information, agroforestry situation, wildfire characteristics and time dummy variables. To avoid perfect multicollinearity in the econometric models, the dummy year for 2001 has been used as a baseline, and time effects are interpreted by using this year as a reference point. As several variables for different groups showed high correlations with each other, a limit of 70% was set for the value of the linear correlation coefficient. Furthermore, the variance inflation factor (VIF) was used to analyse the level of multicollinearity among the chosen variables (Neter *et al.*, 1983). The VIF had values lower than 2.16 for each variable and 3.70 for the set. These values indicate that multicollinearity is not a problem in the selected variables.

Wildfires data were recorded from the Galician Forest Districts. On the other hand, meteorological data were recorded directly by the weather stations, and such data had to be linked and extrapolated to the District level. Finally, the agro-forestry data are mainly recorded by Geographic Information Systems (GIS). Thus, a shape-file with the Galician Forest Districts was designed adding the municipality limits obtained from the National Geographic Institute (IGN, 2011). To conclude, agro-forestry data were obtained cropping GIS information with the previous defined shape-file.

The data for the climatic variables were collected from MeteoGalicia (2012). The climate stations belonging to each district were geographically located. The average maximum temperature and rainfall recorded per month during the summer were collected[2]. The proportion of the protected areas in each district was also included to describe relevant territorial features. The protected areas were obtained from the MAGRAMA (2010). These data were provided by two maps containing the Community Interest Sites (CIS) and Special Protection Areas for Birds (SPAB). Thus, the GvSig software was used to compute the size of both protected areas by Forest District (GvSig, 2014). In this way, the ratio of protected areas is computed using the total protected area divided by total district area.

The density per hectare is used to describe the population structure. Therefore, the total population divided by the total Forest District area is used to calculate this variable. Both data

[2] In some cases, climatological data were not available for all of the time periods and/or forest districts. The unavailable data had to be supplemented with those from other forest districts according to the climatic areas established by Martínez *et al.* (1999).

were recorded from IGE (2012a) and municipality statistics. This density variable presents high correlations with the personal income, level of studies or employment rate. In order to avoid such multicollinearity problems, variables referring to personal income, education and employment rates had to be dropped from the final specification due to their high correlations among each other.

TABLE 2.1: Variables.

VARIABLE	DESCRIPTION	DATA SOURCE	MEAN	STANDARD ERROR	MIN	MAX
WILDFIRES CHARACTERISTICS						
Number of wildfires	Number of wildfires per year in each district[1]	IGE	381.179	275.987	23.000	1,268.000
Ratio of burned-forest area	Affected area, in hectares, between the total forestry areas in each district	IGE	0.017	0.030	0.000	0.223
CLIMATOLOGY						
Summer average rainfall	Annual average rainfall during the summer (l/m^2)	MeteoGalicia	43.217	19.821	13.55	120.917
Summer maximum temperature	Average maximum temperature, in Celsius, during the summer in each district	MeteoGalicia	22.946	2.663	16.747	30.367
SOCIO-ECONOMIC VARIABLES						
Territorial						
Ratio of protected areas	Total protected areas over the total Forest District area	MAGRAMA[2]	0.140	0.142	0.011	0.474
Population						
People Density	People by hectare in each Forest District	IGE	1.049	1.163	0.104	5.081
Agro-Forestry						
Ratio of equine stock	The ratio of equines in Forest District livestock	IGE	0.036	0.028	0.004	0.110
Ratio of natural pasture	Total natural pasture area over the District area	CORINE	0.113	0.074	0.006	0.294
Ratio of *Pinus pinaster*	Total *Pinus pinaster* area over the forested area by District	IFN3	0.390	0.201	0.044	0.831
Economy						
Agricultural cooperatives	Number of cooperatives in each Forest District	IGE	18.158	13.627	2.000	49.000
DUMMY VARIABLE						
Dummy year t[3]	Represents each individual year t		1.100	0.301	1.000	2.000

[1] Forest administrative entity determined by Xunta de Galicia (Xunta de Galicia, 2011)
[2] Ministry of Agriculture, Nature and Food Quality
[3] t= (2002,…,2010)

The Third Spanish National Forest Inventory (NFI3), the Corine Land Cover and the Livestock Census were the main sources to gather information about the agro-forestry situation (IGE, 2012b). Tree dominant tree species were recorded in order to describe the forest plantations. The forestry areas, in which the *Pinus pinaster* is the main specie, were calculated from the NFI3 (MAGRAMA, 2008) while the district-forested areas were recorded from IGE (2012b). Hence, the ratio of *Pinus pinaster* was included in order to describe the forestry structure. The natural pasture was obtained by accounting for the lands where this activity is recorded according to the Corine Land Cover database (European Environment Agency, 2010). The GvSig software was employed to calculate both the agricultural and forestry area (GvSig, 2014). The ratio of equines was also taken into account in order to describe the livestock structure, as in Barreal *et al.* (2011). This variable was considered given that previous literature related the presence of equines with land management and fuel treatments (Rigueiro *et al*., 2002). The percentage of equines represents 1% up to 11% of total livestock according to each Forest District data (IGE, 2012b). Although cattle are the main livestock in Galicia; equines usually graze in pasturelands or forest areas. The number of agricultural cooperatives is also included in the model. This variable can be a proxy for the dynamics of the rural areas. These data were collected from IGE (2012b). However, we should note that there are some years in which yearly data are missing, so that the series had to be completed with the closest data points available.

The wildfire variables were also obtained from the IGE (2012b). For the first six years, municipalities provided the data, then the burned area and the number of wildfires had to be aggregated by forest districts. The ratio of burned area was calculated using the total forest area provided by IGE (2012a). The GeoDa software was used to obtain the spatial statistics of the dependent variables (Anselin *et al*., 2006; GeoDa, 2014). In order to create the final database, and conduct the estimation process, the Stata 10.1 software was used (Stata, 2010).

2.4. METHODOLOGY

2.4.1 Descriptive Spatial Analysis

Graphs and statistics are useful in order to identify the spatial patterns in Galician wildfires. The first one involves the representation of the data to identify the temporal trends and the heterogeneity between the Galician forest districts. Then, in case of existing temporal trends, these could be identified showing differences of each entity's mean value. Another alternative is to represent the data for each year by a graph. The independent years could register more or less spatial differences.

The Moran's I statistic (Moran, 1948) was used for statistical analysis, as well as the Local Indicators of Spatial Association -LISA- (Anselin, 1995). With both statistics, the spatial dependence can be analysed using the autocorrelation coefficients between the Galician forest districts. The first statistics analyses the spatial heterogeneity of the sample. Meanwhile, the second focuses on the relationship between each geographic unit, identifying the clusters of study.

The Moran's I statistic takes into account the number of geographical areas (N); the analyzed areas (j and i); the study variable for each location (y); the mean of the variables of interest in all areas ($\bar{y}$); and finally the weight matrix that describes the relationship between both locations ($W_{j,i}$). Then, the Moran's I statistic could be expressed by the Eq. 2.1.

$$I = \frac{N}{\sum_i \sum_j W_{ij}} * \frac{\sum_i \sum_j W_{ij} \left(y_i - \bar{y}\right)\left(y_j - \bar{y}\right)}{\sum_i \left(y_i - \bar{y}\right)^2} \qquad [2.1]$$

According to the definition of the weight matrix, the relations between close forest districts are included. Therefore, the closest neighbors to each polygon are identified with this matrix. Mathematically, the weight matrix could be expressed as Eq. 2.2, in which $\hat{w}_{ij}$ represents the spatial matrix of adjacent polygon (j), respect to the polygon that we are studying (i).

$$w_{ij} = \frac{\tilde{w}_{ij}}{\sum_j \tilde{w}_{ij}} \qquad [2.2]$$

The spatial relationships in this matrix can be used with different contiguity interpretations. In other words, if a regular grid is designed, the weight matrix could be constructed according to four spatial relationships: linear (Fig. 2.3.a), Rook (Fig. 2.3.b), Bishop (Fig. 2.3.c) and Queen (Fig. 2.3.d). These relations depend on the number and directions of spatial dependences that the researchers may find. In this research, the polygons are irregular, so the criterion with more spatial directions is selected (Moreno and Vayá, 2000), and as a consequence, the queen contiguity is chosen to analyze the spatial patterns. This contiguity can be used at several levels (Lesage and Kelley, 2009). This research analyzes the direct relationships between the closed forest districts in terms of fire occurrence.

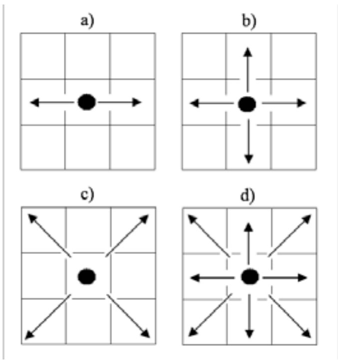

FIGURE 2.3: Types of contiguity for direct relations.

The LISA statistics can be developed from the Moran's I statistics (Anselin, 1995). This is described in the Eq. 2.3 where z_i represents the normalized value of the selected variable in respect to the mean and J_i is all polygons (districts) next to *i*. Therefore, the LISA statistics analyzes the spatial patterns between each entity to the selected data. In other words, the spatial autocorrelation is individually analyzed.

$$I_i = \frac{z_i}{\sum_i z_i^2 / N} \sum_{j \in J_i} W_{ij} z_j \qquad [2.3]$$

2.4.2 Econometric Analysis

In order to analyse the relationship between the previous variables and wildfires in Galicia, a baseline lineal regression estimated by OLS was used. In this baseline estimation the coefficients are controlled by the heterogeneity of each district through the Huber-White correction of standard errors (Cameron & Trivedi, 2009). Thus, the econometric model is presented by Eq. 2.4, in which the variables are arranged into a panel according to each district and their respective periods of time. In this equation, the subscripts *j*, *k*, *h* represent the type of variable, *i* is the forestry district, and *t* is the period.

$$Y_{it} = \beta_0 + \beta_j X_{jit} + \beta_k X_{kit} + \beta_h X_{hit} + \varepsilon_{it} \qquad [2.4]$$

With this common specification, two independent equations were estimated. The first model used the ratio of forest-burned area in each forest district as the dependent variable, and the second specification modelled the number of wildfires. The independent variables in both models include socio-economic factors represented by X_{jit}, (mainly population structure, territorial features, economic information and agroforestry data for each forest district), climatology represented by X_{kit} (including the variables of average maximum temperature and average monthly precipitation); and finally, the vector X_{hit} represents the dummy yearly indicators.

Using the Box-Cox test, the functional form of the Eq. 2.4 was selected. The Box-Cox test develops a transformed dependent variable represented by the Eq. 2.5, in which the residual (μ_{it}) assumes a normal distribution in order to estimate the parameters β and θ.

$$g\left(y_{it}|\theta\right) \equiv \frac{y_{it}^{\theta}-1}{\theta} = X_{it}\beta_i + \mu_{it} \qquad [2.5]$$

As such, if the estimation of θ is close to zero, then the best specification to be used would be the log-lineal model. However, if the respective statistics are significant and close to one, a lineal model should be used. Eq. 2.6 is then formulated according to the following specification.

$$Y_{it} = \beta_j X_{jit}^{\lambda} + \beta_k X_{kit}^{\lambda} + \gamma_h X_{hit} + \varepsilon_{it} \qquad [2.6]$$

Since, the number of wildfires is a counted data variable, the Poisson Regression Model (PRM) shown on Eq. 2.7 is employed, with the specification earlier presented in Eq. 2.4:

$$E\left[y_{it}|x_{it}\right] = \exp\left(\beta_0 + \beta_j X_{jit} + \beta_k X_{kit} + \beta_h X_{hit}\right) \qquad [2.7]$$

Given that count data can exhibit overdispersion (Cameron & Trivedi, 2005), we need to assess whether this is present by estimating Eq. 2.8. Overdispersion implies that the variance depends on the mean plus square parameter (α^2). In this case if $\alpha = 0$, then the variance is equal to the mean and there is no overdispersion; and thus, the PRM can be a suitable model.

$$\mathrm{Var}\left(y_{it}|\mathrm{x}_{it}\right) = \mathrm{E}\left(y_{it}|\mathrm{x}_{it}\right) + \alpha^2 \mathrm{E}\left(y_{it}|\mathrm{x}_{it}\right) \qquad [2.8]$$

On the other hand, if the coefficient α is different from zero, then the number of wildfires should be estimated by a Negative Binomial Regression model (NBRM). This model is more general than the PRM and should prove to have a better goodness of fit in case of overdispersion (Cameron and Trivedi, 2009).

In order to interpret the coefficients of the previous model, the use of the Incidence Rate Ratio (IRR) is recommended as its results are easier to interpret (Long and Freese, 2001). As such, the IRR coefficients are estimated to directly quantify the values of the respective parameter estimates. This ratio is calculated by Eq. 2.9, in which the results can be analysed as a change in the probability of wildfire occurrence, when there is a change in the analysed independent variable, whenever the others parameters are constant.

$$IRR = \frac{E\left(y \middle| x, x_{it} + 1\right)}{E\left(y \middle| x, x_{it}\right)} = e^{\beta_i}$$ [2.9]

In this setting, two different models could be used to analyse the error term: FE and RE. The FE represented by the Eq. 2.10 in which the error term (ε_{it}) of the Eq. 1.4 is broken into two parts: one fixed term (v_i) and another error term (τ_{it}).

$$Y_{it} = \beta_0 + \beta_j X_{jit} + \beta_k X_{kit} + \beta_h X_{hit} + \nu_i + \tau_{it}$$ [2.10]

In the following RE models, the previously fixed term ($\boldsymbol{v}_i$) is now random. The specification of this model is equal to Eq. 2.10, but in this case the random term will have a mean of v_i and different variance from zero (Var($\boldsymbol{v}_{it}$)≠0). These unobservable factors are used for the OLS model but also for the MRP (Eq. 2.11), or NBMR in case of overdispersion.

$$E\left[y_{it} \middle| x_{it}\right] = \exp\left(\beta_0 + \beta_j X_{jit} + \beta_k X_{kit} + \beta_h X_{hit} + \nu_{it}\right)$$ [2.11]

The Hausman test (H) is used to select between RE and FE models. The specification of this test is shown in Eq. 2.12 and analyzes the consistency of estimators for both models. The null hypothesis states that there is no correlation between the unique errors and the independent variables. This hypothesis is tested at the 5% significance level. If the null hypothesis is not rejected, then FE are selected over RE. Otherwise, RE should be used.

$$H = \left(\beta_{RE} - \beta_{FE}\right)' \left[Var\left(\beta_{RE}\right) - Var\left(\beta_{FE}\right)\right]\left(\beta_{RE} - \beta_{FE}\right) \qquad H \sim \chi_n^2$$ [2.12]

2.5. RESULTS

2.5.1 Spatial patterns and temporal trends analysis

The spatial patterns of the number of wildfires and burned-forest area ratio can be observed with graphical displays. The variation of the burned-forest area ratio by year is represented in the Figure 2.4.a In this graph the x-axis represents the Galician forest districts according to each number (Xunta de Galicia, 2011). Different values between the districts are recorded in all graphs; however its difference depends on the year. Another way to identify the existence of spatial patterns is by using the average of the burned-forest area ratio for the sample. This is included in the Figure 2.4.b where the difference between districts can be observed. Also, the temporal trends are observed per year.

b)

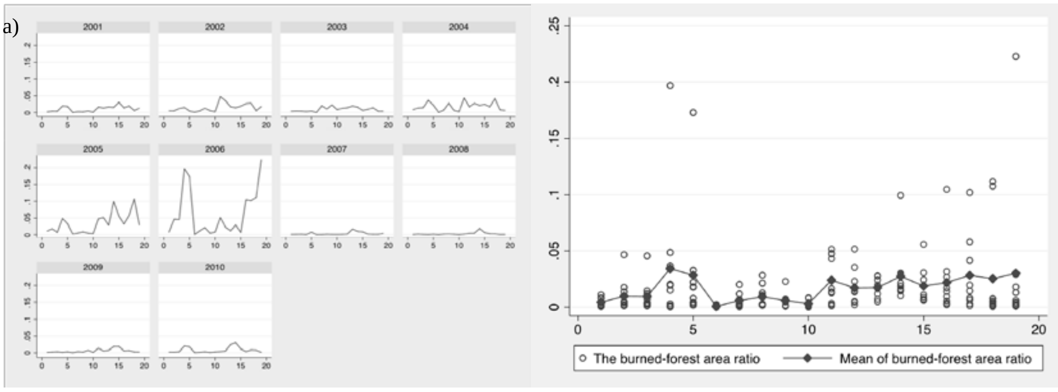

FIGURE 2.4: Graphical representation for variation of burned-forest area ratio in Galicia from 2001 to 2010. a) Data represented by year. b) Data recorded by year and the mean of each district.

Figure 2.5.a and Figure 2.5.b describe the evolution of wildfires per year from 2001 to 2010. The spatial patterns can be identified in this graph. Figure 2.5.b shows also spatial patterns in the mean of wildfires according to each district. Data show significant differences across years, therefore the number of wildfires contains also temporal effects.

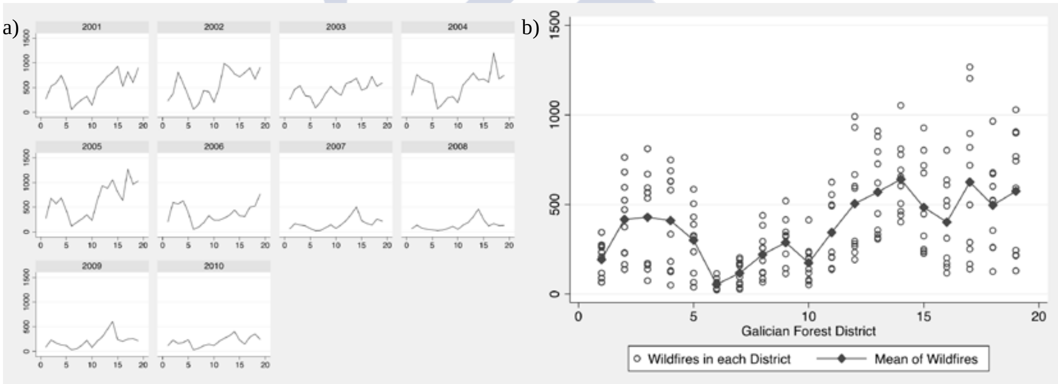

FIGURE 2.5: a) The number of wildfires represented by year in Galicia from 2001 to 2010. b) The number of wildfires recorded each year according to Galician Forest Districts from 2001 to 2010.

A weight matrix should be constructed to develop the spatial statistics. As stated earlier, the direct Queen contiguity is selected to analyse the relationship between districts (Fig. 2.3.d) and its histogram is represented in Figure 2.6. In this graph, it can be observed the lowest and highest contiguity between forest districts. Thus, Galician forest districts have at the minimum two influential neighbours and six as a maximum. This histogram also highlights a big number of districts with six entities around them. However, the biggest contiguity group has only three neighbours.

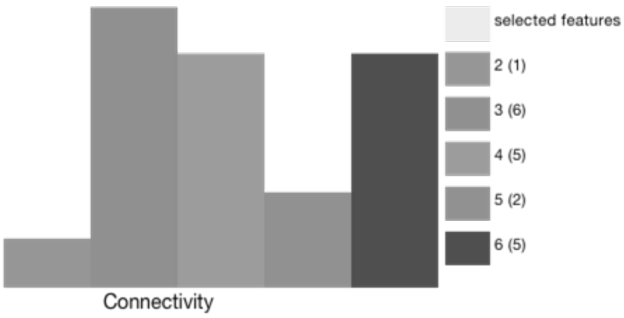

FIGURE 2.6: Histogram of contiguity according to Level 1 for Galician Forest District.

The Moran's I and LISA statistics are used to analyse the spatial patterns of wildfires and the yearly burned-forest area ratio in Galicia. Figure 2.7 reports the Moran's I statistic by year, and its average for the entire sample. It can be observed that Moran's I registers higher values for the number of wildfires than for the ratio of burned-forest area. Thus, more spatial autocorrelation is detected for the number of wildfires than for the ratio of burned-forest area. Also, in 2007 no spatial correlation is found for burned-forest area. This may be explained because in 2006 wildfires affected many areas (Molano *et al.*, 2007). This caused social alarm, therefore over the next year, the wildfires occurrence has been drastically reduced. Even the recorded data for the burned-forest area diminished a 97% in 2007 with respect to 2006.

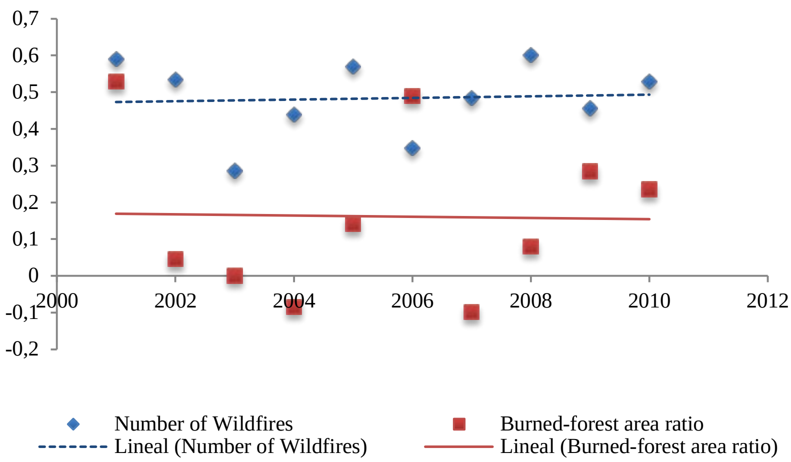

FIGURE 2.7: The Moran's I statistic for the burned-forest area ratio and the number of wildfires recorded in Galicia during 2001-2010.

The LISA statistic represents the various significant spatial patterns as follows (Anselin, 1995; Lesage and Kelley, 2009):

- High-High (H-H): a particular forest district and their neighborhoods have high values. This type of relationship is represented by the red color.
- High-Low (H-L): a particular forest district has high values and their neighborhoods

have lower values. This type of relationship is represented by the pink color.

- Low-High (L-H): is similar to the previous category, but in this case the forest district has high values and their neighborhoods have lower values. This type of relationship is represented by the sky-blue color.
- Low-Low (L-L): the forest district and their neighborhoods have low values. This type of relationship is represented by the blue color.

The remaining values are represented by a grey color because these entities have a random relationship (Moreno and Vayá, 2000). Figure 2.8 represents the LISA statistics related to each dependent variable. The colored results are significant at the 5% level. Taking into account the burned-forest area ratio, the LISA statistics is represented in Figure 2.8.a. In each map the LISA statistic for each district is represented according to the relation with its neighborhoods. With this result, the Low-Low (L-L) relation is mainly recorded in the North of Galicia, although, this relationship was also recorded in the South for some particular years. However, the High-High (H-H) relationship occurs primarily in the South. Thus, Southern forest districts and their neighbourhoods record high values of burned-forest area ratio.

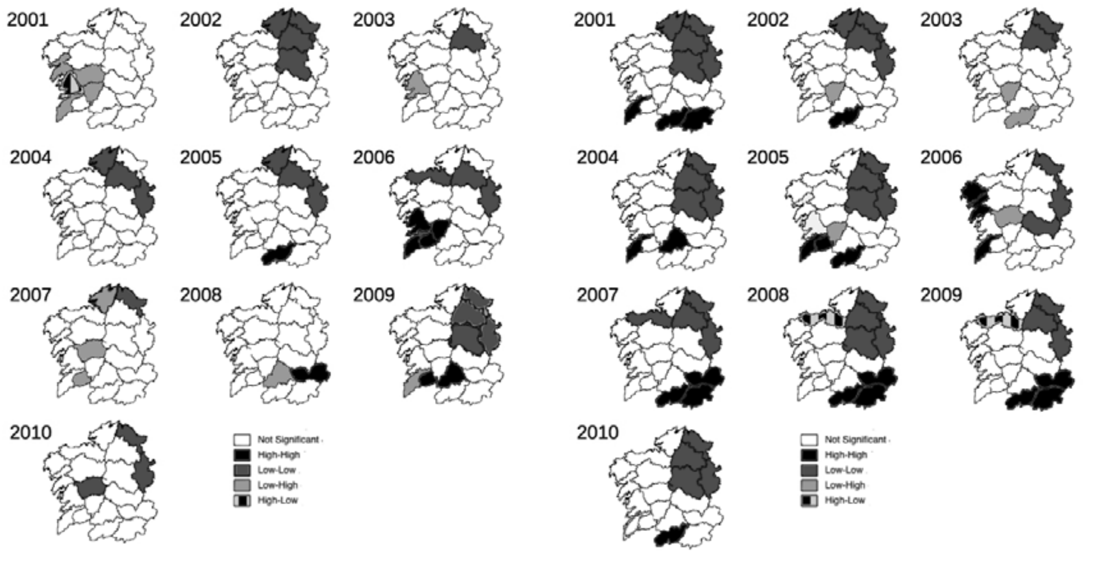

FIGURE 2.8: a) LISA statistic for the burned-forest area ratio in Galicia during 2001-2010. b) LISA statistic for the number of wildfires in Galicia during 2001-2010.

In order to analyze the number of wildfires, the LISA statistics are shown in Figure 2.8.b. In these maps the Low-Low (L-L) relationship could be observed in the Northeast districts. On the other hand, Higher-Higher (H-H) relations are recorded in the South and Southeast. Therefore, there is evidence of spatial patterns in the number of wildfires.

All previous graphs and statistics show the existence of relevant spatial patterns and temporal trends. Therefore, these should be included in the econometric model for both dependent variables. The temporal trends are included in the empirical models by using dummy variables for each year, considering 2001 as the baseline year. On the other hand, in order to correct for spatial patterns in the research, data are set according to a panel of forest districts and controlling the heterogeneity by district through standard errors correction. The spatial patterns are also analyzed using FE and RE models.

2.5.2 Econometric models results

a. Results for the burned-forest area

In order to specify the most suitable econometric model to analyse the evolution of the burned-forest area ratio, a Box-Cox test was estimated (Cameron and Trivedi, 2009), being its results reported in Table 2.2. A logarithmic model is used in accordance with the results obtained in the Box-Cox test. In other words, the statistics could not reject the logarithmic specification both for the dependent and independent variables.

TABLE 2.2: Box-Cox test for the regressions of the ratio of burned-forest area**.**

DEPENDENT VARIABLE				INDEPENDENT VARIABLES			
Test H_0	Restricted log likelihood	LR Statistic chi^2	P-value (Prob > chi^2)	Test H_0	Restricted log likelihood	LR Statistic chi^2	P-value (Prob > chi^2)
$\Theta = -1$	360.932	742.700	0.000	$\lambda = -1$	445.396	9.150	0.002
$\Theta = 0$	732.266	0.030	0.859	$\lambda = 0$	449.422	1.100	0.295
$\Theta = 1$	448.330	567.900	0.000	$\lambda = 1$	448.330	3.280	0.070

Following the results displayed in Table 2.3. the estimation by OLS captures 69.04% of the variation of the burned forest area rate. Taking into account the F-statistic, we find that all parameters are jointly significant. As regards the choice between the use of FE and RE in the previous models, the Hausman test recommends the use of RE to estimate the burned-forest ratio model (Prob>chi2= 0.98).

The dummy variables determine significant effects over several years. A positive trend is identified from 2002 to 2006. The majority of dummy variables are significant and positive with respect to the 2001 year. However, after 2006, the trend is clearly negative and significant for all years. These results are robust across the econometric selected models.

The climatological variables show in particular the importance of rainfall in order to reduce the burned-forest area ratio. This variable is significant carrying a negative effect in the causes of wildfire occurrence. Thus, the average effect of rainfall on burned-forest areas ratio is -0.643, when the precipitation changes by one unit over time and between districts. However, the maximum temperature has a positive effect, although this variable is not significant in order to predict the burned area. The small variability in this variable may be responsible for this finding.

In terms of socioeconomic variables, the ratio of the equines and the number of agricultural cooperatives have both a negative and significant effect on the burned-forest ratio area for the OLS and RE models. Their effects show that if the value changes over time and between districts by one unit, then the average effect of equine radio stock and the number of agricultural cooperatives over the burned-forest area will respectively decrease by a factor of -0.385 and -0.555.

TABLE 2.3: Econometric results for the regressions of burned-forest area.

	OLS		**OLS WITH FE**		**OLS WITH RE**	
	Coef,	P>t	Coef,	P>t	Coef,	P>t
Dummy 2002	0.418	0.046	0.314	0.208	0.357	0.146
	(0.195)		(0.248)		(0.246)	
Dummy 2003	0.173	0.531	0.263	0.301	0.241	0.334
	(0.270)		(0.253)		(0.249)	
Dummy 2004	0.659	0.003	0.681	0.006	0.698	0.004
	(0.1949		(0.245)		(0.243)	
Dummy 2005	0.883	0.000	0.912	0.001	0.942	0.000
	(0.179)		(0.263)		(0.256)	
Dummy 2006	1.172	0.001	1.188	0.000	1.230	0.000
	(0.291)		(0.267)		(0.259)	
Dummy 2007	-1.037	0.002	-1.288	0.000	-1.126	0.000
	(0.290)		(0.271)		(0.259)	
Dummy 2008	-1.557	0.000	-1.827	0.000	-1.632	0.000
	(0.227)		(0.265)		(0.251)	
Dummy 2009	-0.738	0.004	-0.739	0.048	-0.731	0.011
	(0.226)		(0.371)		(0.287)	
Dummy 2010	-0.797	0.005	-0.751	0.044	-0.732	0.008
	(0.248)		(0.369)		(0.277)	
Summer average rainfall	-0.576	0.000	-0.720	0.000	-0.643	0.000
	(0.130)		(0.189)		(0.176)	
Summer maximum temperature	1.043	0.297	-0.749	0.552	-0.215	0.838
	(0.970)		(1.256)		(1.051)	
Ratio of natural pasture	0.119	0.405	0.000		0.084	0.695
	(0.139)		(omitted)		(0.215)	
People Density	0.344	0.026	-2.651	0.272	0.266	0.302
	(0.142)		(2.405)		(0.258)	
Ratio of *Pinus pinaster*	0.538	0.037	-5.369	0.165	0.611	0.027
	(0.239)		(3.851)		(0.277)	
Ratio of equine stock	-0.419	0.054	-0.182	0.612	-0.385	0.045
	(0.203)		(0.357)		(0.192)	
Ratio of protected areas	0.446	0.019	0.000		0.404	0.051
	(0.173)		(omitted)		(0.208)	
Agricultural cooperatives	-0.520	0.002	-0.901	0.621	-0.555	0.029
	(0.141)		(1.819)		(0.253)	
Intercept	-3.352	0.317	-4.353	0.581	0.819	0.836
	(3.256)		(7.864)		(3.949)	
Number of observations	190		190		190	
F Statistic	112.150					
Prob > F	0.000					
R2	0.690					

On the other hand, the density of *Pinus pinaster* and the ratio of protected areas are positively related with this dependent variable. The coefficients are significant for the OLS and RE results. We also find that the ratio of natural pasture has no statistical impact on any of the econometric models.

b. Results of the number of wildfires

For the purpose of determining the functional form for the regression of wildfires, the Box-Cox test does not provide conclusive evidence of the superiority of any functional form (Table 2.4). However, in order to compare the number of wildfires with the regression of the burned-forest area ratio, the logarithmic model is selected. Also, this functional form is estimated to allow for comparability between all regressions.

TABLE 2.4: Box-Cox test for the regression of number of wildfires.

DEPENDENT VARIABLE				INDEPENDENT VARIABLES			
Test H_0	Restricted log likelihood	LR Statistic chi^2	P-value (Prob > chi^2)	Test H_0	Restricted log likelihood	LR Statistic chi^2	P-value (Prob > chi^2)
$\Theta = -1$	-1,368.202	417.560	0.000	$\lambda = -1$	-1,223.004	7.630	0.006
$\Theta = 0$	-1,163.885	8.930	0.003	$\lambda = 0$	-1,221.815	5.250	0.022
$\Theta = 1$	-1,225.002	131.170	0.000	$\lambda = 1$	-1,225.002	11.620	0.001

Following the results displayed in Table 2.5, the estimation by OLS explains 78.60% of the variation of the number of wildfires. In addition, the parameters are all jointly statistically significant. In the OLS results, temporal trends are also identified. Until the year 2005, the coefficients are not significant; however, from this year onwards, all yearly dummies are significant and negative. Therefore, from 2005 onwards, the wildfire occurrence diminishes with respect to 2001. Taking into account the climatological variables, the rainfall carries a significant and negative effect on the number of wildfires (-0.430). On the opposite, the maximum temperature is significant and positively related to wildfire occurrence (1.696).

Some variables, such as the ratio of equines and the agricultural cooperatives do not have a significant relationship with the number of wildfires during 2001-2010, are not significant in the assessment of the wildfires using the OLS models. However, the rest of the socioeconomic variables, are significant and have positive effects over the wildfires occurrence.

The number of wildfires is modelled by count data models. Therefore, overdispersion should be studied in order to select the best econometric model. Taking into account the results of Table 3, the data show overdispersion, and hence, the NBMR is selected to estimate the number of wildfires. The Hausman test recommends the use of RE to estimate the number of fires by the NBMR (Prob.>chi2=1.00).

Analysing the effects of the yearly variables, temporal trends are found according to the NBMR results, both with FE or RE. In this way, since 2006, it is observable that the wildfire occurrence diminishes with respect 2001. However, the NBRM also detects a significant growth in wildfires in 2005 with respect to the baseline year. The OLS and NBMR models, with or without RE, demonstrate the presence of temporal trends in Galician wildfires.

TABLE 2.5: Econometric results for the regressions of the number of wildfires.

	OLS		**NBMR**		**NBMR with FE**		**NBMR with RE**	
	Coef,	P>t	IRR	P>t	IRR	P>t	Coef,	P>t
Dummy 2002	0.147	0.222	1.039	0.665	0.985	0.808	1.003	0.965
	0.116		0.092		0.063		0.063	
Dummy 2003	-0.006	0.968	1.004	0.970	0.950	0.474	0.956	0.502
	0.147		0.110		0.068		0.065	
Dummy 2004	0.067	0.526	1.077	0.351	1.088	0.165	1.088	0.160
	0.104		0.085		0.066		0.066	
Dummy 2005	-0.099	0.552	1.004	0.965	1.160	0.027	1.134	0.055
	0.163		0.094		0.077		0.075	
Dummy 2006	-0.894	0.000	0.602	0.000	0.674	0.000	0.653	0.000
	0.164		0.071		0.053		0.049	
Dummy 2007	-1.366	0.000	0.370	0.000	0.320	0.000	0.328	0.000
	0.214		0.048		0.030		0.030	
Dummy 2008	-2.155	0.000	0.223	0.000	0.218	0.000	0.227	0.000
	0.201		0.027		0.023		0.022	
Dummy 2009	-1.289	0.000	0.405	0.000	0.379	0.000	0.376	0.000
	0.236		0.061		0.040		0.036	
Dummy 2010	-1.625	0.000	0.333	0.000	0.365	0.000	0.345	0.000
	0.187		0.042		0.036		0.032	
Summer average rainfall	-0.430	0.002	0.990	0.000	0.994	0.000	0.994	0.000
	0.120		0.002		0.001		0.001	
Summer máximum temperature	1.696	0.031	1.022	0.576	0.972	0.074	0.981	0.189
	0.726		0.039		0.015		0.014	
Ratio of natural pasture	0.227	0.010	149.018	0.000	43.453	0.109	141.696	0.000
	0.079		213.364		102.163		185.066	
People Density	0.339	0.004	1.173	0.190	1.313	0.078	1.180	0.015
	0.104		0.143		0.203		0.080	
Ratio of *Pinus pinaster*	0.354	0.031	5.437	0.084	5.135	0.074	6.132	0.000
	0.151		5.331		4.705		2.838	
Ratio of equine specie	-0.201	0.227	0.005	0.257	0.035	0.163	0.004	0.007
	0.161		0.022		0.085		0.008	
Ratio of protected areas	0.253	0.042	3.276	0.060	4.334	0.209	4.072	0.024
	0.116		2.068		5.060		2.538	
Agricultural cooperatives	-0.110	0.363	1.012	0.167	1.010	0.421	1.015	0.052
	0.118		0.009		0.013		0.008	
Intercept	3.662	0.138	12,259.780	0.000	1,775.902	0.000	1,391.861	0.000
	2.360		13,443.070		1,497.628		936.366	
Number of	190		190		190		190	
F Statistic	107.240							
Prob > F	0.000							
R2	0.786							
OVESDISPERSION ANALYSIS								
Muhat			0.111	0.000				
			0.015					

Furthermore, the estimator of summer rainfall is significant and carries a negative effect on the number of wildfires (0.994). According to the estimation with RE, if this independent variable changes over time and between districts by one unit, then the average effect of the average summer rainfall over the number of wildfires is significant (0.944). Otherwise, the average of the maximum temperature during the summer is not significant to explain the wildfires according with the NBMR models.

In the NBMR models, the ratio of natural pasture, *Pinus pinaster* and protected areas are statically significant. The effects of these variables on wildfire occurrence are positive. By analysing the IRR, if the ratio of natural pasture, the ratio of *Pinus pinaster* and the ratio of protected areas per landowner show an increase by one unit, then the number of wildfires increases by a factor of 149.018, 5.437 and 3.276, respectively.

In addition, socioeconomic variables are significant in the NBRM with RE. Nevertheless, the remaining variables have different impacts on wildfire occurrence. The agricultural cooperatives and population density have a positive relationship with the occurrence of Galician wildfires. If these previous variables increase by one point, the rate of the number of wildfires would be expected to increase by a factor of 1.015 and 1.180, respectively, while holding all other variables constant. Furthermore, the ratio of equines has a negative relationship with wildfires occurrence.

The summer average rainfall is significant in order to predict the wildfires occurrence. This is explained by the absence of raining, given that this increases the wildfire risk. Nevertheless, the summer maximum temperature is only significant in the OLS results.

2.6. DISCUSSION

Spatial patterns and temporal trends can be observed with graphical data representation. Furthermore, the spatial dependence of wildfires can also be determined by spatial statistics. Various econometric models are employed to assess the impact of socio-economic, climatic and geographical variables, as well temporal and spatial effects. Following the econometric models employed, and in particular those from RE models, the number of wildfires and the affected area ratio are estimated for each Galician forest districts in 2010. The estimations portrayed in Figure 2.9 show the actual data for both dependent variables and predictions. The data of these variables are distributed in quantiles and represent each district. In doing so, the geographical patterns of wildfire occurrence can be clearly differentiated in these maps. It is shown that the wildfire risk depends on the forest district; and as such, regulators should focus their forestry efforts on the areas in which the prediction of wildfires is higher. In other words, and for the area of study, public policy efforts should focus more closely on the southern rather than the northern districts.

In terms of the econometric results, it was found that the agro-forestry features are important factors given that the land cover is conditioned by this activity. The type of forest plantation, the livestock used in the farms or the land assigned to agricultural activity influences the wildfire occurrence. The ratio of equines is slo important in order to reduce the wildfire occurrence (Rigueiro *et al.*, 2002; Pasalodos *et al.*, 2009). This species grazes freely in the surrounding farm; fed mainly with grass, bushes or seeds; keeping the land cover cleaner. Thus, the wildfire risk diminishes where there are more equines than other livestock species. The presence of agricultural cooperatives also affects the wildfires occurrence. This happens because of the traditional agricultural management practices using fires. Nevertheless, the effect is the opposite for the burned area, because in general terms, the lands are better managed when the agricultural sector is more powerful in rural areas.

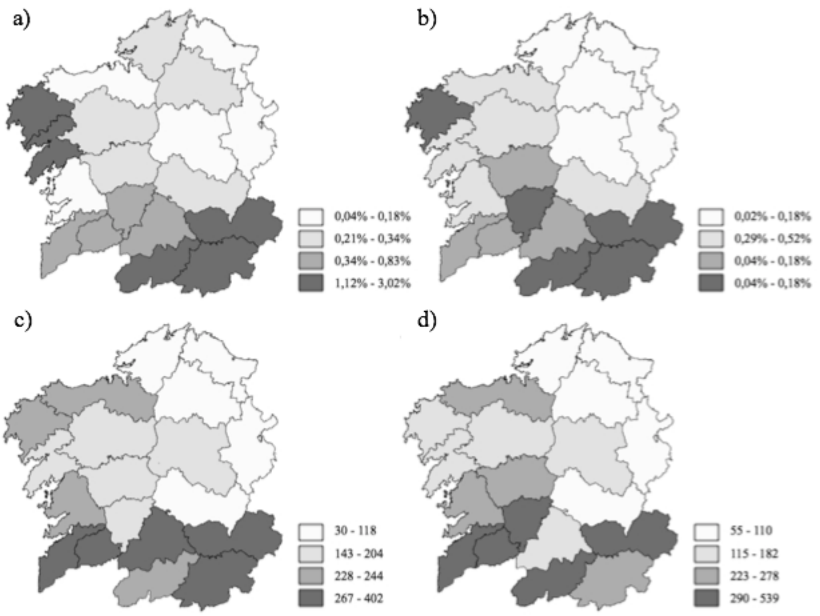

FIGURE 2.9: Estimation of wildfire occurrence in 2010. a) Actual ratio of burned area (%). b) Estimated rate of burned area (%). c) Actual number of wildfires. d) Estimated number of wildfires.

We also find that the *Pinus pinaster* ratio has a positive influence on the occurrence of wildfires, because this species is pyrophyte, with wildfires spreading more where *Pinus pinaster* are being planted. Protected areas could also be expected to have a negative relationship with wildfire occurrence; however the social rejection or ineffective protection measures could cause a positive influence. Furthermore, climatology variables condition the occurrence of wildfires, how they spread or the suppression efforts. Finally, the evolution of wildfires over time demonstrates high variability. This is the justifying reason why yearly dummy variables were included.

In general terms, the population density is important in order to predict the wildfire occurrence. However, in some of the empirical models, results are not conclusive. For example, in the OLS with RE, this variable is not significant when explaining the burned-forest area ratio. The same happens in the NBRM when analysing the wildfire number. In the remaining models, the population density is positively related to the occurrence of wildfires. This result is explained by the progressive migratory flow from the rural to urban areas. Then, the wild land-urban density around to main areas is increasing. In addition, the new residents are not involved in the agricultural sector and they are not involved with forest production (Barreiro and Hermosilla, 2013). This generates worst environmental conditions, causing an increase of wildfires (Herrero-Corral *et al.*, 2012). Public policies may supervise the surrounding environment of these areas and aware society to avoid wildfire occurrence.

The types of forest covers are represented by the ratio of *Pinus pinaster*. The results show a positive influence on both, the ratio of burned-forest area and wildfires number. These results are related with the species characteristics because these are more inflammable and the wildfires, when occurring, move faster than with other species. The preventive measures and supervision should also be incremented in these areas in order to avoid wildfires.

Unexpectedly, the protected areas influence positively the occurrence of wildfires. This result may show the general rejection towards having protected lands in rural areas. This result could also imply an inadequate public policy to manage these areas against wildfires (Carroll *et al.*, 2006). Therefore, the zooning of protection areas may be revised in order to identify the possible social and environmental factors that can be improved when reducing management conflicts. These improvements will imply lower wildfire occurrence if these factors are corrected.

2.7. CONCLUSION

This research provides evidence characterizing the wildfire occurrence in the agricultural sector in relation to the climatic conditions, the forest cover, the social context, and time and spatial patterns. A relevant finding is that the forest species and the farming systems condition the wildfire risk. Hence, public policies may mitigate the factors that affect the wildfire risk.

In this way, the presence of equines and extensive agricultural practices should be promoted in order to reduce the wildfire risk.

According to the main results, some guidelines could be developed as a reference for regional and local governments to help in the fight of wildfires. In particular, public policies could regulate the quality and quantity of woodland made available, as well as the plantation of different species. These regulatory agencies should also consider the geographical and spatial differences in the occurrence of wildfires in order to formulate better forest policies, and deal with possible "contagion" effects across districts.

Finally, we should remark that the current research has some limitations. In particular, additional variables would be desirable by employing more geographical disaggregated data, such as roads and infrastructures. Unfortunately, such data are not currently available, although, they are expected to be in the near future. In spite of that, many of the obtained conclusions could be applicable to other similar European areas, especially in depopulated rural areas. In particular, these main results could be implemented in the French Mediterranean basin (INSEE, 2015; PROMETHEE, 2015) and Portugal (INE, 2015), among others.

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CHAPTER 3: ON INSURANCE AS A TOOL FOR SECURING FOREST RESTORATION AFTER WILDFIRES

Abstract: The recovery of the affected areas after a wildfire is important in order to restore the production of the various ecosystem services. We develop a theoretical valuation model that contains a forest insurance policy, in order to protect the landowner against total or partial losses caused by wildfires. Restoration costs of affected areas are explicitly included. Such model is used to simulate the changes in rotation and profitability of *Pinus pinaster* Aiton. in Galicia (NW Spain). We find that in the areas where the risk of wildfires is higher, forest owners may profit the most from subscribing such insurance. Overall, we conclude that insurance is an effective tool to increase the net present value (NPV) of forest investments, particularly when restoration costs are covered.

K**eywords:** Forest insurance, restoration, optimal forest rotation

3.1. INTRODUCTION

In Europe, forest fires are concentrated in the Southern countries, with Portugal, Spain, Italy, and Greece being the most affected, both in terms of the number of fires recorded and forest area affected (European Commission, 2011). Nevertheless, these Mediterranean countries represent less than 30% of Europe's forestry areas. The case of Spain is even more serious in terms of fire intensity: while representing around 10% of Europe's forest area, it suffers about 24% of the total number of wildfires per year, representing approximately 25% of the total amount of burned forest area in Europe. There are also important regional variations within a given country. For example, in the case of Spain, Galicia is the Spanish region with the most wildfires. Galicia represents 15% of the Spanish forest area, while in recent years it has experienced around 42% of Spain's total number of wildfires (MAFE, 2012).

Wildfires cause significant damage to both, the forest stand and soil quality, while the affected growing stocks may take a long time to recover (Inbar *et al.*, 1997). Therefore, if there are no forest restoration measures in place, the chances of success for a post-wildfire forest depend on its natural regeneration speed and how badly degraded the soil is (Bautista *et al.*, 2009). However, forest restoration is expensive for landowners, who may be interested in covering wildfires losses with insurance in exchange for an insurance premium. In order to mitigate the significant losses caused by wildfires, some private companies offer the possibility to take out forest insurance. In particular, in countries such as Norway, Germany and France, landowners can contract fire insurance (Mahul and Stutley, 2010). In general, these policies can cover damage caused by storms, snow, or wildfires. These damages could affect forest production and ecosystem services during a short or long period (Barrio *et al.*, 2007; González-Gómez *et al.*, 2013). The forest insurance policies in these countries can also cover other restoration costs, including all the damages caused, although different restrictions and conditions may apply. Keeping this in mind, it is therefore necessary to assess the impact of forest insurance as a compensation mechanism for the damage caused by wildfires on forest management. Forest insurance contracts are offered in several countries around the world. In some of them the forest insurance is semi-public, for example in Mexico, and in other countries is private, such as in New Zealand or Brazil. However, in Germany or Canada, where the forest insurance are private, the government subsidize the insurance premium. These insurance policies could cover different risks and damages. For example, the forest insurance in Costa Rica covers timber-standing damages and the forest damages caused by storms are covered in Mexico. This study is motivated by a number of experimental

Spanish fire insurance programmes. Some forest insurance programs have appeared in this country over the last few decades, and a legal protocol for their implementation is currently underway. These insurance programs have been designed to cover the costs of replanting affected areas for a wide range of species, while wood and other commercial losses are only covered for a limited number of species. The size of the insurable Spanish forest reached 6,224,029 hectares in 2010, while only 77,103 hectares were insured in the same year (Agroseguro, 2011). This implies that only 1.25% of the forests that fulfil the criteria to be covered with a forest insurance policy.

The Spanish Strategic Forestry Plan (Ministry of the Environment, 1999) highlights the importance of forest insurance as a mechanism to cover wildfire losses, with a special emphasis on forest restoration. This insurance can have positive implications for the landowner and society, because the forest returns to production faster and provides new environmental and ecosystem services for the community. Consequently, it is necessary to design an insurance model in which these forest restoration costs could be covered in order to improve the forest management. This type of coverage may provide more sustainable forest management strategies, guaranteeing that forest profitability is not depleted and generates higher incentives to invest in forest production. Therefore, insurance may also help to restore and recover forest areas, whilst guaranteeing that landowners do not lose all their investments. With this insurance program, the recovery of burned areas is expected to be quicker in insured forests than in uninsured ones.

In this research area of forest insurance against wildfire hazards, there are still few references (Manley and Watt, 2009), although research had already begun in the first half of the twentieth century (Averill and Frost, 1933; Shepard, 1935; Willians, 1949). Recently, the issue of forest insurance is gaining again importance in the literature, particularly in Europe (Brunette and Couture, 2008; Pinheiro and Ribeiro, 2011; Brunette *et al.*, 2012). A relevant contribution in this area of forest insurance is the research carried out by Holecy and Hanewinkel (2006) in which an insurance model was developed for coniferous forests in southwest Germany. These researchers developed a forest destruction probability model, in which several elements, such as fire and windstorms are taken into account. Subsequently, they carried on a number of forest valuations which depended on timber production and forest management. They described a possible insurance model that analysed the damage risk and the insurance premium. However, none of the previous references to forest insurance explicitly analyse the possibility of covering forest restoration costs. Meanwhile, there are many researchers who have highlighted the importance of forest restoration after wildfires.

Authors such as Kauffman (2004) or Alloza and Vallejo (2006) also underline the positive consequences of the application of insurance policies for the environment (Beschta *et al.*, 2004). With this in mind, this paper aims to develop a forest insurance model against wildfires, in which timber damages and restoration costs after wildfires will be included, given that these are important for landowners' wealth and secondly for providing ecosystem services.

The main goal of this paper is to analyse the implications of forest insurance policies with restoration measures in private forest management. To achieve this, a private insurance model is developed in which the level of coverage, the productive variables and the risk level of a wildfire occurring are included. With this insurance, forest restoration and timber damages could be covered (either wholly or in part). These characteristics should be included implicitly or explicitly in the insurance policy. In this study, some hypotheses will be enunciated and demonstrated in order to analyse the effect of this type of insurance on forest rotation and on forest economic returns, measured by the Net Present Value (NPV). Following this theoretical section, an empirical simulation applying this insurance model to a *Pinus pinaster* Aiton. plantation in the region of Galicia (Spain) is represented. Finally, in the last part of this paper, the main results and conclusions of this research will be presented. The importance of insurance in reducing the volatility of forest investments will be highlighted.

3.2. THEORETICAL FRAMEWORK

3.2.1 Forest insurance model

A number of previous research papers have developed economic insurance models from different perspectives. For example, Holecy and Hanewinkel (2006) developed an insurance model in which the gross insurance premium was analysed, and the probabilities of forest destruction were computed. Another interesting piece of research is by Brunette and Couture (2008), who presented an insurance model to analyse the impact of public subsidies after natural disasters. This model uses the landowner's preferences in order to investigate the implications of a subsidy on forest management. Therefore, in these papers, the effect of an insurance policy on the landowner's wealth and the effect of this financial asset on forest rotation is not explicitly studied.

In this study, the NPV will be used to understand the economic implications of forest insurance policies on forest management for one forest rotation period (Hanewinkel *et al.*, 2011). Taking into account previous contributions, such as those by Amacher *et al.* (2005) or

Martell *et al.* (1998), the insurance model includes the forest management costs, which contain the cleaning and maintenance costs to prevent wildfires, amongst others. Additionally, the application of public subsidies for forest management and the intensity of the wildfire are taken into account as variables of interest that modify the NPV estimate.

In order to motivate a forest insurance model, it is first necessary to consider a landowner's forest wealth, which suffers damages (*D*) when a wildfire occurs. These losses cannot be greater than the initial landowner's wealth and are related to the risk of a wildfire. The wildfire risk is defined as δ, while the complementary probability of a wildfire not occurring is the remainder ($1-\delta$). As stated, this wildfire risk depends on the forest management (*s*); so, if preventive efforts are applied, the risk may decrease (González *et al.*, 2005). These preventive actions influence the forest insurance (Ehrlich and Becker, 1972). Therefore, if the insurance requires preventive strategies that make it possible to reduce the probability of a disaster (self-protection efforts), then insurance and preventive measures will be complementary. However, when the insurance premium does not depend on prevention efforts, then the insurance and self-protection will be substitutes. In this paper, the risk depends inversely on forest management efforts [$\delta'(s)<0$]; this relationship is concave, as there is a level after which additional forest management efforts cannot reduce the wildfire risk [$\delta''(s)<0$](Martell *et al.*, 1998; Amacher *et al.*, 2005). Therefore, landowners can alter the risk with their actions (Chang, 1983, 1984; Amacher *et al.*, 2009). We acknowledge that there are other exogenous variables to the landowners, such as climatic and geographic conditions that may play an important role in the risk. However, this last set of variables will not be considered into the model as they cannot be altered or modified by any contracting party. In summary, the wildfire risk will depend on all of the preventive measures that are designed to reduce the risk of wildfire occurrence, and it is assumed that the insurer will have information about this preventive effort.

However, forest management implies a cost to the landowner, although this management cost may be altered if the government provides public subsidies in order to share the forest management costs with the landowner (Lankoande *et al.*, 2005; Yoder, 2008). We consider that the rate of the cost paid by the landowner is defined by α, while ($1-\alpha$) indicates the level of public subsidies contributing to forest management. The value of this proportion is between zero and one, so that mathematically $\alpha \in [0,1]$.

Otherwise, if the landowner is insured against wildfire damages, then they have to pay an insurance premium (γ), which offers a chance to receive compensation (Ω) after a wildfire (Brunette and Couture, 2008; Brunette *et al.*, 2012). In this model, forest restoration costs (h)

are covered by this insurance, while this coverage can be total (full coverage) or partial. This coverage will be linked to the recovery plan in order to determine the possible expenses and the type of restoration that the landowner desires to undertake. In order to simplify this model, the insurance policy will predefine the recovery costs, which do not vary as a function of wildfire intensity. Thus, compensation could be determined using Eq. 3.1, where μ is the damage rate covered by the insurance policy, while (1-μ) is the proportion that is not covered by the insurance program. If $\mu = 1$, then the insurance would cover all direct damages (full coverage), whereas if $\mu = 0$, then no insurance has been taken out. Nevertheless, the insurer covers up to the level λ of forest restoration expenditures, while the remainder is covered by the insured landowner. Thus, if $\lambda = 1$, the insurer will bear all of the costs of forest restoration, and if $\lambda = 0$, then, the insured landowner will cover these costs. We will therefore define the compensation as:

$$\Omega = \mu D + \lambda h \qquad 0 \leq \mu \leq 1, 0 \leq \lambda \leq 1 \tag{3.1}$$

According to the previous considerations, landowners have to take out an insurance policy if they wish to be entitled to receive a compensation in the case of a wildfire. As landowners face different payments depending on the state of nature, then the owner's wealth will be modified accordingly (Rees and Wambach, 2008). In this way, and for motivation purposes, the net revenues associated with two different states of nature (x = no wildfire and y = wildfire occurs) are represented in the two following equations:

$$x = PQ(t) - C(Q,s,\alpha) - \gamma(Q,t,s,\mu,\lambda) \tag{3.2}$$

$$y = PQ(t) - C(Q,s,\alpha) - D(Q,t,I,\mu) - h(\lambda) - \gamma(Q,t,s,\mu,\lambda) \tag{3.3}$$

In the first case, timber revenues (PQ), forest management cost (C) and the insurance premium (γ) are taken into account. Subsequently, it is assumed that the forest produces a growing stock (Q) which depends, for a given site productivity, on the time factor (t). The relationship between production and time is positive and concave [$Q'(t)>0$; $Q''(t)<0$]. Also, it is assumed that the timber price (P) is constant over time. Moreover, the management cost depends on the public subsidy (α), the forest management effort (s), and the timber production (Q). Further, the management costs depends inversely on public subsidies [$C'(\alpha)<0$; $C''(\alpha)>0$]; while they exhibit the following relations with respect to the aforementioned variables [$C'(s)>0$; $C'(Q)>0$; $C''(s)<0$; $C''(Q)<0$].

All the previous variables depend on the landowner's attitudes toward risks, although these have not been included in the present model (Brunette and Couture, 2008). The insurance premium depends on the time factor (t), the coverage level (μ; λ), the management effort (s), and growing stock (Q). Eq. 2.3 presents the forest net revenues in the specific case where the damages are not covered by a wildfire insurance. These damages (D) depend on the forest management effort (s), and on forest restoration cost [$h(\lambda)$]. The damages depend on time (t), the growing stock (Q), the insurance coverage (μ) and the wildfire intensity (I).

3.2.2 The optimal forest rotation model

The techniques used to value forest wealth are usually based on the Faustmann's rotation model (Faustmann, 1849). This model has been applied and extended by many researchers, such as Hartman (1976), Samuelson (1976) or Reed (1984). The aim of these models is to calculate the optimal rotations. Forest characteristics and/or financial variables, such as the afforestation costs (R) or timber revenues (PQ) are taken into account. Following earlier work by Barreto *et al.* (1998); Hyytiäinen and Haight (2010); or Hanewinkel *et al.* (2011), the NPV computation is used in this paper. We also followed Reed (1984), in order to select the use of the continuous discount factor in this model. This continuous discount factor depends on the interest rate (r), and the time period (t) that is taken as the reference point. The equation of interest is presented in Eq. 3.4, in which the NPV for one rotation is described.

$$NPV_t = PQ(t)e^{-rt} - R \qquad [3.4]$$

In order to better describe the NPV, and as an extension of this paper, the wildfire risk and insurance policy will be included. As a result, the new valuation depends on the risk of damages. This extended NPV is presented in Eq. 3.5. In this case, the forest management cost and damage risk are also considered. Forest management influences both forest production risks and costs, and so it is an important variable for determining the NPV, and consequently, the optimal forest rotation. However, these effects are opposed to each other; if the forest management effort increases, then the premium to be paid for the insurance and the expected damage will decrease, although the management effort and related management costs will increase. The expected damage is the cross product of the wildfire probability (δ) and damage (D); which depends on the forest management effort (s), and the amount of the possible losses, which occur in the timber stand (Q), plus other forest restoration cost (h).

$$NPV_t = \left[PQ(t) - C(Q,s,\alpha) - \delta(s)\big(D(Q,t,I) + h\big)\right]e^{-rt} - R \qquad [3.5]$$

If a landowner takes out wildfire insurance, the previous equation should reflect the insurance characteristics. So, the insurance premium (γ) should be included as an additional cost.

Therefore, if the coverage level (μ, λ) and timber value increase, or if the forest management effort decreases, then the insurance premium cost increases. Also, the damages show a negative relationship with respect to the coverage level. Consequently, the expected damage to the timber stand or forest restoration costs will decrease with higher levels of coverage. However, if the wildfire intensity is high, then the damage increases. This new modified NPV function is represented by Eq. 3.6, in which a landowner's decision to take out an insurance policy or not is taken into consideration.

$$NPV_t = \left[PQ(t) - \gamma(Q,t,s,\mu,\lambda) - C(Q,s,\alpha) - \delta(s)\big(D(Q,t,I,\mu) + h(\lambda)\big)\right]e^{-rt} - R \quad [2.6]$$

The optimal forest rotation is now computed. According to the previous literature (Reed, 1984; Clarke and Reed, 1989; Alvarez and Koskela, 2006), this rotation could be conditioned by different elements. Thus, there are economic and forestry uncertainty variables that condition forestry management (Marshall, 1987; Gong and Löfgren, 2003; Pasalodos-Tato *et al.*, 2010). Following González *et al.* (2005), we can see that the rotation length decreases with both economic and wildfire risks, but the difference depends on the relative importance of both variables. Therefore, the landowner's decision depends on both types of risks.

Proposition 3.1: *At the optimal forest rotation point, the landowner is indifferent between keeping the forest growing with the protection of wildfire insurance, or cutting down the forest and investing the money from the harvest at a rate « r ».*

Demonstration 3.1: As the landowner wants to maximize the forest's expected value, they have to maximize the previous equation. To achieve this, the partial derivative with respect to time is taken and set equal to zero. This result determines the optimal forest rotation (T^*). By rearranging this expression, Eq. 3.7 emerges, in which the optimal forest rotation is achieved when the rate of growth value of the forest stand with insurance against wildfire risks, which also covers restoration costs, is equal to the interest rate.

$$\frac{PQ'(T^*) - \gamma'(Q,T^*,s,\mu,\lambda) - \delta(s)D(Q,T^*,I,\mu)}{PQ(T^*) - \gamma(Q,T^*,s,\mu,\lambda) - C(Q,s,\alpha) - \delta(s)\big(D(Q,T^*,I,\mu) + h\big)} = r \quad [3.7]$$

The left hand side (LHS) of Eq. 3.7 depends on the forest stand value, forest management, the wildfire risk and/or the insurance policy. Conversely, the RHS only depends on the interest rate. Therefore, the point where both functions cross each other determines the optimal forest rotation point. Based on the previous demonstration, if the wildfire risk increases, then the

LHS of the equation will decrease and the optimal forest rotation will increase, *ceteris paribus*. However, if some values vary and offset the increment of the wildfire risk, then this rotation will not be modified. An opposite effect would occur if the forest management costs decrease. Thus, if the government increases subsidies for forest management, the costs will be reduced, making the denominator smaller; and consequently, the optimal forest rotation will be shorter. In cases when the government decides to reduce these subsidies, the optimal forest rotation would be increased, *ceteris paribus*.

Proposition 2: *Marginal timber revenues should be equal to the marginal increase of the insurance premium plus the marginal expected losses in order for the optimal forest rotation to remain unchanged.*

Demonstration 2: According to Eq. 3.7, timber production, the insurance premium and the risk of damage of the forest stand could modify the slope of the rate of the marginal net revenue curve with insurance against the risk of wildfires. Therefore, if the forest stand grows faster or prices increase significantly, then the optimal rotation may be shorter than for other types of forests or locations where growth occurs at slower rates, *ceteris paribus*. In the same way, if the insurance premium or damage risk increases, the optimal forest rotation should take longer. The reverse happens if these variables decrease with respect to the rotation length. Following Eq. 3.7, the slope will not change if the rotation effects are void. This is represented in Eq. 3.8. In this expression, the marginal growth of timber revenues is equal to the marginal increase of the insurance premium and the marginal change of expected damage.

$$PQ'(t) = \gamma'(Q,t,s,\mu,\lambda) + \delta(s)\big(D'(Q,t,I,\mu)\big) \qquad [2.8]$$

Proposition 3: *An optimal change in forest management effort should equal the corresponding reduction in the insurance premium and expected losses.*

Demonstration 3: The optimal management effort is achieved when the derivative of Eq. 3.6 with respect to forest management efforts (*s*) is set equal to zero. Eq. 3.9 is then obtained. The (RHS) of this equation represents the marginal costs due to management efforts, while the corresponding reduction of other associated costs linked to management are presented on the LHS. So, if the cost of forest management is greater than the reduction of the premium and wildfire risk [$C'(Q,s,\alpha)>\gamma'(Q,t,s,\mu,\lambda)+\delta'(s)$], then the optimal forest rotation will be larger, *ceteris paribus*. The opposite occurs if the reductions of the premium and wildfire risks are higher than the costs [$C'(Q,s,\alpha)<\gamma'(Q,t,s,\mu,\lambda)+\delta'(s)$].

$$C'(Q,s,\alpha) = -\gamma'(Q,t,s,\mu,\lambda) - \delta'(s)\big(D(Q,t,I,\mu)+h(\lambda)\big) \qquad [3.9]$$

Following this equation, the landowner will try to achieve the equilibrium point where the NPV will be the highest with respect to forest management. This optimal point is reached when the marginal management costs are equal to the marginal net revenues of forest management.

3.3. EMPIRICAL SIMULATION

According to Figure 3.1, wildfires affect Galicia more than any other Spanish region. This region has the highest number of wildfires and the highest ratio of burned forest area in Spain.

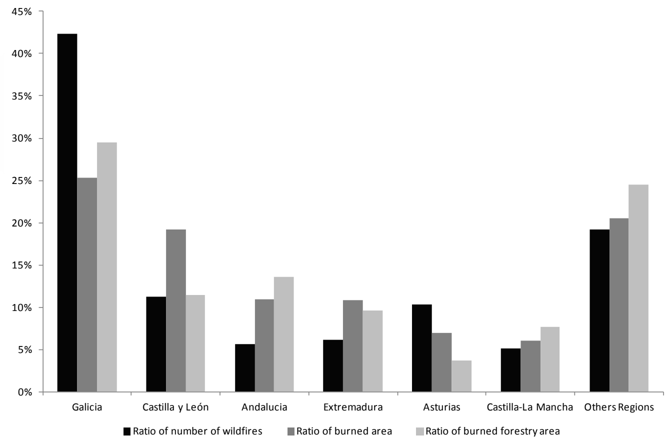

FIGURE 3.1: Ratio of wildfire occurrence in the regions of Spain during 2001-2010 (MAFE, 2012).

For the purpose of simulating the effects of the previous theoretical models, we first compute the expected wildfire risk in the study areas. Thus, it is assumed that the risk will be accounted for by considering geographic variations throughout the Galician forest districts (See Figure 3.2). Based on previous research by Barreal *et al.* (2012), the wildfire risk was calculated as a prediction based on socio-economic and geographical variables, as well as climate related variables for each of the administrative demarcations. Running regression models, fire risk prediction indexes were obtained for all of the districts, only selecting those that corresponded respectively to low, medium and high-risk indexes. In particular, the wildfire risk used in the following simulation is the estimated 0.07% for the area of "A

Mariña Lucense" (very low risk), 0.53% for the area of "Fisterra" (representing the average monthly risk in the entire region) and 1.57% (higher risk) for "Verín-Viana" (Figure 3.2).

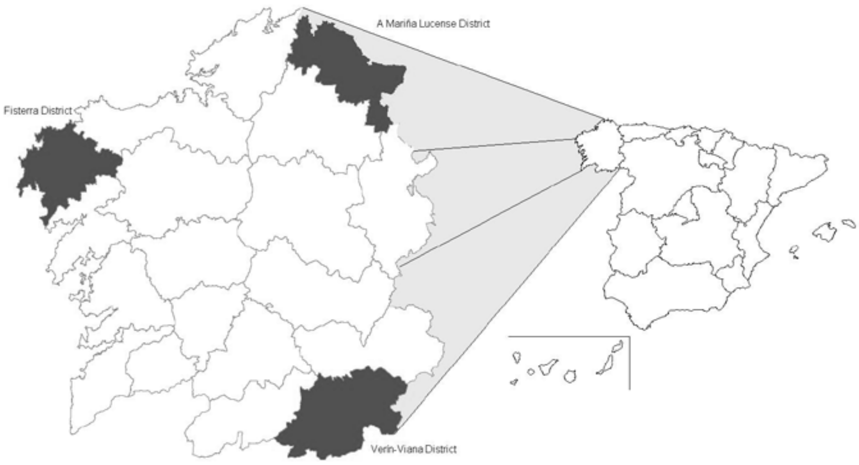

FIGURE 3.2: Galician Forest Districts.

As a working hypothesis, it is assumed that these risk levels do not vary within each specific forest district. Another assumption is that all landowners could take out the forest insurance described above, and all owners have the same wildfire risks, regardless of the size of their lands or their management. To select the discount factor, the simulation employs a given interest rate of 3%, as used by Pasalodos-Tato *et al.* (2010). The rest of the variables take random values, as their respective roles are only to simulate the effect of a forest insurance program and to identify their possible implications if this kind of insurance is used. Therefore, the given values are set to μ=70% and λ=95%, assigned to damage and restoration coverage respectively. Therefore, there is a deductible that is represented by a portion of damages and costs that landowners have to face, respectively. Using the previous values, we assume that 30% of restoration costs and 5% of timber damage are not covered by the insurance respectively. The timber damage coverage is set as partial coverage, and only commercial values are considered. Note that a proportion of the non-commercial value is not refundable due to the deductible that is not covered for restoration costs.

In order to determine the NPV of the forest stand, an example based on the silvicultural production system of a regular stand of *Pinus pinaster* Aiton. is used. This species is chosen because it attracts large commercial interests in Galicia, and this region has suitable edaphoclimatic conditions for its cultivation. Also, one should note the importance of this species in traditional production and uses of the Galician forest, while this is one of the species included in the experimental forest insurance program. The growth rate of this species depends on climatic conditions and on soil characteristics, among other factors. The Quality II for *Pinus pinaster* Aiton. corresponds to a site index of 1.70 m with 20 years as a reference age. The average forest productivity differs between districts, but to prevent this differential effect the current research has compared stands with the same site index.

This simulation uses a simplified silvicultural regime, which includes the plantation of 1,111 trees per hectare, no thinning during the length of the rotation and a final clear-cut. By increasing the growing space available to the remaining trees, a landowner can increase the growth rate of the remaining trees and, more importantly, the rate at which their value increases. Thinning can also be used to remove poorly formed trees that would have little future value. Thus, if the landowner does not make these intermediate cuts, the average tree in the final cut will be smaller and it will have less commercial value. Nevertheless, in the case of the Galician small non-industrial forest owners, this is a common forest management method due to the cost and difficulty of thinning.

To determine restoration costs, the prices included in the afforestation incentives enacted by the Galician Government are applied. These costs are set to a maximum of 1,853 €/ha and include the cost of preparing the soil, purchasing the seeds or saplings, and the subsequent sowing or planting, in addition to the cost of defending these plants with protectors, or other necessary materials, and the elaboration of preventive actions against wildfires (Consellería de Medio Rural, 2009). It also includes other tasks that could be carried out immediately after plantation. Therefore, considering the average slope of the land and soil conditions and the initial density of this silviculture regime, the cost of restoration is assumed to be 1,400 €/ha (BOE, 2010).

The forest stand value is calculated based on the possible income generated from the final harvest for each possible rotation. The timber price is obtained from Molano *et al.* (2007). These values are the average price at mill gate for the year 2006, which have been updated with an enquiry to companies and loggers. Production tables and profile curve for this species have been obtained for each year according to regional publications (Rodríguez *et al.*, 2000).

Finally, in order to obtain the net revenue of the timber that will be received by the landowner, transportation (6 €/m^3) and logging costs will be subtracted. The latter costs depend on the tree size and machinery performance as shown in Nakagawa *et al.* (2010). In this way, Eq. 3.10 is used to calculate forest stand value per hectare (V_k) for *Pinus pinaster* Aiton.

$$V_k = n_k \sum_{i=1}^{3} \left[Q_{ik} \left(Pf_i - C_t - Ca_{i,k} \right) \right] \quad [3.10]$$

In the previous equation the timber stand net value depends on the density of trees per hectare (n) for the respective year (k) and the value of the timber stand. This valuation depends on the timber grade (i). In this model, the timber is graded as pulpwood, sawlogs and premium sawlogs. The description of this timber classification is detailed on Table 3.1. The growing stock per hectare (Q), the mill gate price (P_f) and the harvesting cost (C_a) per m^3 of timber depends on its grade of forest production. Finally, to determine the timber stand net value, the cost of transportation to the factory per m^3 (C_t) is subtracted.

TABLE 3.1: Timber classification according to technical characteristics.

TYPE OF TIMBER	LOGS	DIAMETER	DESTINATION
Pulpwood	2.5 m	Between 4 and 14 cm	Panel manufacturing as well as pulp
Sawlogs	2.5 m	Between 14 and 24 cm	Sawn wood manufacturing
Premium sawlogs	2.5 m	bigger than 24 cm	Premium sawn wood manufacturing

Based on the previous considerations, the timber stand value per hectare is represented by Figure 3.3. This graph shows that for the first thirteen years the production value is zero, as the timber stand does not have any commercial value or it is too low to cover the costs of harvesting, hauling and transport. From that point on, the timber stand value starts to grow, but the first stage of production is mainly of pulpwood and sawlogs which have less value than premium sawlogs. This happens because as the tree increases in diameter, first it produces pulpwood, then later sawlogs and finally premium sawlogs, so the price received increases as the timber age increases. Timber valuation increases when timber technology changes from pulpwood to sawlogs and even more if this change is from sawlogs to premium sawlogs.

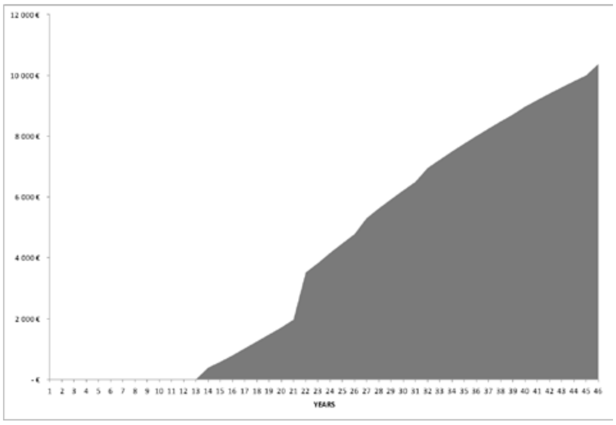

FIGURE 3.3: Forest stand value for *Pinus pinaster* Aiton. in Galicia.

In order to take out the insurance policy, the landowner has to pay a premium according to Eq. 3.11. This equation is based on Eq. 3.6. Therefore, if a landowner is indifferent about buying insurance, the NPV should be the same in both states of nature. Thus, the optimal premium will be calculated between the difference in expected damage with and without insurance.

$$\gamma(Q,t,s,\mu,\lambda)=\delta(s)\big(D(Q,t,I)+h\big)-\delta(s)\big(D(Q,t,I,\mu)+h(\lambda)\big) \qquad [2.11]$$

3.4. Results

3.4.1 NPV of forest investment

Using the previous data and Eq. 3.6, the NPV for different risk levels is calculated on the last row of Table 3.2. As expected, the main result is that forest fire risk reduces the NPV. If landowners can purchase an insurance policy, then their NPV does not necessarily increase, as the risk is transferred to the insurance company in exchange for an insurance premium. The maximum NPV is reached on the optimal rotation point, which in this case is about 36 years for all considered districts. Thus, the risk levels do not vary sufficiently across districts to impact the optimal rotation length significantly. This is due to the fact that the optimal rotation is conditioned mainly by the interest rate or by a very high wildfire risk (Reed 1984; González *et al.*, 2005; Pasalodos-Tato *et al.*, 2010). However, in these results it is possible to empirically observe the importance of reducing wildfire risks in order to achieve a better NPV for the landowners. The NPV for the three districts is also detailed in Table 3.2. According to this, in the presence of risk, landowners prefer to invest in timber production in the safest area, “A Mariña Lucense”, instead of investing in the other two areas, where risk levels are higher (“Fisterra” and “Verin-Viana”) at an interest rate of 3%.

TABLE 3.2: NPV for *Pinus pinaster* Aiton. plantation.

YEAR	NPV WITHOUT RISK	NPV WITH RISK		
		A Mariña Lucense	Fisterra	Verín-Viana
0	-1,400.00 €	-1,400.98 €	-1,408.02 €	-1,421.66 €
5	-1,400.00 €	-1,400.84 €	-1,406.90 €	-1,418.64 €
10	-1,400.00 €	-1,400.72 €	-1,405.94 €	-1,416.04 €
15	-899.26 €	-900.23 €	-907.24 €	-920.81 €
20	-323.62 €	-324.90 €	-334.18 €	-352.15 €
25	855.77 €	853.74 €	839.06 €	810.64 €
30	1,242.34 €	1,240.11 €	1,223.95 €	1,192.66 €
35	1,402.33 €	1,400.04 €	1,383.48 €	1,351.40 €
40	1,369.13 €	1,366.91 €	1,350.86 €	1,319.77 €
45	1,289.25 €	1,287.12 €	1,271.77 €	1,242.03 €
Max.	1,402.33 €	1,383.56 €	1,400.05 €	1,351.63 €

3.4.2 The effect of insurance on the NPV

The mean wildfire risk in Galicia can be used to calculate an average premium for each district. Employing this average, the NPV for the three districts changes, as described in Table 3.3. These values underline the importance of identifying properly the genuine wildfire risk or expected risk. Following this, if the premium charged is significantly higher than the expected damage, then the NPV decreases, as expected.

TABLE 3.3: NPV with a normal insurance premium for *Pinus pinaster* Aiton.

YEAR	NPV WITH A NORMAL INSURANCE		
	A Mariña Lucense	Fisterra	Verín-Viana
0	-1,408.59 €	-1,415.63 €	-1,429.27 €
5	-1,407.39 €	-1,413.46 €	-1,425.20 €
10	-1,406.36 €	-1,411.58 €	-1,421.69 €
15	-906.85 €	-912.09 €	-922.25 €
20	-332.87 €	-338.36 €	-348.99 €
25	842.20 €	835.47 €	822.43 €
30	1,227.71 €	1,220.86 €	1,207.59 €
35	1,387.50 €	1,380.81 €	1,367.85 €
40	1,354.87 €	1,348.57 €	1,336.37 €
45	1,275.68 €	1,269.80 €	1,258.40 €
Max.	1,380.98 €	1,387.60 €	1,368.15 €

As such, the landowners in "A Mariña Lucense" have a lower NPV than in the case of paying a premium closer to a fair premium, so they have incentives to demonstrate their genuinely low wildfire risk. Nevertheless, the landowners of "Verín-Viana" obtain a higher valuation, and may prefer to take out this insurance paying this premium. Finally, in the "Fisterra" district, the NPV does not change because in this area the wildfire risk is set equal to the mean risk level (used to compute the premium), so landowners are indifferent between taking out insurance coverage or assuming the wildfire risks. Thus, the establishment or reasonable premiums (according to expected risks) is crucial in order to promote the diffusion of insurance programs.

3.4.3 Expected losses when a wildfire occurs

If landowners take out forest insurance, they have the option of receiving compensation for the covered losses. All of these results are shown in Table 3.4, in which the different scenarios reflect a lower NPV at the start of the rotation, given that there is no timber production. Meanwhile, it can be seen that compensation only partially covers commercial damages. Following the results in the next table, the landowners have less variability in their forest investment if they take out insurance with restoration because they reduce their possible wildfire losses.

TABLE 3.4: Economic losses for *Pinus pinaster* Aiton.

		NPV of Landowner with forest damage and insurance					
Year	Discounted losses with forest damage and without insurance	Without restoration insurance			With restoration insurance		
		A Mariña Lucense	Fisterra	Verín-Viana	A Mariña Lucense	Fisterra	Verín-Viana
0	1,400.00 €	1,400.00 €	1,400.00 €	1,400.00 €	70.93 €	77.62 €	90.57 €
5	1,400.00 €	1,400.00 €	1,400.00 €	1,400.00 €	256.06 €	261.81 €	272.97 €
10	1,400.00 €	1,400.00 €	1,400.00 €	1,400.00 €	415.40 €	420.35 €	429.95 €
15	1,900.74 €	1,550.47 €	1,552.23 €	1,555.65 €	703.01 €	709.04 €	720.72 €
20	2,476.38 €	1,723.44 €	1,727.23 €	1,734.57 €	994.03 €	1,001.49 €	1,015.94 €
25	3,655.77 €	2,077.83 €	2,085.77 €	2,101.16 €	1,450.02 €	1,461.12 €	1,482.63 €
30	4,042.34 €	2,193.99 €	2,203.30 €	2,221.32 €	1,653.63 €	1,665.65 €	1,688.94 €
35	4,202.33 €	2,242.06 €	2,251.93 €	2,271.04 €	1,776.97 €	1,789.18 €	1,812.83 €
40	4,169.13 €	2,232.09 €	2,241.84 €	2,260.73 €	1,831.78 €	1,843.55 €	1,866.33 €
45	4,089.25 €	2,208.09 €	2,217.55 €	2,235.90 €	1,863.54 €	1,874.74 €	1,896.44 €

3.4.4 The effect of wildfire intensity on expected losses

The intensity of a wildfire causes variations in the NPV of forest investments. Thus, in all previous cases it is assumed that the wildfire burns all of the forest area and that there is no salvageable wood. Table 3.5 has been designed to analyse the effect of intensity on the landowners' damage, in which it is supposed that a different percentage of burned timber could be salvageable for the purpose of selling.

TABLE 3.5: Economic damage to landowner depending on wildfire intensity.

Year	Without insurance	Area low-Risk: A Mariña Lucense		Area Mid-Risk: Fisterra		Area High-Risk: Verín-Viana	
		Without restoration	With restoration	Without restoration	With restoration	Without restoration	With restoration
0	1,400.00 €	1,400.00 €	70.93 €	1,400.00 €	77.62 €	1,400.00 €	90.57 €
5	1,400.00 €	1,400.00 €	70.80 €	1,400.00 €	76.56 €	1,400.00 €	87.71 €
10	1,400.00 €	1,400.00 €	70.69 €	1,400.00 €	75.64 €	1,400.00 €	85.24 €
15	1,550.22 €	1,375.21 €	115.90 €	1,376.97 €	121.93 €	1,380.39 €	133.61 €
20	1,722.91 €	1,346.71 €	167.91 €	1,350.50 €	175.37 €	1,357.84 €	189.82 €
25	2,076.73 €	1,288.31 €	274.56 €	1,296.25 €	285.66 €	1,311.64 €	307.16 €
30	2,192.70 €	1,269.17 €	309.48 €	1,278.47 €	321.50 €	1,296.50 €	344.79 €
35	2,240.70 €	1,261.25 €	323.90 €	1,271.12 €	336.11 €	1,290.23 €	359.76 €
40	2,230.74 €	1,262.89 €	320.85 €	1,272.64 €	332.62 €	1,291.53 €	355.41 €
45	2,206.77 €	1,266.85 €	313.58 €	1,276.32 €	324.79 €	1,294.66 €	346.49 €

In order to represent the economic damage of a wildfire, we assume for illustration purposes that 50% of the wood production has been burned. In this situation, and as expected, the landowners' damage diminishes in comparison with higher degrees of affection, so that the affected timber is reduced. The losses are even smaller if the landowners have taken out insurance with post-wildfire restoration. So, the landowners are not only concerned about the occurrence of wildfires, but also about their intensity and the wood value that cannot be recovered after a wildfire.

3.5. Discussion

Manley and Watt (2009) highlight the existence of a limited number of studies that deal with forest insurance models (Brunette and Couture, 2008; Holecy and Hanewinkel, 2006). This reduced amount of literature has been recently extended by Brunette *et al.* (2012). However, these contributions provide different perspectives on forest insurance issues and depart significantly on their methodological approaches. In this regard, for example, Brunette and Couture (2008) look at public compensation versus insurance, highlighting the negative influence of public compensation after catastrophic events on both, the investment in protective forest management activities, and the development of private insurance markets. The authors conclude that public funds are used to compensate private damages that could be otherwise covered by private insurance markets without affecting the public budget. Holecy and Hanewinkel (2006) provide a theoretical framework and empirical estimation of forest insurance premiums that may be useful for researchers in this field, finding that the insurance model provides high premiums, especially for higher age clasess. Brunette *et al.* (2012) look at the demand of insurance under an ambiguous scenario, characterized by the existence of unknown probabilities about the occurrence of risky events. In an experimental context, they find that ambiguity increases the willingness to pay for insurance. The current contribution adds to the previous literature in two ways. First, it looks at the impact of the provision of forest insurance covering restoration costs after wildfires on forest optimal rotations, finding that forest rotation is sensitive to insurance conditions. Furthermore, it assess empirically the changes in NPV that may occur for landowners when they buy a private insurance covering restoration costs. Economic results expressed by NPVs are simulated under different risk scenarios. Future research may add to the present conclusions by analysing how insurance contracts (that are currently being offered in various countries, see for example Mahul and Stutley, 2010) may change incentives for better management and landowner's preventive efforts. Furthermore, and in a more aggregated level, industry incentives may also be changed due to the existence of insurance and differences in rotations; and as such, productivity of some regions may be enhanced just by the development and provision of insurance markets, particularly if potential restoration costs are included. Thus, multiple applications remain to be analysed in order on how to better design insurance policies that increase social welfare.

3.6. CONCLUSION

Landowners may take out the insurance policy described in this study, as a result of which the expected forest losses in the event of fires are reduced. However, returns from forests also depend on the landowners' investment in forest management. This influences the risk of wildfire and, subsequently, the insurance premium. Forest management depends on its cost and the forestry policy applied. The latter is exogenous to the landowners and to the insurance company, but it can affect the wildfire risk depending on the stringency of public policy (Yoder, 2008). All of this is taken into account to determine the optimal premium, which is calculated according to the wildfire risk, the value of possible damage, the cost of forest regeneration and the fire intensity. Finally, this insurance premium is conditioned by the level of coverage.

However, if the insurance policy does not cover any restoration measures, then the landowners may only be able to guarantee possible timber damages and not retiming a new harvest of forest land. Therefore, a restoration policy could guide the production of wood after wildfires. Without restoration, timber production is not guaranteed in the future, and this may pose additional future effects related to the viability of the forest sector and the availability of timber.

In this research, the optimal rotation is linked to the risk of wildfires and the interest rate, in the same way as Reed (1984). Nevertheless, the differences between the risk levels of the districts are fairly low, so the optimal rotation does not change significantly throughout the areas. However, larger risk differences will result in significant changes. Furthermore, if the insurance company does not identify the individual risk of each insured landowner or if there are larger differences between the expected average risk (which is used to compute the premium) and the specific district risk, this will affect the NPV.

The presence of forest restoration in the insurance policy deserves further consideration. Reforestation after a wildfire is important in order to be able to continue with forest production and to prevent land being abandoned. This coverage is also important because the landowner may not have enough resources after suffering from wildfire losses to cover additional costs. Restoration actions also have positive effects for society, because continuing forest production increases overall ecosystem services.

This research framework extends the knowledge of wildfire insurance, and helps to understand the different assets that could be covered with an insurance policy and how they affect forest management and profitability. Future research may extend these results using actuarial methods.

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CHAPTER 4: THE PRODUCTION OF FOREST ECOSYSTEM SERVICES WITH INSURANCE

Abstract: The production of forest ecosystem services is very important for the wellbeing. In many countries, wildfires are the main risks that affect forest production, resulting in both private and public losses (due to the loss of ecosystem services). We analyse the role of forest insurance as an incentive to provide ecosystem services. In our setting, forest insurance can be subsidized by social planners in order to increase the provision of ecosystem services. We find that forest insurance policies can create suitable incentives for producing forest ecosystem services. We simulate the impact of forest insurance in a special case of production of *Pinus pinaster* Aiton. In this simulation, an economic incentive is included in order to link the landowner and public interests through the insurance policy. In summary, this paper highlights the importance of forest insurance as a means of guaranteeing the continuous production of forest ecosystem services.

Keywords: Ecosystem services, provision of public goods, forest management, forest valuation, incentives, insurance.

4.1. INTRODUCTION

For a landowner, decisions related to forest management are conditioned by the value of timber and forest management costs. However, society at large is also influenced by private forest management decisions, as ecosystem services are needed for their survival or recreation. In this way, the society consumes environmental services to improve their wealth. Some examples of these services are the water or air quality, the biodiversity or the recreational values. Hence, the production of these services is very important to the society and the social planner is interested in protecting this forest output using public policies. In many countries wildfires are becoming the main risks that affect forests. If a wildfire occurs, the forest value decreases, both in economic terms (private value) and social terms (public good), due to the reduction of the ecosystem services generated. The risk of fire depends on several factors, including socio-economic characteristics, forest management, and forestry law. Certain preventive measures may reduce wildfire risks.

The wildfire risk influences the forest valuation, given that the production of each forest rotation depends on whether wildfires occur or not. Therefore, both, the private landowner and the society as a whole will lose welfare if a wildfire occurs. To calculate the forest valuation the wildfire risk should be included as well as the timber stock and the ecosystem services. In practice, calculating the Net Present Value (NPV) of a forest involves both market and non-market values. The former is related to the forest production that can be valued at market prices, while the latter does not have specific market prices, valuated using special techniques, such as contingent valuation, travel cost or hedonic prices, among others. However, the landowners will include in their valuation the goods and services for which payments are received.

On the other hand, forest management also has a private or public cost, and this affects the quality and quantity of forest production and other natural resources, such as water or soil. Thus, the landowners' decisions determine, for example, the effect of the size of timber stock on carbon sequestration, or the biodiversity level that society can enjoy as a whole. Following this argument, it is important to develop policies to encourage the creation of ecosystem services (Wünscher *et al*., 2008). Therefore, the public policy may influence the production of ecosystem services using incentives, and regulations. Therefore, the government decisions also influence the ecosystem services production.

The social planners can design public policies in which payments or incentives are included to encourage the creation of ecosystem services. Therefore, some different types of contracts can be used with the aim of involving the landowner in the generation of ecosystem services (Engel *et al*., 2008) and as a result, social welfare may increase (Pagiola *et al.*, 2005; Wunder, 2008). In this context, the landowner will also have more public and private economic incentives to carry out production in their forest land (Tallis *et al.*, 2008), and consequently less rural land may be abandoned (Daniels *et al.*, 2010). These contracts could give landowners the chance to access certain markets or resources (land-use rights and/or access to markets through certification), and to also receive a partial transfer or a form of payment in exchange for the provision of ecosystem services (Wymann von Dach *et al.* 2004). Therefore, a public policy could introduce tax incentives, subsidies or regulations to encourage the production of forest goods and services (Cortner *et al.*, 1996; Jacobson *et al.*, 2009). These actions may have different objectives, such as cleaning, prescribed burning and/or the implementation of preventive infrastructure (Vaske, 2005). Therefore, an insurance payment could be used to motivate the landowner decisions according to ecosystem services production. This type of incentive for ecosystem services is not considered in any previous research. In the current paper these incentives are included in the forest valuation to identify their influence on forest management decisions.

As the wildfires is one of the most important hazards that forest investments are exposed to, the landowners could contract a forest insurance policy to protect themselves against wildfire losses (Chen *et al.*, 2014). In several countries, this type of insurance is subsidized to encourage market provision (Goodwin and Vado, 2007). However, this could be also used to develop better forest management practices or to increase the production of ecosystem services. In this way, the public policy could be more or less extrict in order to achieve its objectives. Thus, if the forest policy includes compulsory forest insurance to encourage the production of ecosystem services, then the behaviour of landowners, and forest management are likely to change. Mandatory insurance may also be important for choosing the type of forest or the level of investment in forest management. Accordingly, all of these considerations can change the production of ecosystem services and forest valuation.

This paper introduces a forest insurance policy as a tool to cover wildfire damages, as it outlines incentives for the generation of forest ecosystem services. This insurance policy is considered when assessing the present value of forest rotation, using the rotation model postulated by Faustmann (Faustmann, 1849), and extending it according to Hartman's model (Hartman, 1976). Using this model, the landowner's wealth and the creation of social welfare will be analysed. Following these models, in this research will be developed incentives to produce environmental services. To achieve these goals, this chapter begins with a literature review about forest valuation and forest insurance literature. The research carries on describing the wealth of both, the landowner and society at large. Therefore, the NPV is presented to value the timber stock from the perspective of the landowner, public interest and society. Next, the effects of insurance on private and public welfare are examined in depth, followed by an analysis of the implication of forest incentives in private and public welfare. To this end, an empirical simulation which complements the theoretical previous framework is developed for the Galician production of *Pinus Pinaster* Aiton. Finally, forest valuations with and without insurance incentives are simulated. The main conclusions of this research and simulations are described in the final section.

4.2. BACKGROUND

Traditional applications of the Faustmann rotation model (Faustmann, 1849) make it possible to calculate the optimal forest rotation, ignoring all of the externalities of forest production. However, more recent research allows for the inclusion of ecosystem services into forest valuation, after the seminal paper by Hartman, (1976), including the recreational value (Englin *et al.* 2000), or water quality (Creedy and Wurzbacher, 2001). There are many services in addition to wood production that should be included in forest valuation, including the quality and the quantity of ecosystem services (Krieger, 2001). Nevertheless, the Faustmann rotation model is taken into account in this research, as it is used accounting for other variables, such as the insurance (as a cost in forest valuation or incentives to produce ecosystem services). We acknowledge that others papers, such as Reed (1984), have taken into account the wildfires risk in the forest valuation.

There is a considerable amount of academic research in which insurance is studied as coverage against possible damages ((Brunette and Couture, 2013; Ehrlich and Becker, 1972; Rees and Wambach, 2008). The application of forest insurance depends on the policymaker and the insurance companies (Goodwin and Vado, 2007). If subsidies are provided for forest management, then the behaviour of the landowners will change in such a way that they will invest less in management and take out less insurance (Brunette and Couture, 2008). Depending on whether the insurance policy is pooled or individualized, the insurance demand and the investment in forest management will also be affected (Lankoande *et al.*, 2005). All of these issues may have an impact on the generation of ecosystem services. Therefore some of them are taking into account in the current research.

Research in environmental economics and forest management has not yet examined in depth the use of forest insurance as a tool to cover wildfire damages (Manley and Watt, 2009). One contribution is the study by Holecy and Hanewinkel (2006), in which an insurance model was developed for the conifer reserves in the southwest of Germany. In their analysis, a catastrophic risk model is used and forest production is valued. As far as we know, there are no scientific references in which insurance is analysed as an incentive to produce or guarantee a certain level of ecosystem services. In one of the closest references to this work, Brunette and Couture (2008), compares public compensation versus private insurance after catastrophic events, highlighting the negative influence of public compensation after catastrophic events, on both the investment in protective measurements and the development of insurance markets. Most recently, Brunette *et al.* (2012) applied an insurance model under ambiguity, observing that the willingness to pay is higher in the context where there are unknown probabilities of wildfire occurrence. This paper contributes towards this scarcely explored area, analyzing the influence of insurance policies on forest management. Pinheiro and Ribeiro (2013) and Barreal *et al.* (2014). use the forest insurance to private landowners to reduce their investment risk. In particular, in Pinheiro and Ribeiro (2013) the forest valuation is applied to analyse the wildfire risk, the forest insurance and the forest plantation implications. Barreal et al. (2014) analyse the forest insurance as a tool to secure the restoration forest. The forest valuation is also used to analyse the effect of forest insurance on landowners' wealth.

. Recent papers relate the insurance program with the coverage of carbon credits (Subak, 2003; Wong and Dutschke, 2003 Figueiredo *et al.*, 2005). In this area, Grover *et al.* (2005) design an insurance program in which only the losses of carbon credits are covered. With this framework, the research analyses the effect of hurricanes risk and forest insurance in the carbon sequestration. Therefore, some papers study the forest insurance a tool to protect the income that the ecosystem services provide to the landowner or society. However, none of them uses the forest insurance as a tool to protect and promote carbon sequestration.

4.3. THE LANDOWNERS' INVESTMENT MODEL

Landowners aim to maximize profits on their forest investment. The most commonly used baseline model is Faustmann's rotation model (1849), which was later extended by several authors, including Pearse (1967) and Reed (1984). According to this framework, authors such as Gaffney (1957), Samuelson (1976) and Walter (1980) have examined the forest valuation models in depth, in which the discount factor and/or the forest production expenses are included.

Based on this earlier research, the NPV of forest production for one rotation is calculated in order to understand the economic implications of forest insurance on forest management (Hanewinkel *et al.*, 2011). This is also considering that landowners could take management or financial decisions at the end of each rotation. In this way, the forest production has returns that are related to the forest growth rate and its price. It is assumed that the standing timber stock value is represented by V_m, which depends positively on the standing timber stock [$V_m'(Q)>0$], and the time factor [$V_m'(t)>0$], while the timber price is exogenous, and given by the market.

On the other hand, additional forest management costs (C) could be included. These costs depend on the self-protection expenses (s) and standing timber stock (Q), which are positively related to these management expenses [$C'(s)>0$; $C'(Q)>0$]. In all forest rotations, the landowner pays these costs, so the new NPV should take this into account.

If we assume that the forest production is conditioned by the risk of a wildfire, this risk depends on the self-protection expenses (Chang, 1983, 1984; Amacher *et al.*, 2009), so that this relationship is represented by δ (s) $\in$ [0,1], which has a negative effect on the NPV [$NPV'(\delta)<0$], and on the self-protection expenses [$\delta'(s)<0$] (Martell *et al.*, 1998; Amacher *et al.*, 2005). The forest management influences the forest insurance demand. Thus, depending on whether the insurance integrates the self-protection strategies that allow for the reduction of the probability of a disaster, the insurance contract and self-protection measures will be respectively complementary or substitutive (Ehrlich and Becker, 1972). In this model, the landowners pay all self-protection expenses. This payment identifies the landowners' aptitude towards wildfire risk and their knowledge of it.

The wildfire risk will affect the NPV because it could cause damages (D_v), which depend on the fire intensity (I), standing timber stock (Q), the time factor (t), and restoration costs after wildfires (h). Thus, damages will increase if the intensity, the standing timber stock or restoration costs increase. As a result, there is a positive relationship between these variables and the damage function [$D_v'(I)>0$; $D_v'(Q)>0$; $D_v'(h)>0$].

In order to protect against the risk of wildfires, landowners may wish to take out a forest insurance policy in order to be covered against the possible losses. The owner (insured) has to pay an insurance premium (α), which is positively related to the potential losses, which include the burned standing timber stock and potential restoration costs [$\alpha'(Q)>0$; $\alpha'(h)>0$]. The insurance premium is the cost of being insured. In case of wildfire, landwonwers have the right to receive compensation for their damages. This compensation will be set according to recoverable timber, insurance coverage and timber stock. Therefore, the possible economic losses will be reduced.

In this model, it is assumed that the restoration costs are fully covered by the insurance policy [h=1]. Otherwise, the premium is negatively related to coverage rate of timber damages (μ) and self-protection expenses [$\alpha'(s)<0$; $\alpha'(\mu)<0$]. So, if the risk of damages, or coverage level increases and/or self-protection expenses decreases, then the insurance premium is higher. The self-protection expenses are very difficult to be observed by the insurance company; however, in the insurance policy certain requirements to evaluate this self-protection could be included. For example, the insurance company could require prior forest certification or all information about the self-protection activities that are developed according to a protection plan. In this way, the asymmetric information can be also reduced. The coverage rate of timber damages could be total, partial or not being considered [$\mu \in [0,1]$]. If the landowners take out an insurance policy, then the total cost of forest production will be higher, while the risk of recording wildfire damages will decrease. This reduction depends on the coverage level, *ceteris paribus*. Also, the model assumes that the landowner contracts forest insurance at the beginning of the forest rotation. However, the insurance policy will be paid every year until the end of the forest rotation. Finally, afforestation costs (R) are considered as a fixed cost that all landowners should pay. All previous factors are updated by a continuous discount factor with an interest rate (r). However, this factor is not applied to the harvesting cost, as this is paid at the beginning of the forest rotation. Therefore, taking into account all these previous considerations, Eq. 4.1 is formulated.

$$NPV_t = \left(V_m\left(Q,t\right) - \alpha\left(Q,t,s,\mu,h\right) - C\left(Q,s\right) - \delta\left(s\right)D_v\left(Q,t,I,\mu\right)\right)e^{-rt} - R \qquad [4.1]$$

Proposition 4.1: *Landowners maximize their NPV, when the growth rate of the value of the standing timber stock with insurance against the risk of wildfires is equal to the interest rate. This is directly derived from the Hotelling rule. Meanwhile, the equilibrium point determines the optimal forest rotation (T^*).*

Demonstration 4.1: Landowners try to maximize the previous equation in order to obtain the highest forest value. Therefore, the period that maximizes the NPV according to the value of the standing timber stocks (T^*) is found.

To obtain the optimal forest rotation, the first order conditions are computed. Thus, the partial derivative of this equation is taken with respect to time and its result is set equal to zero. Then, Eq. 4.2 is obtained, which represents the maximum NPV. Solving Eq. 4.2, we find the solution expressed in Eq. 4.3. On the left hand side, this shows the interest rate, while on the right hand side, it represents the rate of growth value of the standing timber stock with insurance against the risk of wildfires. Therefore, the optimal forest rotation is achieved when the value of the marginal growth of forest value is equal to the interest rate. This equilibrium depends on the insurance policy, the wildfire risk, the timber stand, and the forest management.

$$\frac{\partial NPV_t}{\partial t} = \left(V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - \delta(s) D_v'(Q,t,I,\mu)\right) e^{-rt} - re^{-rt}\left(V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s) D_v(Q,t,I,\mu)\right) = 0 \quad [4.2]$$

$$\frac{V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - \delta(s) D_v'(Q,t,I,\mu)}{V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s) D_v(Q,t,I,\mu)} = r \quad [4.3]$$

This equation reflects how the variables included in the NPV equation affect the optimal forest rotation. In this way, if the timber stock grows quickly, then the optimal forest rotation will be achieved faster than in the case of slow growing species, ceteris paribus. In summary, the type of standing timber stock will condition the optimal forest rotation.

Proposition 4.2: *Optimal forest management will be achieved when the marginal costs of forest management are equal to the marginal reduction of the insurance premium and wildfire damages.*

Demonstration 4.2: Returning to Eq. 4.1, it is possible to compute the optimal forest management that maximizes the NPV. The landowner invests in management until the marginal revenues of this activity are equal to zero, so that the partial derivative of Eq. 4.1 is taken with respect to the self-protection expenses and its result is set equal to zero. Using this expression, the point at which the landowner is indifferent between investing or not in forest management can be established (See Eq. 4.4). Thus, if this equation is solved, Eq. 4.5 can be obtained.

$$\frac{\partial NPV_t}{\partial s} = \left(-\alpha'(Q,t,s,\mu,h) - C'(Q,s) - \delta'(s) D_v(Q,t,I,\mu)\right) e^{-rt} = 0 \quad [4.4]$$

$$C'(Q,s) = -\alpha'(Q,t,s,\mu,h) - \delta'(s) D_v(Q,t,I,\mu) \quad [4.5]$$

According to the previous equation, the landowners will make efforts in forest management up to the point where the marginal cost of forest management is equal to the marginal reduction on the insurance premium and the expected losses. In this way, if the marginal cost of forest management is larger than the marginal reductions on wildfire risk, then the landowner will be spending more money than the reduction caused to the risk of damage. The opposite occurs when the marginal cost is lower than the marginal reduction on risk.

Proposition 4.3: *The NPV is maximized (with respect to the quantity of standing timber stock), when the marginal value of the timber stock is equal to the sum of the marginal insurance cost, the expected marginal losses caused by fires, and the marginal management expenses.*

Demonstration 4.3: If the landowners wish to maximize their standing timber stock value, then they should maximize the NPV with respect to the timber stock. Therefore, the partial derivative of Eq. 4.1 with respect to the timber stock is taken and its result is set equal to zero. In this way, Eq. 4.6 is obtained, and reorganizing the terms, the optimal standing timber stock which maximizes the NPV can be achieved (Eq. 4.7).

$$\frac{\partial NPV_t}{\partial Q} = \left(V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - C'(Q,s) - \delta(s) D_v'(Q,t,I,\mu)\right) e^{-rt} = 0 \quad [4.6]$$

$$V_m'(Q,t) = \alpha'(Q,t,s,\mu,h) + C'(Q,s) + \delta(s) D_v'(Q,t,I,\mu) \quad [4.7]$$

According to the previous equation, the optimal NPV is achieved when the marginal increase in the timber stock value is equal to the marginal increase of forest management, marginal expected damages and the marginal insurance premium.

4.4. THE TOTAL NPV FOR SOCIETY

When taking into account the fact that the timber stock produces ecosystem services (Hartman, 1976), then the valuation of these externalities (γ) should be included into Eq. 4.1. These ecosystem services depend on time (t) and on the standing timber stock (Q). Also, the value of such ecosystem services has to be updated by a discount factor. It is assumed that these services are all positive and depend inversely on the wildfire risk [$\gamma>0$; $\gamma'(\delta)<0$]. Consequently, the wildfire risk conditions the total NPV for the society as a whole.

Therefore, the new forest valuation could be formulated as in Eq. 4.8, in which the first part of the equation represents the net profits that the landowner makes from wood production, while the second part is the wealth that the society achieves through the ecosystem services produced by the forests.

$$\begin{aligned} NPV_t = & \left[\left(V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s)D_v(Q,t,I,\mu)\right)e^{-rt} - R\right] + \\ & + \left[\left(\gamma(Q,t) - \delta(s)D_\gamma(Q,t,I)\right)e^{-rt}\right] \end{aligned} \qquad [4.8]$$

In the previous equation, the private and public damages are different [$D_v(Q,t,I,\mu) \neq D_\gamma(Q,t,I)$]. The damages depend, in both cases, on the standing timber stock, time and wildfire intensity. However, the landowner can recover the rate of affected timber stock that is insured.

Proposition 4: *The optimal forest rotation is achieved when the net growth rate of the value of the timber stock and the value of ecosystem services with insurance is equal to the interest rate.*

Demonstration 4: The optimal forest rotation can change with respect to Eq. 4.7 when private and public interests are taken into account, so that there is a new rotation that is achieved when Eq. 4.8 is maximized respect to time. To solve the maximization problem, the partial derivative of Eq. 4.8 has to be taken with respect to time, and its result should be set equal to zero. Thus, Eq. 4.9 is reached.

$$\begin{aligned} \frac{\partial NPV_t}{\partial t} = & \begin{bmatrix} \left(V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - \delta(s)D_v'(Q,t,I,\mu)\right)e^{-rt} \\ -re^{-rt}\left(V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s)D_v(Q,t,I,\mu)\right) \end{bmatrix} + \\ & + \left[\left(\gamma'(Q,t) - \delta(s)D_\gamma'(Q,t,I)\right)e^{-rt} - re^{-rt}\left(\gamma(Q,t) - \delta(s)D_\gamma(Q,t,I)\right)\right] = 0 \end{aligned} \qquad [4.9]$$

This is described in Eq. 4.10 and it is also based on the Hotelling rule, while including the production of positive externalities. The equilibrium determines that the optimal forest rotation is achieved when the rate of growth of the value of the standing timber stock and production of ecosystem services with insurance is equal to the interest rate.

$$\frac{V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - \delta(s)D_v'(Q,t,I,\mu) + \gamma'(Q,t) - \delta(s)D_\gamma'(Q,t,I}{V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s)D_v(Q,t,I,\mu) + \gamma(Q,t) - \delta(s)D_\gamma(Q,t,I)} = r \qquad [4.10]$$

One conclusion of this equation shown above is the importance of externalities on the optimal forest rotation. If the generation of ecosystem services occurs quickly, then the optimal forest rotation should be shorter in comparison with the case of slow growing forest species, ceteris paribus. The presence of externalities increases the total NPV for society and it is larger than if the standing timber stock is only valuated. The optimal forest rotations of Eq. 4.3 and Eq. 4.10 are different if the marginal growth of forestry externalities is positive [$\gamma'(t)>0$]. This happens because the private interests do not include the externalities, or the risk of losing them, in their productive decisions. To sum up, to create incentives for the creation of externalities, measures should be developed to share the value of ecosystems services with landowners. With this, the optimal forest decisions will depend, mainly, on standing timber stock but, secondarily, on the value of these services.

Proposition 4.5: *From the perspective of forest externalities, the optimal rotation depends on the marginal production of ecosystem services and their potential destruction.*

Demonstration 4.5: If we only consider that the ecosystem services valuation is represented by Eq. 4.11, the optimal forest rotation will change. This valuation is determined by the production of ecosystem services and the risk of losing them.

$$NPV_{t(Externalities)} = \left(\gamma(Q,t) - \delta(s) D_{\gamma}(Q,t,I)\right) e^{-rt} \quad [4.11]$$

With the previous equation, the optimal forest rotation of the production of ecosystem services can be obtained. Then, this equation has to be derived with respect to time and this result has to be set equal to zero. Thus, the optimal forest rotation is represented by the equilibrium point of Eq. 4.12.

$$\frac{\gamma'(Q,t) - \delta(s) D_{\gamma}'(Q,t,I)}{\gamma(Q,t) - \delta(s) D_{\gamma}(Q,t,I)} = r \quad [4.12]$$

There are no variables in this equation that alter the NPV for the landowners, as they decide on the optimal forest rotation without considering the production of ecosystem services. This situation is common because public policy often does not pay for these services and the landowners will not receive any income for this kind of production.

Proposition 4.6: *The optimal valuation of forest production is achieved when the marginal productions of timber and ecosystem services are equal to their respective marginal costs.*

Demonstration 4.6: The forest production involves the standing timber stock and ecosystem services. Accordingly, in order to find the optimal forest production, in which the maximum total NPV for society is obtained, Eq. 4.8 will be maximized with respect to the standing timber stock. To solve this problem, the partial derivative of Eq. 4.8 has to be taken with respect to the standing timber stock in order to obtain the maximum forest value according to timber stock and ecosystem services will be reached.

To solve the maximization problem, as customary, the partial derivative has to be taken with respect to Q and the result set equal to zero. Reorganizing the terms, the optimal standing timber stock could be described as a point at which its marginal production is equal to its marginal costs and risks. This equilibrium is depicted by Eq. 4.13.

$$V_m'(Q,t)+\gamma'(Q,t)=\alpha'(Q,t,s,\mu,h)+\delta(s)\left[D_v'(Q,t,I,\mu)+D_\gamma'(Q,t,I)\right]+C'(Q,s) \qquad [4.13]$$

This new approach determines that the optimal forest production may be different to that of Eq. 3.7. This is because this new valuation takes into account both the marginal revenues and marginal costs of standing timber stock and ecosystem services.

4.5. ECOSYSTEM SERVICES, INCENTIVES AND INSURANCE

To encourage the production of ecosystem services, it is necessary to develop appropriate forest policies. Based on this approach, the landowner could receive an incentive to produce and manage their forest lands, so that the ecosystem services will also be produced.

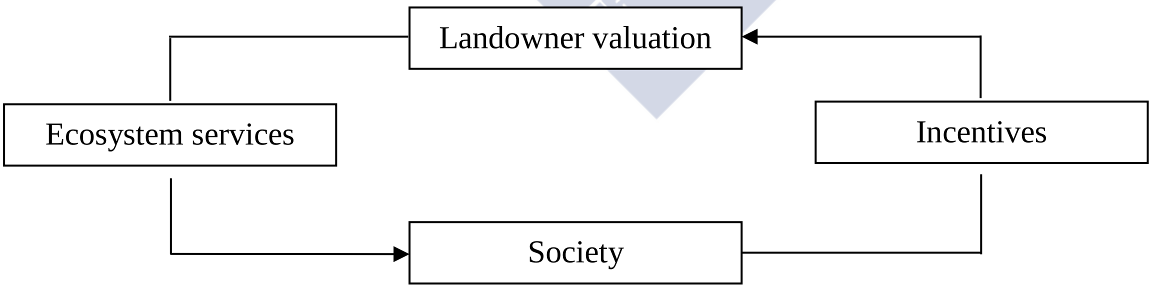

FIGURE 4.1: Incentives to produce ecosystem services.

In Figure 4.1, the welfare gain of public interests and landowners is illustrated. Incentives can be paid by the public policy to encourage landowners to produce ecosystem services. In this way, society could achieve better ecosystem services, but will have to pay for them. Thus, the landowners earn more money through forest production but have to satisfy the demand for ecosystem services. In this case, the public authorities may design measures to develop this sharing of benefits, which could be achieved through public policy.

The marginal cost (*MC*) and marginal revenues (*MR*) for both private landowners (P_v) and the general public (P_u) should be analysed to learn more about the suitability of various forest policies. Following Eq. 4.7 and Eq. 4.13, the difference of marginal revenues and costs between the landowner and public interests can be calculated. Thus, the condition that should be satisfied in order to introduce forestry incentives is described by the Eq. 4.14.

$$MR_{Pu} - MR_{Pv} > MC_{Pu} - MC_{pv} \qquad [3.14]$$

The equation shown above concludes that a given public policy would be designed to apply economic incentives for the production of ecosystem services, if the difference between marginal revenues is greater than the corresponding difference of marginal costs. Thus, a given forest policy could include incentives to take out an insurance policy as long as the difference in the marginal revenues between the private and public interests is greater than the difference in their corresponding marginal costs.

Proposition 4.7: *The regulator should invest in incentives to produce ecosystem services as long as the marginal value of their production is greater than the expected marginal damage.*

Demonstration 4.7: Based on Eq. 4.14, Eq. 4.15 can be obtained. The marginal increase of the externality should be equal or greater than its potential destruction. This condition will be met when the wildfire risk is equal or greater than zero and lower than one ($0 \leq \delta(s) < 1$). According to this condition, the expected damage risk will grow below proportionally with the services. However, Eq. 3.15 is not met if the wildfire risk is equal to one ($\delta(s)=1$). Therefore, the public authorities will be interested in investing in incentives to introduce forest insurance if the marginal increase of ecosystem services is greater than the marginal damage risk.

$$\gamma'(Q,t) > \delta(s) D_{\gamma}'(Q,t,I) \qquad [4.15]$$

Assuming that the public policy provides an economic incentive (w_γ) to landowners for the production of ecosystem services, this payment will depend on timber stock (*Q*) and time (*t*). A direct relationship between the growth of ecosystems services and incentives is also assumed [$w_\gamma'(t)=\gamma'(t)$], but not necessarily related with the timber production [$w_\gamma'(t)\neq V_m'(t)$]. This consideration is taken given that the timber production does not grow at same rate as forest services production. Therefore, there may be payments from the public policy to the landowners, and consequently, there is a wealth sharing between the private and public interests. This payment could be designed according to several criteria. Nevertheless, in this paper, this incentive is focused on subsidizing the forest insurance in order to protect the production of ecosystem services.

Proposition 4.8: *The government will be interested in investing in incentives to produce ecosystem services if the marginal cost of this incentive will be equal to the marginal growth of the ecosystem services net of the marginal expected damage.*

Demonstration 4.8: The change in public wealth is determined by Eq. 4.16.

$$NPV_{t(Externalities)} = \left(\gamma(Q,t) - \delta(s) D_{\gamma}(Q,t,I) - w_{\gamma}(Q,t)\right) e^{-rt} \qquad [4.16]$$

Based on this equation, the society wants to maximize the public wealth, including the production of ecosystem services with respect to the standing timber stock. Then, the partial derivative with respect to the timber stock is taken and this result is set equal to zero. Solving this equation results in Eq. 4.17, in which society would pay for their ecosystem services until their marginal costs are equal to their marginal values, net of the marginal risk. The following expression is obtained:

$$w_{\gamma}'(Q,t) = \gamma'(Q,t) - \delta(s) D_{\gamma}'(Q,t,I) \qquad [4.17]$$

Proposition 4.9: *The optimal forest rotation will change if the incentives for ecosystem services production are included in the public and private landowner's NPV.*

Demonstration 4.9: Following Eq. 4.16, the partial derivative with respect to time can be taken. Therefore, if this result is rearranged, the optimal rotation is obtained. The optimal age for forest rotation, is achieved when the rate of growth value of externalities with incentives and risk of wildfires is equal to the interest rate. This equilibrium is represented by Eq. 4.18.

$$\frac{\left[\gamma'(Q,t) - \delta(s) D_{\gamma}'(Q,t,I) - w_{\gamma}'(Q,t)\right]}{\left[\gamma(Q,t) - \delta(s) D_{\gamma}(Q,t,I) - w_{\gamma}(Q,t)\right]} = r \qquad [4.18]$$

Now, if the optimal rotation of the previous equation is compared with Eq. 4.12, it is observable that the optimal forest rotation depends on the economic incentives. In other words, the optimal rotation for ecosystem services with incentives is different with respect to those provided without incentives. Note that the effects of the incentives on wildfire risk are not considered.

On the other hand, if the landowner's valuation includes the reception of incentives, then this new NPV is represented by Eq. 4.19. In this case, the landowners earn money for producing ecosystem services, although it is assumed this does not impact the wood production and forest management.

$$NPV_t = \left(V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s) D_v(Q,t,I,\mu) + w_\gamma(Q,t)\right)e^{-rt} - R \qquad [4.19]$$

The optimal rotation for the landowner with incentives can be obtained by taking the partial derivative with respect to time, setting this result equal to zero. In this way, the optimal rotation is reached when the rate of growth value of the standing timber stock with insurance against the risk of wildfires and incentives is equal to the interest rate. This equilibrium is represented by Eq. 4.20.

$$\frac{V_m'(Q,t) - \alpha'(Q,t,s,\mu,h) - \delta(s) D_v'(Q,t,I,\mu) + w_\gamma'(Q,t)}{V_m(Q,t) - \alpha(Q,t,s,\mu,h) - C(Q,s) - \delta(s) D_v(Q,t,I,\mu) + w_\gamma(Q,t)} = r \qquad [4.20]$$

If we compare this equation and Eq. 4.3, it is observable that the optimal rotation for the landowner is modified by the application of incentives, given that the slope of marginal productivity is greater than the marginal productivity without incentives for the same interest rate. Also, it should be noted that the incentives can be of different types, as they could be directed to reduce the forest management expenses, the premium cost or the reduction of the wildfire intensity. All of these measures depend on the public policy.

4.6. EMPIRICAL SIMULATION

4.6.1 The insurance model

In order to simulate the insurance model, firstly, the risk of wildfires should be determined. Thus, it is assumed that the risk is going to be measured geographically according to the Galician Forest Districts in Northern Spain. These districts represent a forest limit which the regional administration organizes the plan to protect forest areas against wildfire. Therefore, this demarcation could be used to implement incentives to produce environmental services because the regional government uses this area to apply other forest policies. Then, following the research of Barreal *et al.* (2012), this risk index is calculated according to the predictions based on climatic and socio-economic conditions for each of the administrative demarcations from 2001 to 2010. Three districts are selected according to the highest, average and lowest wildfire estimated risk indexes. These areas are shown in Figure 4.2. Meanwhile, the dependent variable, which determines the wildfire risk, is the ratio of the total burned forest area divided by the forest area. In summary, and based on the results obtained, the risk of wildfire used in the simulation is 0.07% for “A Mariña Lucense”, 0.57% for Fisterra and 1.55% for Verín-Viana.

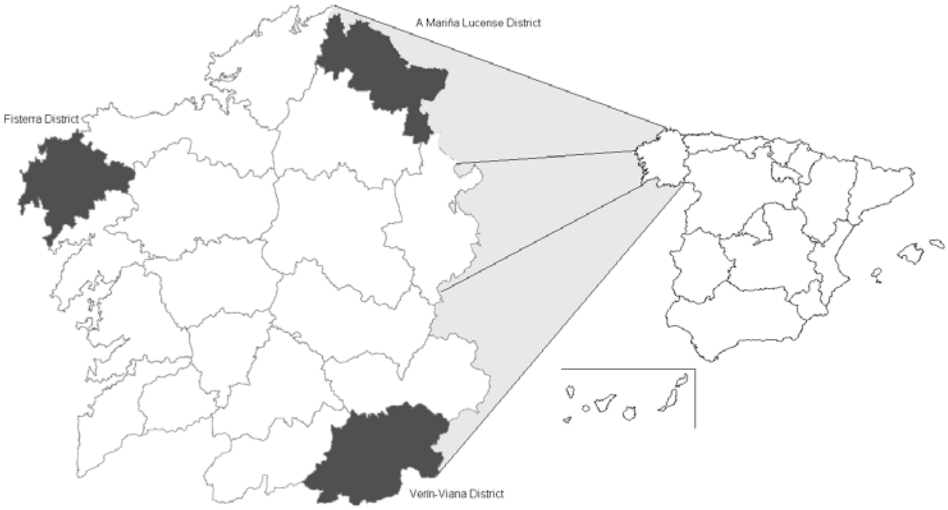

FIGURE 4.2: Galician Forest Districts.

In this research, it is assumed as a main hypothesis that these risk levels do not vary within the same district. Another assumption is that all of the landowners could take out the previously described forest insurance, so all the owners have the same wildfire risk regardless of the size of their land or their type of management. To select the discount factor, the simulation employs a given interest rate of 3%, as used by Pasalodos-Tato *et al.* (2010). The rest of the variables take arbitrary values, given that their respective roles are only to simulate the effects of the forest insurance and to identify their possible implications. The selected value for the insurance coverage is μ=70%, so that on average, the insurance policies do not provide full coverage of the damages, given the existence of deductible fees. In addition, the timber damage coverage is set as a partial coverage, so only commercial values are considered.

4.6.2 Timber forest production

To determine the standing timber stock value, the silvicultural production system based on a regular stand of *Pinus pinaster* Aiton. is taken into account. This species is chosen as it is of great commercial interest in Galicia, and the region has the suitable edaphoclimatic characteristics for its growth. Also, this species is particularly important in terms of the traditional production and uses of the Galician forest, as it is one of the species included by the regional government in the forest incentives program in reforested agricultural lands. The growth rate of this species depends on climate and or soil characteristics, amongst other factors. The Quality II for *Pinus pinaster* Aiton. corresponds to a site index of 170 dm with 20 years as the reference age.

This research uses a simplified regime, which includes the plantation of 1,111 trees per hectare, no thinning during the whole rotation, and a final clear-cut. By increasing the growing space available to the remaining trees, a landowner can increase the growth rate of those trees and, more importantly, the rate at which they increase in value. Thinning can also be used to remove poorly formed trees that would have little future value. Thus, if the landowner does not make these intermediate cuts, the average tree in the final cut will be smaller and it will have less commercial value. Nevertheless, in the case of Galician small non-industrial forest owners, these intermediate cuts is frequently used due to the cost and difficulty of programming thinning. This model also allows for the simplification of the calculations, and easily describes the application in Galicia of the theoretical framework of the restoration insurance model developed in this research.

To determine the restoration costs, the prices included in the afforestation incentives promoted by the Galician Government are applied. These costs are set to a maximum of 1,853 €/ha and include the cost of preparing the soil, buying the seeds or saplings and sowing or planting them, the cost of defending the plants with protectors, or other necessary materials, and the design of preventive actions against wildfires (Consellería de Medio Rural, 2009). It also includes other tasks that could be done immediately after plantation. Therefore, considering average slope and soil conditions and the initial density of this silviculture regime, the restoration cost is assumed to be 1,400 €/ha (BOE, 2010).

The standing timber stock value is calculated from the possible income generated from the final harvest for each possible rotation. The timber price is obtained from Molano *et al.* (2007); these values are the average price at mill gate for the year 2006, which have been updated based on a survey of companies and loggers. The profile curves for this specie have been obtained for each year according to regional publications.

Finally, the net price of forest timber at stump, which is received by the landowner, will have to be reduced by the transportation (6 €/m^3) and logging costs. This last expense depends on the tree size and machine performance, as described in Nakagawa *et al.* (2010). In this way, Eq. 4.21 is used to calculate the timber stock value per hectare (V_k) for *Pinus pinaster* Aiton.

$$V_k = n_k \sum_{i=1}^{3} \left[Q_{ik} \left(Pf_i - C_t - Ca_{i,k} \right) \right] \qquad [4.21]$$

In the previous equation, the forest stand value depends on the density of trees per hectare (n) for the respective year (k) and the value of the standing timber stock. This valuation depends on the timber grade (i). In this model, the timber is graded as pulpwood, sawlogs and premium sawlogs (Table 4.1). The stock per hectare of timber (E), the factory price (Pf) and the harvesting cost (Ca) per m^3 of timber depend on the grade of the forest products. Finally, to determine the net timber stock value, the cost of transportation to the factory per m3 (C_t) is subtracted.

TABLE 4.1: Timber classification according to technical characteristics.

TYPE OF TIMBER	LOGS	DIAMETER	DESTINATION
Pulpwood	2.5 m	Between 4 and 14 cm.	Panel manufacturing as well as pulp
Sawlogs	2.5 m	Between 14 and 24 cm.	Sawn wood manufacturing
Premium sawlogs	2.5 m	bigger than 24 cm.	Premium sawn wood manufacturing

Based on these considerations, the timber stock value per hectare is shown in Figure 4.3. This figure shows that for the first thirteen years, the production value is zero, because the standing timber stock does not have any commercial value or it is too low to cover the costs of harvesting, hauling and transportation. From this point on, the timber stock value starts to grow, although the first stage of production is mainly pulpwood and sawlogs, which have less commercial value than premium sawlogs. This happens because as the diameter of the tree increases, it first produces pulpwood, then sawlogs and finally premium sawlogs, so that the value increases as the timber ages.

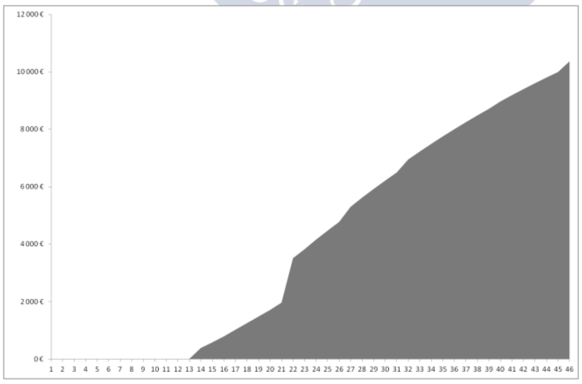

FIGURE 4.3: Timber Stock Value for *Pinus pinaster* Aiton. in Galicia.

4.6.3 A proposal of payment for ecosystem services

The government could pay to guarantee the production of ecosystem services. Then, the public policy could consider the payment for environmental services as an incentive to protect them. In order to design this incentive, it will be necessary to take into account that when the production of ecosystem services increases; the incentive should grow at the same rate. This could be expressed as Eq. 4.22.

$$\frac{\partial w_{\gamma}(Q,t)}{\partial t} = \frac{\partial \gamma(Q,t)}{\partial t} \qquad [4.22]$$

Furthermore, this incentive is not related to the value of the standing timber stock. The growth of this production does not imply that ecosystem services increases at same rate, so the incentive should not depend on timber production. Therefore, the marginal increase of incentive is not equal to the marginal growth of timber stock. Mathematically, this could be expressed as Eq. 4.23:

$$\frac{\partial w_{\gamma}(Q,t)}{\partial t} \neq \frac{\partial V_m(Q,t)}{\partial t} \qquad [4.23]$$

The insurance premium and carbon sequestration are taking into account to design the incentive. In other words, the landowner will receive a payment based on the insurance premium. However, the incentive is designed as a proportional payment of forest insurance according to the carbon sequestration that the plantation made during each year. This proposal takes into account that the incentive not influences the insurance cost, so the incentive does not influence in the premium. To sum up, the Eq. 4.24 represents the premium payment that the landowner will receive for the production of ecosystem services.

$$w_{\gamma}(Q,t) = \frac{\gamma_t}{\gamma_{t-1}} \alpha(Q,t,s,\mu) \qquad [4.24]$$

Other type of incentives could be considered to involve the production of ecosystem services into the landowner valuation. However, this research takes into account the forest insurance because this financial mechanism protects the next forest rotation.

4.6.4 Ecosystem services valuation

Forest carbon sequestration is considered to simulate the production of ecosystem services. To determine this type of externality, the carbon sequestration of *Pinus pinaster* Aiton. is obtained for the Galician forests using the research of Balboa-Murias *et al.* (2006), Barrio-Anta (2006) and Diéguez-Aranda (2009). Based on this information, we obtain the tonnage of CO_2 sequestered per hectare for this type of forest. Then, the production of carbon sequestration is shown in Figure 4.4, in which the ecosystem production grows up during the forest rotation.

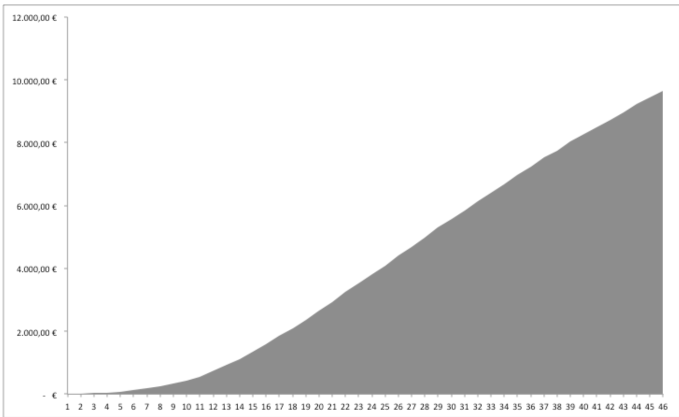

FIGURE 4.4: Carbon sequestration for *Pinus pinaster* Aiton. in Galicia.

To obtain the value of carbon sequestration, the average price of the electronic trading service of carbon dioxide emission rights is employed (SENDECO2, 2013). The average price was 12.67 € per ton for the period between 02/01/2008 to 31/10/2013. The economic value of CO^2 sequestration is calculated by using this market price.

4.7. RESULTS

According to the above data, and Eq. 4.1 and Eq. 4.8, the NPV of forest production for private and public interests can be simulated. Also, the production of ecosystem services can be valued separately from the private and public perspective; namely, this valuation is developed according to Eq. 4.11. The main results are shown in Table 4.2, in which the importance of wildfire risk on the NPV is demonstrated, in the same way as in Reed (1984). Thus, in the district where there is a lower wildfire risk, the forest will be more highly valued. On the other hand, the valuation of ecosystem services is also affected by the wildfire risk, and if their value is added to the NPV, then it will increase. Finally, the optimal forest rotation for the landowner is 36 years and for the public interest is 38 years, considering in first case only the ecosystem services and in second all the forestry production. None of these rotations are affected by the various risk levels used in the simulation. This happens because the insurance premium used equals the risk of wildfires and does not take into account other intermediate cost (such as commercial costs). Furthermore, there is only a minor difference in the optimal forest rotation between forestry districts because the wildfire risk does not change in practice sufficiently to allow for this (Reed, 1984).

TABLE 4.2: Net Present Value for *Pinus pinaster* Aiton.

YEAR	NET PRESENT VALUE FOR LANDOWNER				NET PRESENT VALUE FOR EXTERNALITIES				TOTAL NET PRESENT VALUE FOR SOCIETY			
	Without risk	With risk			Without risk	With risk			Without risk	With risk		
		A Mariña Lucense	Fisterra	Verín-Viana		A Mariña Lucense	Fisterra	Verín-Viana		A Mariña Lucense	Fisterra	Verín-Viana
0	-1,400.00€	-1,400.98€	-1,408.02€	-1,421.66€	0.00€	0.00€	0.00€	0.00€	-1,400.00€	-1,400.98€	-1,408.02€	-1,421.66€
5	-1,400.00€	-1,400.84€	-1,406.90€	-1,418.64€	107.96€	107.88€	107.34€	106.29€	-1,292.04€	-1,292.96€	-1,407.52€	-1,420.31€
10	-1,400.00€	-1,400.72€	-1,405.94€	-1,416.04€	412.97€	412.68€	410.60€	406.58€	-987.03€	-988.04€	-995.34€	-1,009.46€
15	-899.26€	-900.23€	-907.24€	-920.81€	1,007.10€	1,006.39€	1,001.33€	991.52€	107.84€	106.17€	94.09€	70.70€
20	-323.62€	-324.90€	-334.18€	-352.15€	1,606.16€	1,605.04€	1,596.96€	1,581.31€	1,282.54€	1,280.14€	1,262.78€	1,229.16€
25	855.77€	853.74€	839.06€	810.64€	2,084.62€	2,083.17€	2,072.68€	2,052.37€	2,940.39€	2,936.91€	2,911.75€	2,863.01€
30	1,242.34€	1,240.11€	1,223.95€	1,192.66€	2,379.74€	2,378.08€	2,366.11€	2,342.93€	3,622.09€	3,618.19€	3,590.07€	3,535.59€
35	1,402.33€	1,400.04€	1,383.48€	1,351.40€	2,535.94€	2,534.18€	2,521.42€	2,496.71€	3,938.27€	3,934.21€	3,904.90€	3,848.11€
40	1,369.13€	1,366.91€	1,350.86€	1,319.77€	2,560.48€	2,558.70€	2,545.82€	2,520.87€	3,929.62€	3,925.61€	3,896.68€	3,840.65€
45	1,289.25€	1,287.12€	1,271.77€	1,242.03€	2,504.90€	2,503.15€	2,490.55€	2,466.15€	3,794.15€	3,790.28€	3,762.32€	3,708.18€
Max.	1,402.33€	1,400.04€	1,383.48€	1,351.40€	2,560.48€	2,558.70€	2,545.82€	2,520.87€	3,938.27€	3,934.21€	3,904.90€	3,848.11€

The government can provide incentives to encourage landowners to take out forest insurance, so that the forestry policy can include subsidies for the insurance premium based on the production of carbon sequestration amenities. It is therefore simulated that the government pays one part of the insurance cost according to the marginal increase in the carbon sequestered. The NPVs of landowners and public interests are represented in Table 4.3 according to respectively Eq. 4.19 and Eq. 4.16.

TABLE 4.3: Net Present Value with a partial insurance subsidy for *Pinus pinaster* Aiton.

YEAR	NET PRESENT VALUE FOR LANDOWNER WITH PARTIAL INSURANCE SUBSIDY			TOTAL NET PRESENT VALUE FOR PUBLIC INTEREST WITH PARTIAL INSURANCE SUBSIDY		
	A Mariña Lucense	Fisterra	Verín-Viana	A Mariña Lucense	Fisterra	Verín-Viana
0	-1,400.98€	-1,408.02€	-1,421.66€	0.00€	0.00€	0.00€
5	-1,400.84€	-1,406.90€	-1,418.64€	107.88€	107.34€	106.29€
10	-1,400.72€	-1,405.94€	-1,416.04€	412.68€	410.60€	406.58€
15	-900.08€	-906.01€	-917.50€	1,006.24€	1,000.10€	988.20€
20	-324.79€	-333.26€	-349.68€	1,604.93€	1,596.04€	1,578.83€
25	853.86€	840.08€	813.40€	2,083.04€	2,071.66€	2,049.62€
30	1,240.19€	1,224.65€	1,194.53€	2,378.00€	2,365.42€	2,341.06€
35	1,400.10€	1,384.04€	1,352.92€	2,534.11€	2,520.86€	2,495.20€
40	1,366.96€	1,351.24€	1,320.80€	2,558.65€	2,545.44€	2,519.85€
45	1,287.16€	1,272.09€	1,242.89€	2,503.12€	2,490.24€	2,465.29€
Max.	1,400.11€	1,384.10€	1,353.08€	2,568.40€	2,555.03€	2,529.15€

Based on these results, we can observe that the NPV increases slightly for the landowners, so they are more interested in forest production. On the other hand, the net public value of the externalities decreases because the public policy will pay the incentive, although there are more guarantees of continuing the production of ecosystem services because the insurance model includes restoration after wildfires.

Therefore, an insurance policy may include these restoration costs, as this measure guarantees future forest production: the next forest plantation may be controlled then by the insurance policy and, subsequently, the public policy could shape the characteristics of the restoration process that will continue the production of ecosystem services. However, this measure also involves the landowners in the forest production, as their timber stock is insured, at least partially, in exchange for paying a lower insurance premium in comparison to purchasing it in a free insurance market. As a result, the social planner may pay all the coverage of forest restoration and also one part of the timber coverage cost according to the previous incentive. The NPV for the landowner and the ecosystem services to the public interest are included in Table 4.4. However, the landowner faces a lower risk in the forest investment because the losses are smaller at the beginning of the forest rotation. Therefore, if the interest rate does not change, the investment in forestry production is more attractive. Consequently, the ecosystem services are guaranteed by the forest insurance, and the landowners have more incentives to invest in forest production, and also less land may be abandoned.

TABLE 4.4: Net Present Value (NPV) with public subsidy in restoration costs and partial insurance premium for *Pinus pinaster* Aiton.

YEAR	LANDOWNER FOREST VALUATION WITH FULL COVERAGE IN RESTORATION COSTS AND PARTIAL INSURANCE SUBSIDY			EXTERNALITY VALUATION WITH FULL COVERAGE IN RESTORATION COSTS AND 11. PARTIAL INSURANCE SUBSIDY		
	A Mariña Lucense	Fisterra	Verín-Viana	A Mariña Lucense	Fisterra	Verín-Viana
0	-1,400.00€	-1,400.00€	-1,400.00€	-0.98€	-8.02€	-21.66€
5	-1,400.00€	-1,400.00€	-1,400.00€	107.04€	100.44€	87.64€
10	-1,400.00€	-1,400.00€	-1,400.00€	411.96€	404.66€	390.54€
15	-899.56€	-901.78€	-906.07€	1,005.73€	995.87€	976.77€
20	-324.31€	-329.33€	-339.04€	1,604.45€	1,592.11€	1,568.20€
25	854.28€	843.57€	822.82€	2,082.62€	2,068.18€	2,040.20€
30	1,240.57€	1,227.74€	1,202.90€	2,377.62€	2,362.33€	2,332.69€
35	1,400.43€	1,386.73€	1,360.19€	2,533.78€	2,518.17€	2,487.92€
40	1,367.24€	1,353.59€	1,327.14€	2,558.37€	2,543.09€	2,513.51€
45	1,287.41€	1,274.11€	1,248.36€	2,502.87€	2,488.21€	2,459.82€
Max.	1,400.43€	1,386.73€	1,360.19€	2,568.10€	2,552.56€	2,522.47€

4.8. CONCLUSION

This forest valuation exercise extends the models of Faustmann (1849), Hartman (1976) and Reed (1984) with the implications of forest insurance in landowners' valuations. This framework also includes the incentives in the NPV and their effects on the landowner's decisions, with the incentives affecting the NPV and encouraging landowners to produce ecosystem services. The role of the insurance with incentives to produce ecosystem services increases with the forest conservation status, given that the landowners have more economic incentives to develop a better forest management in order to guarantee their production. In order to minimize the moral hazard, the insurance policy should include certain specific forest management requirements that the landowners have to fulfil. In that way, a minimum forest management would be guaranteed, given that the landowners could lose the payments for ecosystem services, if they do not fulfil the insurance policy. In several countries, such as Spain, Canada or Brazil (Mahul and Stutley, 2010), the government currently provides incentives to sign forest insurance contracts through their national agriculture subsidies program. These incentives depend on the public policy and government requirements. Therefore, if the government introduces forest management requirements to obtain insurance subsidies, this public policy could be a measure to protect the production of ecosystem services. Taking into account the results of this research, these subsidies should focus on linking the production of ecosystem services with the subsidy payment. Furthermore, if this subsidy involves conditions to encourage a better forest conservation, then this payment will link the private and public interest.

The application of these incentives is extensive and can be a good mechanism to introduce or consolidate the insurance policy on the forestry areas to produce ecosystem services. Also, these incentives could be used to develop some variables that affect the insurance policy or reduce others, such as forest management expenses or taxes. Obviously, the success of this application depends on the context and on the specific public policies. Therefore, more sustainable development could be achieved in the forest and rural areas through this type of public policy. This research could be extended with an analysis of the landowners' management, based on the type of incentives applied through public policies. Other way to expand this research is by assessing the landowner preferences according wildfire risk perceptions and incentives.

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CHAPTER 5: ANALYSIS OF FOREST INSURANCE DEMAND IN THE NORTH OF GALICIA

Abstract: Forest production faces many risks, including wildfires, pests, floods or strong winds, among others. Landowner may contract a forest insurance to avoid the possible economic losses caused by such events. The current research uses a choice experiment to identify the insurance attributes desirable by landowners. Also, this framework allows for the estimation of the willingness to pay (WTP) for the different insurance attributes and their corresponding marginal utilities. The insurance cost, the coverage level of timber losses, the coverage of restoration costs and the requirement of forest certification are all included as attributes of the insurance contract. A survey of forest owners/managers was conducted in the North of Galicia (NW Spain) collecting a total of 210 responses. Results show that the coverage of restoration costs is the most desirable attribute. The Random Parameters Logit is used to identify the influence of socioeconomic variables the landowners' decisions, showing that social factors, such as the age or the type of landowner affect considerably the forest insurance demand.

Keywords: choice experiment, forest certification, forest insurance, restoration cost, wildfire.

5.1. INTRODUCTION

Wildfires cause many losses in the forest areas which affect both private landowners and public goods (Barrio *et al.*, 2007; González-Gómez *et al.*, 2013). While the landowners lose timber production, they are also focused to restore the burned area to start a new forest rotation. Furthermore, wildfires damage the production of ecosystem services (Hurteau *et al.*, 2013). Thus, society loses the production of environmental services, at least until the starting of a new forest rotation. In Spain, there were around 17,127 wildfires each year during the first decade of the current century (2001-2010). In average, these wildfires affected 113,850 forestry hectares each year (MAAMA, 2012a). The *Pinus Pinaster* (102,117 Ha.) is the main affected species by wildfires in Spain, and the *Eucalyptus globulus* (52,598 Ha.) and *Pinus halepensis* (41,743 Ha.) are respectively the second and the third most affected species during this period (MAAMA, 2012a).

In the specific case of Galicia, located in Norwest Spain, an annual average of 7,242 wildfires affects 28,890 forestry hectares during 2001-2010 (IGE, 2013a). These wildfires mainly affected the plantations of *Pinus pinaster* (54,108 Ha.) (MAAMA, 2012a). *Eucalyptus globulus* (40,906 Ha.) is the second most affected plantation, and the third, *Quercus robur* (5,315 Ha.). In this area, wildfires affect more the private than public lands, with 72.65% of the burned area belonging to private landowners. The remaining area depends on public or forest committee management.

With this forest potential, Galicia is logging a total of 6,876,697 cubic meters of timber (Xunta de Galicia, 2011), which represents 52% of Spanish logs (MAAMA, 2013). However, only 7.78% of this forest area is certified, representing only 111,249 hectares MAAMA (2011). The lack of certification is a serious shortcoming for Galician forests, given that nowadays, the global markets demand eco-labeled goods and services. Therefore, forest certification demand is increasing and this carries a higher premium for the certified production. To achieve forest certification, the landowner should fulfil some technical and economic requirements (Nussbaum, 2013). Forest certification may also imply better forest management (Rametsteiner and Simula, 2003), which in turn, it may decrease wildfire risk.

In Spain, private firms offer forest insurance, usually subsidized by the public administration (BOE, 2011)[3]. The evolution of forest insurance in Spain and Galicia can be observed in

[3] Thus, one of these requirements determines that the forest insurance should cover the damages caused by wildfires, floods, driving rain or strong winds. In case of damages, the reforestation or restoration cost is covered to shrub mass, conifers, broadleaf and mixed plantations. However, this subsidy only covers production damages to cork plantation. The coverage on restoration cost and production damage depends on the land and

Table 5.1. These data show that the forest insurance policy is not popular among landowners, and it is not being used as a management tool. The insured area, number of contracts, and insured production have been increasing during the last three years[4]. However, the insured areas have been decreasing in relative terms with respect to the amount of insurable production. As a result, in Galicia, the forest insurance is not widely used by landowners either, in spite of the high hazard rates. The number of insurance policies that have been sold over the years is very low, considering that there are a half million of landowners in Galicia and three thousand communities of mountain landowners (Dans, 2006). Furthermore, the Galician forest insurance represents 5.5% of Spanish forest insurance. This percentage is very low because the Spanish production of conifers and broadleaf is mainly harvested in Galician forests (MAAMA, 2011).

TABLE 5.1: Forest insurance policies in Spain.

	Spain					Galicia			
Season	Insurable production (Ha)	Insured production (Ha)	Implementation % (Insured Prod. / Insurable Prod.)	Number of policies	Value of insured production (in 1M €)	Number of Contracts	Production (Kg.)	ENESA Subsidy (in €)	Net cost (in €)
2011	13.165.576	83.473	0,63	1.760	108,08	156	45.886.811	20,628.72	75,672.14
2010	6.224.029	77.103	1,24	1.588	96,50	144	41.975.020	23,813.30	87,947.32
2009	1.228.716	66.834	5,44	1.453	81,12	145	43.561.298	17,710.62	63,177.86
2008	ND	ND	ND	ND	ND	167	48.928.321	21,128.46	71,670.07

Source: Agroseguro (2011a)

Based on this lack of use, the landowners' preferences for this type of insurance should be analysed in other to assess any potential barriers for its implementation. Therefore, stated preferences are used to identify the utility of different insurance attributes given by landowners as well as to discover their preferences. The first section of this chapter describes the previous literature about insurance policies and environmental valuation. Next, the methodology is described, following with the model used and the data collection. Next, the paper presents the main results according to the methodology and data collected. Finally, some conclusions based on these results are drawn.

plantation characteristics. This public policy establishes that insurance coverage is full for reforestation or restoration cost. Nevertheless, the timber coverage is partial and has a 10% deductible.

[4] Some technical requirements should be fulfilled to insure the forestlands. One of them is that the landowner should contract an insurance policy to a minimum area (0.25 Ha.), which can be forest or farm land. Moreover, the insurance subsidy requires a minimum forest management, which is determined according to laws, regulations and cultural conditions. Some examples of this requirement can be mentioned: the species should be set according to site characteristics; the land should be adequate by following a restoration plan and the plantation should be made considering the optimal density of selected species (BOE, 2011).

5.2. BACKGROUND

A considerable amount of surveys were developed in order to analyze public policies or to value forest services. In this field, Choice Experiments (CE) has been used to value non-market forest goods or services; and to evaluate incentives or public policies (Kramer *et al.,* 2003; Horne, 2006; Meyerhoff *et al.*, 2009; Mogas *et al.*, 2009; Farreras and Mavsar, 2012). The CE here executed is similar to previous applications, in which this method was used to assess the WTP for some environmental services and risk avoidance (Hanley *et al.*, 1998; Soliño *et al.*,2010; Varela *et al.*, 2014) and recreational preferences (Christie *et al.*, 2007; Holmes *et al.*, 2012).

The CE has been used in insurance research before, such as in health insurance in several countries, including Switzerland (Becker and Zweifel, 2008), the United States of America (Nganje *et al.*, 2004), and Vietnam (Lofgren *et al.*, 2008). CE has also been used to analyse the crop insurance program in Cataluña (Spain) (Mercadé *et al.*, 2009). In our particular study, the insurance cost, the coverage, the minimum damage to be claimed and the insurance compensation are included as attributes contract of the choice. However, as far as we know, preferences towards forest insurance contracts have not been much analysed around the world. An exception is Brunette *et al.* (2008), who applied a survey to obtain the insurance demand according to a fixed wildfire risk and public compensation[5]. Therefore, we consider this present work innovative, given that it discovers preferences for the design of various insurance policies.

5.3. METHODS AND DATA

5.3.1 CE theory

The CE is based on Random Utility Theory (RUT). Thus, the respondents' behavior is analysed by a discrete choice in which the utility is maximized (Ben-Akiva and Lerman, 1985). The respondents have a choice set (J), in which they could choose between some alternatives [$j=1,\dots, J$]. These options are associated with the utility function [U], which depends on objective or deterministic variables (v) and a random error component (ε). Then, if the respondent n^{th} prefers the option j, his/her utility is described in the Eq. 4.1 as:

[5] Some researchers study the forest insurance (Holecy and Hanewinkel, 2006; Brunette and Couture, 2008; Brunette *et al.*, 2012; Barreal *et al.*, 2014) however, none of them analyses the utility of forest insurance programs for landowners.

$$U_{nj} = \nu_{nj} + \varepsilon_{nj} \qquad [5.1]$$

The election implies that the n^{th} respondent prefers the option *j* than any other alternative *p*, so that the utility of *j* is greater than the utility of any other alternative *p*. Therefore, the probability of choosing the option *j* is determined by the Eq. 5.2.

$$\text{Prob}(j) = \text{Prob}(\nu_j + \varepsilon_j \geq \nu_p + \varepsilon_p) \qquad \forall j, p \in m \qquad [5.2]$$

If the error term is independent and identically distributed according to a Gumbel distribution (Greene, 2008), the probability of the individual n^{th} choosing alternative *j* is represented by Eq. 5.3. This following expression represents the Conditional Logit Model (CLM) developed by McFadden (1974),

$$\text{Prob}(y_n = j) = \frac{\exp^{\beta v_{nj}}}{\sum_{j=1}^{m} \exp^{\beta v_{nj}}} \qquad [5.3]$$

where y_n is a random variable that indicates the choice made by the respondent. Then, the probability of choosing *j* is calculated according to its exponential utility over exponential utility of total choice set. The v_{ij} involves both the attributes of the choice and the characteristics of the respondent. The log-likelihood is defined by Eq. 5.4. In this equation, d_{jp} takes values equal to 1 when *j* is chosen by the respondent, and d_{jp} is equal to 0 otherwise, for *J* possible outcomes.

$$\ln L = \sum_{i=1}^{N} \sum_{j=1}^{m} d_{ij} \text{Prob}(y_i = j) = \sum_{i=1}^{N} \sum_{j=1}^{m} d_{ij} \ln \left(\frac{\exp^{\beta v_{nj}}}{\sum_{j=1}^{m} \exp^{\beta v_{nj}}} \right) = \qquad [5.4]$$

$$= \sum_{i=1}^{N} \sum_{j=1}^{m} d_{ij} \exp^{\beta v_{nj}} - \sum_{i=1}^{N} \sum_{j=1}^{m} d_{ij} \ln \left(\sum_{j=1}^{m} \exp^{\beta v_{nj}} \right)$$

The empirical specification of CLM is represented by Eq. 5.5. In this expression the utility depends on the insurance policy (X_{ij}) and the error term (ε_{ij}). Each insurance attribute (*i*) included in the model is related to the utility through the term β_i. The following linear form is commonly assumed in most empirical models.

$$U_{ij} = \beta_i X_{ij} + \varepsilon_{ij} \qquad [5.5]$$

The willingness to pay for each attribute is obtained according to the odds ratio of the Eq. 5.6. In this expression, the WTP estimate is obtained as a result of dividing the estimated parameters (β_i) by β_k, in which k represents the variable related to the cost attribute, and i represents the other attributes.

$$WTP = -\frac{\partial \widehat{u} / \partial X_i}{\partial \widehat{u} / \partial X_k} = -\widehat{\beta}_i \Big/ \widehat{\beta}_k \qquad [5.6]$$

Taking into account the previous considerations, the Independence of Irrelevant Alternatives (IIA) should be assessed. The IIA implies that the probability of selecting any alternative is independent of other alternatives in the choice set (Hausman and McFadden, 1984).

The Hausman test can be used to analyse the IIA property (Hausman and McFadden, 1984). It is assumed that β_C is a vector of consistent and efficient estimates under the null hypothesis of IIA; nevertheless this coefficient is inconsistent under the alternative hypothesis. The β_D is consistent under the null and the alternative hypotheses, but inefficient under the alternative (Fry and Harris, 1998). Using standard notation, Ω^- is the inverse of the covariance matrix of a subset D and full choice of a set C. The Hausman test is defined in Eq. 5.7 as follows.

$$H = \left(\hat{\beta}_D - \hat{\beta}_C \right)' \left(\Omega_D - \Omega_C \right)^- \left(\hat{\beta}_D - \hat{\beta}_C \right) = q' \Omega^- q \qquad [5.7]$$

The CLM assumes the IIA property because the relative probabilities of two options in one single set are unaffected by other alternatives. Therefore, if the Hausman test fails to reject this property, then, this model is suitable (Birol *et al.*, 2006). Otherwise, if the IIA property is rejected, then the CLM will be biased. Hence, it will be required an econometric model that is not conditioned by the IIA property. One of these possible models is the Random Parameter Logit (RPL).

The RPL model assumes heterogeneous preferences and the model could be described by Eq. 5.8. In this expression, the utility (U_{ij}) is described by the insurance attributes, which are represented by X_{ij}. The β_i and η_i relates the utility with forest insurance attributes. The coefficient η_i allows the random parameter to be included in the model (Cameron and Trivedi, 2005: page 513). These random parameters follow a normal distribution,

$$\begin{aligned} &U_{ij} = \beta_i X_{ij} + \xi_{ij} \\ &\xi_{ij} = \eta_i X_{ij} + \varepsilon_{ij}; \eta_i \left[0, \sum\nolimits_{\beta} \right]; Cov\left[\xi_{ij}, \xi_{ik} \right] = X_{ij} \sum \beta X_{ik}, j \neq k \end{aligned} \qquad [5.8]$$

The probability of choosing the option j is represented by the Eq. 5.9.

$$\text{Prob}(y_n = j) = \frac{\exp^{(\beta+\eta_i)v_{nj}}}{\sum_{j=1}^{m} \exp^{(\beta+\eta_i)v_{nj}}} \qquad [5.9]$$

The RPL does not explain the sources of heterogeneity (Boxall and Adamowich, 2002). Thus, the interactions between the social and/or economic variables with the choice attributes are included in order to detect the observable heterogeneity.

5.3.2 CE survey

The CE has been selected to analyse the landowner preferences for different forest insurance alternatives. To this end, three choice alternatives were designed in the CE. The two first alternatives represent different insurance contracts; meanwhile, the latter is the *status quo* option (no contract option). The insurance cost, as well as the coverage level of timber losses and restoration costs, and the additional requirement of forest certification are included as attributes in the choice set. In this way, each choice card includes four attributes. Table 5.2 shows an example of a specific choice card (all choice cards are included in the Appendix 5.1).

TABLE 5.2: Example of CE card.

	OPTION A	**OPTION B**	**NOT TO CHOOSE FOREST INSURANCE**
Insurance cost	5.04 €/Ha.	3.36 €/Ha.	
Timber damage coverage	50%	0%	
Restoration coverage	100%	50%	
Forest Certification	Yes	No	
Mark X to show your main preference:			

According to the insurance companies that offer forest insurance, the average of the forest insurance premium in Spain is 4.20 € per hectare. However, a factor of +/- 20% is used to provide some variation to the insurance premium into the questionnaire. Therefore, 3.36 €/Ha. and 5.04 €/Ha. are also included as potential insurance premium costs in the CE. The coverage level in the current National Forest Insurance Program (*Agroseguro*) only involves the forest damages on cork production (BOE, 2011). Nevertheless, this present research aims to assess the importance of this coverage into all type of forest productions. The coverage could be full (100%), partial (50%) or none (0%). The coverage of forest restoration after a wildfire could also be full (100%) or partial (50%). To sum up, Table 5.3 describes all the different levels as used in the CE. Appendix 4.1 reproduces the nine choice cards included in the survey.

TABLE 5.3: Attribute levels of CE cads.

ATTRIBUTES	LEVEL
Insurance cost	5.04 - 4.20 - 3.36 €/Ha.
Timber damage coverage	100 - 50 - 0 %
Restoration coverage	100- 50 %
Forest Certification	Yes – No

The SSPS program has been used to define the number of choice cards included in the survey. Firstly, an orthogonal design was created, in which the orthogonal matrix and the optimal number of cards was obtained according to Appendix 5.2. Following the generator according to Street and Burgess (2007) and employing a random vector of ones, the D-efficient rate was calculated[6]. A design was found containing 9 CE cards with a D-efficiency of 99.79%. This result is for a choice set size equal to two. If this size is changed, then D-efficiency diminishes. Therefore, in order to retain the previous D-efficiency level, the following optimal design was used.

The survey was directed towards landowners and/or forest managers. In total, 210 completed responses were collected, with a response rate of 46%. The survey was structured in seven sections: (1) the description of the type of land owned, (2) the CE exercise, (3) the characteristics and perceptions about their forest management practices, (4) the understanding of wildfire risks and its causes, (5) the future patterns on forestry management, (6) risk aversion question, and to conclude with (7), socio-economic features of respondent.

5.3.3 Data collection

The data collection was conducted in the area known as “A Mariña Lucense”, in the region of Galicia (Figure 5.1). According to the Galician forest administration (Xunta de Galicia, 2012), this area represents the Forestry District VI. This area was chosen due to its good management practices, and its low number of wildfires with respect to others forestry districts of Galicia (Barreal *et al.*, 2012).

[6] D-Efficiency rate compares the information matrix and optimal design for choice experiment (Bailey and Kind, 2008).

FIGURE 5.1: Research area.

Within this study area, the managers and landowners are focused on producing forest resources, making decisions to maximize their production, and hence those maybe interested in protecting themselves against risks. Around 74.500 habitants live in this area, in a total surface of 1,395.5 Km^2 (IGE, 2013b). Rural lands represent 134,943 hectares that are distributed in 379,864 plots (IGE, 2013c). Of particular relevance is the forestland, which represents 76.30% of the total surface (106,492 Ha.). A significant amount of it, about 82.49% (87,849 Ha.) represents productive forestry, while 17.51% (18,643 Ha.) are scrubland areas (IGE, 2013d).

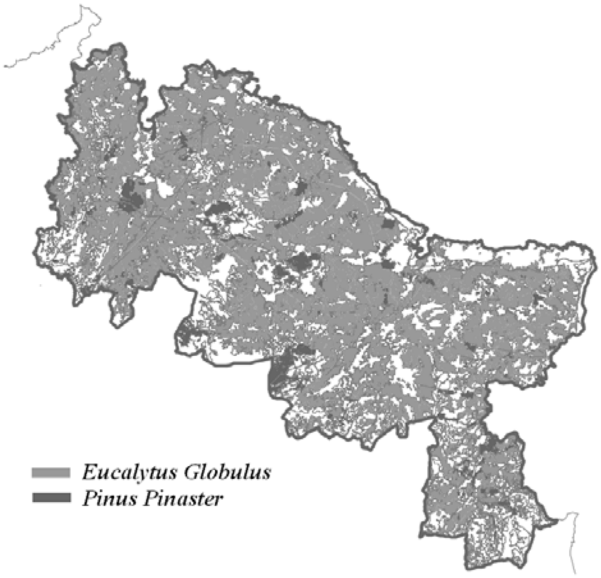

FIGURE 5.2: Main forest productions in the study area.

According to Figure 5.2, the main forest production is *Eucaliptus globulus* (MAAMA, 2012b). This is the main species on 67,524 Ha., representing 76.86% of forest areas. The second species in terms of importance is the *Pinus pinaster*, planted on 6,662 Ha., although this species only represents 7.58% of the forestry area.

In Table 5.4 the main socioeconomic characteristics of the sample are depicted. In particular, 54% of respondents are male with an average age of 50 years. Around 53% of sample respondents have primary education, while 21% and 13.5% hold respectively professional and university degrees. Finally, 12.5% do not have any formal education. Forty nine per cent live in the rural areas, and most have a family income below 16,700 €/year (62% of respondents). Meanwhile 38% of the respondents belong to an income interval from 16,700 € to 52,100 €, and only 0.6% are over 52,100 €[7].In this sample, 36% of respondents are landowners, 39% are forest managers and, finally, 25% are both landowners and forest managers. The 94% of respondents plant eucalyptus at least in one of their forestlands; and for 71% of the participants this is the only species they harvest. Nearly 48% of respondents have logged their forest lands during the last 10 years, while 82% of these respondents have received from the last logging less than 12,000 €.

In terms of their preferences for the various contracts, the respondents have selected 790 times (41.8%) the s*tatus quo* option; meanwhile the contract A and contract B were selected 664 (34.6%) and 446 (23.6%) times, respectively. These selections show a high preference for the s*tatus quo* option. A control question was also formulated to identify the level of knowledge about this insurance. In this question, the respondent selected in a Lickert scale from 1 (corresponding with forest insurance being totally unknown) to 5 (denoting that the forest insurance is widely known). Overall, it was found that the majority of respondents have very little knowledge, selecting levels below 3 (99%). An open-ended follow-up question was formulated in case of selection of the status quo option. Overall, respondents prefer not to ensure the forestlands because they think that the forest insurance in unnecessary to their forest management decisions. To sum up, the high response of s*tatus quo* option should be motivated by the respondents' lack of knowledge about the wildfire insurance and their perception that there is no need for this financial instrument

[7] This economic classification corresponds with the Spanish Statistical Office questionnaires, although different ranges are added to calculate the lower, medium and high family income.

TABLE 5.4: Summary statistics.

VARIABLE	DESCRIPTION	MEAN	STD. DEV.
PERSONAL CHARACTERISTICS			
Female	1 = if the respondent is a female; 0 = otherwise	0.462	0.499
Age	Age of respondents	50.086	17.896
No formal education	1 = if the respondent does not have formal education; 0 = otherwise	0.125	0.331
Basic education	1 = if the respondent has a primary or high school degree; 0 = otherwise	0.529	0.499
Professional degree	1 = if the respondent has a professional degree; 0 = otherwise	0.211	0.408
University Degree	1 = if the respondent holds a university degree; 0 = otherwise	0.135	0.341
LIFESTYLE			
Rural area	1 = if the respondent lives in a rural area; 0 = otherwise	0.486	0.500
Low income	1 = if the respondent has a family income below 16,700 €; 0 = otherwise	0.619	0.486
Medium income	1 = if the respondent has a family income between 16,701 € and 52,100 €; 0 = otherwise	0.376	0.485
High income	1 = if the respondent has a family income over 52,101 €; 0 = otherwise	0.006	0.074
FORESTRY DESCRIPTION			
Only landowner	1 = if the respondent is only a landowner and not a forest manager; 0 = otherwise	0.357	0.479
Only forest manager	1 = if the respondent is only forest manager and is not a landowner; 0 = otherwise	0.390	0.488
Landowner and forest manager	1= if the respondent is a landowner and a forest manager; 0 = otherwise	0.252	0.434
Eucalyptus	1 = if the respondent has planted eucalyptus at least in one forestland; 0 = otherwise	0.938	0.242
Only Eucalyptus	1 = if the respondent has only planted eucalyptus in his/her forestland; 0 = otherwise	0.707	0.455
Pine	1 = if the respondent has planted pine at least in one forestland; 0 = otherwise	0.274	0.446
Oak	1 = if the respondent has planted oaks at least in one forestland; 0 = otherwise	0.024	0.153
Chestnut	1 = if the respondent has planted chestnut at least in one forestland; 0 = otherwise	0.067	0.251
Logging	1 = if the forest area was logged during the last 10 years at least once; 0 = otherwise	0.478	0.500
Year of logging	Year in the last 10 years in which the last logging took place	2.008.879	2.750
Less of 3.000€	1 = if the last payment for selling timber in the last 10 years is below 3,000 €; 0 = otherwise	0.283	0.450
From 3.000€ to 6.000€	1 = if the last payment for selling timber in the last 10 years is between 3,000 € to 6,000 €; 0 = otherwise	0.283	0.450
From 6000€ to 12.000€	1 = if the last payment for selling timber in the last 10 years is between 6,000 € - 12,000 €; 0 = otherwise	0.253	0.435
More of 12.000€	1 = if the last payment for selling timber in the last 10 years is more than 12,000 €; 0 = otherwise	0.141	0.349

5.4. Results

The Hausman test carries a χ_4^2 equal to 26.734 with a 0.00002 probability. Thus, the IIA property is failed to be rejected with a probability of 99% (Birol *et al.*, 2006). Therefore, both the CLM and RPL can be used. The CLM assumes homogeneous preferences across the respondents, while the RPL takes into account the heterogeneity (Birol *et al.*, 2006).

TABLE 5.5: Conditional Logit Model.

	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
Insurance cost (premium)	-0,546***	0.031	-17.49	0.000	-0,607	-0.485
Timber damages coverage	1.337***	0.102	13.09	0.000	1.137	1.537
Forest restoration coverage	1.411***	0.137	10.27	0.000	1.142	1.681
Forest certification requirement	0.155***	0.039	4.02	0.000	0.080	0.231
Log likelihood	-3,362.37					
Sample Size	5670					

Note: ***, **, * ==> Significance at 1%, 5%, 10% level

The CLM provides the results displayed in Table 5.5. All of these results are statistically significant at the 1% critical level. As we can observe, the insurance premium decreases respondents' utility. On the other hand, both insurance coverage and forest certification increase the respondents' utility. In addition, the forest restoration costs coverage is more preferred than timber damage coverage. Landowners have also a positive view for the requirement of certification. This requirement implies a cost for landowners and better forest management. This implies, as well, that the wildfire risk is reduced, because the certification is related to a specific forest management, which is focused on taking care of the forest production. On the other hand, the timber companies increase the wood price when the forest production is certified; so this certification also increases the landowner revenues.

The RPL Model provides evidence about the same relationship between the respondents' preferences and the attributes of forest insurance. The results are shown in Table 5.6. This RPL specification assumes the invariability of the insurance payment. There is also statistical evidence that the other insurance attributes follow a normal distribution. In accordance, the scale parameters are all significant. All variables are significant at the 1% level or below and the signs of the coefficients are the same as in the CLM. The willingness to pay (WTP) for the forest insurance attributes is obtained dividing the absolute value of the respective random parameters by the price coefficient (as shown Eq. 5.6). Preferences for insurance attributes are however different when comparing them with the previous CLM results, given the consideration of heterogeneity. This is particularly relevant for the timber damages coverage becoming the most preferred attribute among all.

TABLE 5.6: Random Parameters Logit model.

	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
Non random parameters						
Insurance cost	-0.619***	0.022	-27.82	0.000	-0.663	-0.575
Means for random parameters						
Timber damages covered	1.159***	0.093	12.43	0.000	0.976	1.342
Forest restoration cost covered	0.833***	0.112	7.40	0.000	0.612	1.053
Forest Certification	0.262***	0.035	7.55	0.000	0.194	0.330
Scale parameters for dists. of random parameters						
Timber damages covered	2.471***	0.115	21.49	0.000	2.246	2.696
Forest restoration cost covered	3.651***	0.148	24.75	0.000	3.362	3.940
Forest Certification	1.172***	0.056	20.91	0.000	1.062	1.282
Sample Size	5670					
Log likelihood	-2,855.01					
Restricted log likelihood	3,449.60					
Chi squared [3 d.f.]	1,189.19					
McFadden Pseudo R-squared	0.172					
Inf.Cr.AIC	5,724.0					
Bayes IC	5,770.5					

Note: ***, **, * ==> Significance at 1%, 5%, 10% level

The WTP for the various forest insurance attributes is displayed in Table 5.7. Based on these, the respondents are willing to pay 3.64 €/ha. for an insurance contract that covers the timber damages and the forest restoration cost and forest certification.

TABLE 5.7: Willingness to pay of RPL model.

Insurance Attributes	Coefficient	Standard Error	z	Prob. |z|>Z*	95% Confidence Interval	
Timber damages covered	1.872***	0.135	13.89	0.000	1.608	2.136
Forest restoration cost covered	1.345***	0.154	8.74	0.000	1.043	1.647
Forest Certification	0.424***	0.057	7.40	0.000	0.311	0.536
Insurance premium with all attributes	3.641***	0.145	25.17	0.000	3.357	3.924

Note: ***, **, * ==> Significance at 1%, 5%, 10% level

In the case of timber damages and restoration costs, the respondents have a positive WTP for both; respectively 1.87 €/Ha. and 1.35 €/Ha. Meanwhile, for the eco-certification, the respondents have a WTP of 0.42 €/Ha. for this requirement. This cost also influences forest production revenues because timber companies pay more for forest certified timber. Therefore, the respondents prefer to pay more for an insurance contract that includes forest certification as a requirement. Both insurance coverages have a positive relationship with the utility function, as expected.

The RPL with interactions is developed in order to understand the sources of heterogeneity. The interaction between the insurance attributes and the socioeconomic variables is used in this model. The forest manager is who makes the decision to insure the forestland, this is why these socioeconomic variables were chosen; being the age variable of particular relevance, affecting experience, and risk attitudes. The landowner, who does not take forest management decisions, does not decide if forest insurance could be contracted. The results are shown in Table 5.8.

All variables are significant at the 1% critical level, except for the relationship between being a manager and the coverage of timber damages. Thus, the age of the respondent has a negative relationship with the two types of insurance coverage and forest certification. If the landowner or forest manager is older, the utility of insurance coverage and forest certification are also more negative in comparison with the mean utility of each insurance attribute. On the other hand, if the landowner is a forest manager, he/she has a negative relationship with the restoration cost coverage and forest certification. Therefore, if the respondent is a forest manager, then this situation implies a negative preference about contracting forest insurance.

TABLE 5.8: The RPL model with interactions.

INSURANCE ATTRIBUTES	COEFFICIENT	STANDARD ERROR	Z	PROB. |z|>Z*	95% CONFIDENCE INTERVAL	
NON-RANDOM PARAMETERS						
Insurance premium	-0.621***	0.022	-27.70	0.000	-.66508	-0.577
Timber damages covered*AGE	-0.025***	0.006	-4.19	0.000	-.03707	-0.013
Forest restoration cost covered*AGE	-0.031***	0.005	-6.19	0.000	-.04110	-0.021
Forest Certification*AGE	-0.007***	0.002	-3.19	0.001	-.01195	-0.003
Timber damages covered*FOREST MANAGER	0.291	0.227	1.28	0.200	-.15403	0.735
Forest restoration cost covered*FOREST MANAGER	-0.650***	0.189	-3.44	0.001	-1.021	-0.279
Forest Certification*FOREST MANAGER	-0.340***	0.087	-3.92	0.000	-0.509	-0.170
MEANS FOR RANDOM PARAMETERS						
Timber damages covered	2.202***	0.404	5.45	0.000	1.410	2.995
Forest restoration cost covered	2.945***	0.340	8.66	0.000	2.278	3.611
Forest certification	0.852***	0.157	5.42	0.000	0.544	1.161
SCALE PARAMETERS FOR DISTS. OF RANDOM PARAMETERS						
Timber damages covered	2.505***	0.117	21.38	0.000	2.275	2.734
Forest restoration cost covered	3.453***	0.139	24.86	0.000	3.181	3.725
Forest certification	1.206***	0.057	20.99	0.000	1.094	1.319
Sample Size	5670					
Log-Likelihood	-2,847.39					
Restricted log likelihood	-3,405.21					
Chi squared [3 d.f.]	1115.64					
McFadden Pseudo R-squared	0.164					
Inf.Cr.AIC	5720.8					
Bayes IC	5807.1					

Note: ***, **, * ==> Significance at 1%, 5%, 10% level

5.5. CONCLUSIONS

The insurance demand is studied by conducting a survey addressed to landowners and forest managers. In this questionnaire, most of respondents decided not to select any forest insurance contract, among those offered; showing their preferences for assuming the current wildfire risk. Therefore, the data collection shows a high proportion of responses in the *status quo* option. This behaviour could be common on respondents who ignore the forest insurance options or who believe that they do not need this policy. In this way, the lack of awareness about this insurance could also make the respondents more suspicious. Subsequently, insurance companies should advertise the insurance policy to increase its knowledge. If the landowners know the forest insurance, then contracting may be increased.

The insurance demand depends on the coverage of the insurance policy. Nevertheless, previous results highlight the importance of the forest insurance with respect to the damage coverage. Following the RPL results, the landowner prefers to pay for guaranteeing the expected timber profits, than for restoring their forestland. The WTP estimated using the RPL is near the average of the forest insurance premium in Spain. However, this average price includes the commercial costs and subsidies, but the WTP found for this research does not involve such elements. It is pointed that National Forest Insurance Program (*Agroseguro*) has lower insurance coverage and forest management requirement than the proposed in this research. The dissertation results show that the WTP for a restoration cost is below the *Agroseguro* average cost. Then, the National Forest Insurance Program should cover higher forest damages or reduce its insurance cost, given the landowners demand.

The timber coverage is very important for the landowners' finances. If the landowner is insured, the forest investment will have lower volatility when a wildfire occurs. This result also shows that the landowners' awareness of timber profits is bigger than the importance of restoring the burned land. Accordingly, landowners prefer the actual timber production than the expected futures incomes, so they perceive the forest plantation as "savings" to be used in the emergency occasions of need. In other words, the landowner will pay more for ensuring the present stock than for the guarantee of the next rotation. However, the forest policy should encourage both types of coverages. On one hand, the restoration coverage implies the production of environmental services, so the social welfare will be guaranteed. On the other hand, the timber coverage represents an economic incentive to invest in forest productions. Therefore, both public and private interests are considered if the forest policy includes both types of insurance coverages.

The RPL results evidence different landowner perceptions about forest insurance attributes. The WTP for forest certification is an unexpected result because this requirement is an initial cost for the landowner. Nevertheless, this finding could have two interpretations. The first one is that the landowners identify this requirement as a lower cost in comparison with the "induced" wildfire risk reduction. The second is that the respondents ignore this certification and they identify this requirement as included in the insurance price. If this requirement is also included in an insurance policy, then the insurance companies could avoid information problems using forest certification as a proxy of forest management types. Therefore, the landowners will expect that to be insured and certified is cheaper for their forest management in opposite to contract these two attributes separately.

This research also recognizes the need of having knowledge about the socioeconomic characteristics of the landowners in order to identify the insurance demand. A RPL model is developed to identify the respondent's aptitudes according to some socioeconomic features. In this case, the age and the type of forest management conditions determined the demand of forest insurance.

All previous results are conditioned by the research sample and area of study. The survey was conducted in a special area in which the forest production has high economic value and landowners have a business oriented management. This area also records lower wildfire risk during the last decades in comparison with other Forest Galician Districts. Consequently, these issues could explain in a way the lower WTP of landowners. These results could be expanded to other Spanish forest areas in where there is a high importance of the forest sector and lower wildfire risk is recorded. If the traditional wildfire risk is higher, the insurance coverage would be more demanded and its WTP would be also higher.

Finally, the risk aptitudes of forest managers should be studied in order to improve the present findings. This could be done by using utility functions in which the risk perceptions could be included. In this way, taking into account the cultural factors such as the educational background, family income or the economic use of forest could also be also included in order to gain a deeper understanding of the demand for forest insurance.

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Appendix 5.1: CE Cards included in the survey

Choice card 1

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

Choice card 2

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	0%	100%	
Restoration coverage	100%	50%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

Choice card 3

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	100%	50%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

Choice card 4

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	0%	100%	
Restoration coverage	50%	100%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

Choice card 5

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

Choice card 6

	Option A	Option B	Neither A or B: Without
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	0%	100%	

Restoration coverage	100%	50%	**FOREST INSURANCE**
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 7

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 8

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	50%	100%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 9

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	50%	100%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

APPENDIX 5.2: ORTHOGONAL MATRIX

ID CARD	ATTRIBUTE 1	ATTRIBUTE 2	ATTRIBUTE 3	ATTRIBUTE 4
1	Level 2	Level 3	Level 2	Level 1
2	Level 2	Level 2	Level 1	Level 1
3	Level 3	Level 1	Level 2	Level 1
4	Level 3	Level 3	Level 1	Level 2
5	Level 1	Level 1	Level 1	Level 1
6	Level 1	Level 2	Level 2	Level 2
7	Level 1	Level 3	Level 1	Level 1
8	Level 2	Level 1	Level 1	Level 2
9	Level 3	Level 2	Level 1	Level 1

CHAPTER 6: CONCLUSION

6.1. MAIN FINDINGS BY CHAPTER

The current thesis consists of six chapters that present several conclusions. Chapter II shows the main socioeconomic, climatic and environmental factors that influence wildfire risks. These factors were identified using econometric models, spatial patterns and temporal trends. They are relevant to explain wildfire occurrence in Galicia, and should be taken into account by regulators when designing public policy. If socioeconomic factors such as population structure, the stage of the rural economy or the type of land cover are included in the public policy, then effectiveness of preventing wildfires may increase. Public policy should also encourage landowners to plant species that are less vulnerable to fire and to develop sustainable rural management.

In Chapter III, a wildfire insurance model was designed and proposed to safeguard forest restoration after wildfires. It includes coverage for timber damages and restoration costs, thereby incorporating both financial and environmental factors into the proposed policy. This implies greater security for forest investments while guaranteeing the next forest rotation and preventing forestland abandonment. This kind of insurance policy is novel in the theory of forest valuation and expands the relevant literature. Wildfire risk, insurance premiums and corresponding compensations were included in the proposed forest valuation model. This chapter mainly concludes that the landowner will obtain a higher NPV when the wildfire risk is lower or when the insurance premium is fair in low-risk areas.

In Chapter IV, the previous insurance models were enhanced by using public policies to encourage the production of ecosystem services. The proposed forest valuation involves landowner and public interests. To link both interests, mandatory restoration after wildfire was included in the insurance policy, making it a mechanism for guaranteeing ecosystem services production and preventing forestland abandonment. Wildfire risk affects timber production and ecosystem valuation, according to the Faustmann model. However, the economic and environmental impact of fire can be reduced if forest insurance is implemented. This mechanism impacts both landowners and social interests. Forestlands would be better protected and appropriate environmental management could be achieved if the proposed insurance was implemented as a form of payment for providing ecosystem services.

In Chapter V, landowner's demand for insurance was analysed, including interest in contracting forest insurance with timber and restoration coverage. The mean WTP for forest insurance is 3.64 €/Ha according to RPL results. Landowners have higher WTP for covering timber damages than restoration costs. Forest certification emerged as an important factor for insuring forestland. Landowners were aware of the positive effect of certification as a way of reducing wildfire risk and increasing timber prices. Thus, the payment of insurance premium can generate better forest management and economic results. This chapter concludes that the landowners' characteristics influences insurance demand: WTP for insurance attributes varies according to landowners' age and performance of management activities.

6.2. DISCUSSION

Forest management are affected by several factors that threat its production. Wildfires are one of the most important risks that influence forest management in Galicia. Hence, understanding the factors that explain wildfire occurrence, forest policy could be improved and forest production could be protected. Previous literature has established the importance of identifying these factors in order to reduce and prevent wildfire occurrence (Butry, 2009, Martínez *et al*., 2009). The current dissertation shows how both spatial patterns and temporal trends explain wildfire occurrence. In light of this, Moran's I and LISA statistics are proposed for studying wildfire patterns (Moran, 1948; Anselin, 1995; Ord and Getis, 1995).

The results shows that both meteorological and socioeconomic factors affect wildfire occurrence. Study of these components suggests that precipitation and temperature should be considered in predicting wildfire occurrence. Socioeconomic variables such as population structure, rural economy, agricultural characteristics and forest distribution are also relevant to explain wildfire occurrence. These factors should be considered in order to design better forest regulations and the public policies that affect rural areas. Some spatial patterns can be also observed by using graphs, statistics and econometric models. Wildfire prevention plans should consider these spatial patterns when organizing fire fighters and preventive efforts, in order to reduce wildfire suppression time cost and affected areas.

Landowners may reduce forest investment risk by contracting wildfire insurance. The use of this financial asset can change forest valuation (Faustmann, 1849). The contracting of forest insurance implies a management cost for landowners: while wildfire risk would be shared with the insurance company. Insurance could be also used as a measure for avoiding forest abandonment by making restoration costs mandatory in the policy. Wildfire risk should also be considered according to real threats. Landowners will not be interested in contracting insurance if insurance premiums do not accurately reflect the real wildfire risk. Thus, forest valuation will be lower if the premium is calculated using higher wildfire risk in comparison with real wildfire exposure. If premiums are standard, the forest valuation will be worse in lower risk areas.

Ecosystem services production could also be included in forest valuation (Hartman, 1976; Samuelson, 1976). Society is interested in conserving this production because it increases well-being. Therefore, public policy could be designed to preserve ecosystem services production after wildfires. However, since landowners' take forest management decisions, the private forest rotation could be different than that based on public interests. In this setting, an incentive that addresses both sets of interests and increases both NPV's should be designed. Thus, forest insurance could be subsidized to link the landowner with the ecosystem services. The insurance premium would be partially paid by society according to the degree of ecosystem services production. Thus, forest insurance could be used as a partial payment for ecosystem services. The proposed insurance policy covers both timber damage and restoration costs.

Demand for forest insurance is studied in the fifth chapter of this dissertation. The proposed insurance policy attributes includes timber damages, restoration costs and forest certification requirement. The Random Parameters Logit is used to calculate the mean WTP for the proposed insurance policy. Landowners express a WTP for both insurance coverage and forest certification requirements. The landowner may expect an increment of timber prices if forest production is certified, show that the certification requirement has a positive average utility. Demand for forest insurance depends on the landowner's characteristics; particularly age or profile. This suggests that insurance companies may consider landowner's characteristics in order to increase forest insurance policy demand.

6.3. GENERAL CONCLUSIONS

The second chapter demonstrates that social and natural factors influence Galician wildfire patterns. Therefore, public policies should be designed in order to avoid wildfires for either both normal and extreme years with high affected area. Different econometric models can be used to research wildfire occurrence. Here, OLS regression, NBMR and RE were used to identify the main factors that explain wildfire occurrence. The results concluded that the wildfire risk could be reduced by good public policies. These results may help to develop an effective public policy against wildfires.

The third and fourth chapters present some conclusions about the effects of forest insurance on landowner management, along with the policy implications of such insurance. Scientific research is not extensive in this area and the current thesis expands the relevant literature. The proposed insurance model could include different types of insurance coverage, such as timber stock and ecosystem services production. Optimal forest rotation would depend on forest valuation that incorporates private and public goods, services and costs. If public and private interests are not connected, optimal forest rotations will differ. Management activities do not currently involve both agents and all forest decisions correspond exclusively to the landowner's interests in private forestlands. However, public policy could develop incentives to better align both sets of interests: forest insurance could be used as a singular or complementary payment for ecosystem services. The landowner could receive a portion of insurance premium by year based on the production of ecosystem services. If this insurance includes coverage for timber damage and restoration costs, public and private interests would be accounted for: timber production is one of the most important factors in landowner decision-making, while restoration coverage guarantees ecosystem production and prevents forestland abandonment. Landowners would thereby reduce investment volatility as a function of ecosystem services production and would be motivated to produce these societal services. Besides, the society would be willing to pay for this insurance premium because it guarantees ecosystem services production. In summary, the reduction of forest investment volatility and the guarantee of ecosystem services production constitute the main benefits of applying the insurance premium as a payment for ecosystem services.

The fifth chapter concludes that the demand for forest insurance is fairly low in Galicia. This situation could change if insurance providers designed a policy based on landowner characteristics. The landowner should be able to contract different insurance attributes according to his/her personal preferences. Other requirements could be taken into account in order to calculate the premium by considering the real risk. The forest insurer could design attractive policies for the best forest managers by using these requirements. A management qualification would evaluate the manager's interest in his/her own forest resources. The forest certification requirement could be included to accurately measure risk. The insurance provider should also include coverage for timber damage in the policy design. Currently, only restoration costs are considered in public forest insurance subsidy, but landowners were positive about increasing insurance coverage. To increase the demand for forest insurance, the contracts should offer timber coverage and the policy should also be adapted to socioeconomic characteristics.

Finally, the limited scope of relevant scientific literature regards that forest insurance must be highlighted. This underscores the need to study the implications of insurance in forest management. Previous literature has not addressed the demand for insurance as a mechanism to improve the forest management. The current dissertation expands the research on wildfire risk by contributing to literature in forest insurance.

6.4. FUTURE RESEARCH NEEDS

Each chapter of the current thesis could be extended. In the second chapter, econometric models could be expanded by using more disaggregated data (perish level). Geographical information systems might also be used to obtain new variables from socioeconomic or environmental maps. Other infrastructures, such as roads or railways could also be used to achieve this goal. The econometric models and statistics developed in this chapter could be as well implemented in other geographical regions.

The third and fourth chapters could be extended by using actuarial methods to analyse the economic results of forest insurance. The influence of premium cost and wildfire risk in forest management should be taken into account. The insurance could be analysed by using utility theory in order to understand landowner's behaviour. Additionally, the proposed insurance as a payment for ecosystem services could be studied as public policy for protecting income stability in areas of high hazard rates. This model could be studied as a pro-poor measure that provides poor landowners the opportunity of insuring their forestlands.

The fifth chapter could be improved by expanding the sample to include other Galician forestry districts that record different kinds of wildfire risk. Districts with lower, medium and higher wildfire risk should be also considered. Forest insurance demand could thus be analysed in different contexts of wildfire risk. The relationship of the different kinds of wildfire risk with the preferences for insurance attributes could also be studied. Likewise, this chapter could be expanded by analysing insurance offer and identifying the factors that explain the non-offer of the type of forest insurance proposed in this thesis. With this, it might be possible to identify and refine the insurance policy that providers would be interested to offer. The findings of the current dissertation may contribute in this direction.

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APPENDIX 1: RESUMEN EN CASTELLANO

1. INTRODUCCIÓN

La producción forestal se enfrenta a numerosos riesgos que pueden dañar la riqueza forestal. En Galicia los incendios son el principal factor de riesgo al que se enfrenta la producción forestal (Barrio *et al.*, 2007; González-Gómez *et al.*, 2013). Por ello esta tesis estudia el riesgo de los incendios y cómo actuar sobre sus factores a través de las políticas públicas. Seguidamente se estudia la implicación del seguro forestal en las decisiones productivas. En este apartado se propone un seguro con diversas coberturas en los que se intenta englobar tanto los intereses privados como los públicos. En este sentido los intereses privados abarcan todos los intereses del productor forestal. Mientras que los intereses públicos están relacionados con el bienestar que a la sociedad produce determinados servicios ambientales. En este sentido la tesis propone un seguro forestal como pago por la prestación de servicios medioambientales. Con esta propuesta se estudia que implicación tiene en ambas riquezas forestales la existencia de este tipo de incentivo. Finalmente, la tesis concluye con un estudio de la demanda de seguro forestal centrado en la propuesta formulada en los capítulos anteriores.

Los incendios forestales en Galicia dependen de factores climáticos o medioambientales, sin embargo también se ven altamente condicionado por el comportamiento humano. Esta situación se puede controlar a través de las políticas públicas. Al conocer la relación entre las variables socioeconómicas o ambientales con la ocurrencia de incendios, se pueden diseñar políticas enfocadas a prevenirlos y mitigar sus daños.

Para conocer cómo influyen los factores socioeconómicos, ambientales o climáticos en el riesgo de incendio se emplean modelos estadísticos y econométricos (Aguado *et al.*, 2007; Chuvieco *et al.*, 2010; Martínez *et al.*, 2009; Romero-Calcerrada *et al.*, 2010).Los incendios se pueden medir por número y por superficie afectada, por ello en esta tesis se estudia el número de incendios y el ratio anual de superficie forestal quemada en Galicia. Los dos anteriores factores serán considerados como variables dependientes y se analizará a través de diversos modelos econométricos su relación con las variables socioeconómicas, ambientales o climáticas. Por otra parte, los incendios no afectan homogéneamente a los montes gallegos. Esto es, la ocurrencia de los incendios en Galicia tiene un alto componente espacial al presentar un mayor o menor número de incendios dependiendo del municipio, parroquia o área de referencia. Teniendo en cuenta dicha dependencia espacial, esta tesis también emplea estadísticos para analizar y corroborar esta situación en Galicia (Balsa-Barreiro and

Hermosilla, 2013; Fuentes-Santos *et al*., 2013). Para el desarrollo de los modelos estadísticos se tiene en cuenta que los servicios de prevención y extinción en Galicia se ordenan en función de los Distritos Forestales. Por tanto, dicha ordenación territorial es la empleada para analizar el comportamiento de los incendios en Galicia. Asimismo, también se tiene considera en los modelos econométricos empleados el componente temporal que presentan los incendios en Galicia,

El riesgo de incendio es un factor que añade incertidumbre a la inversión forestal. Por lo que conocer los factores que lo explican ayuda a predecirlo mejor. Sin embargo, el propietario puede realizar esfuerzos en la gestión forestal con el fin de reducir su exposición al riesgo de incendio. Así, el propietario o gestor forestal también puede contratar activos financieros que cubran las posibles pérdidas. Uno de esos mecanismos es el seguro forestal.

El seguro supone un mecanismo que reduce el riesgo en la inversión, pues minimiza el impacto económico de la pérdida en caso de incendio forestal. Cabe mencionar que tanto el esfuerzo en gestión forestal como el empleo de activos financieros suponen medidas complementarias no excluyentes para la buena administración de los recursos forestales. De tal manera que el propietario o gestor forestal puede emplear ambos mecanismos para reducir el riesgo de pérdida en su producción.

La valoración forestal y la rotación óptima del cultivo se verán condicionada por la presencia de un seguro forestal. Así, a partir de fórmula de Faustmann y considerando sus posteriores desarrollos (Faustmann, 1849; Hartman, 1976; Samuelson, 1976; Reed, 1984), se incluye el riesgo de incendio y el seguro para calcular la valoración forestal. De tal manera que la rotación forestal dependerá de ambos factores. Las coberturas son muy importantes cuándo se diseña un seguro forestal. En este sentido la cobertura en reforestación ayuda a recuperar la producción de una manera más rápida y controlada. Sin embargo, la cobertura por daños en la madera, supone para el asegurado recuperar parte de la inversión esperada y tener cierta liquidez a pesar de los daños ocasionados. De estas dos coberturas, la primera tiene un interés más alto desde el punto de vista social mientras que la segunda desde un punto de vista financiero. Así, después del incendio se garantiza la producción de servicios medioambientales, mientras que la cobertura en daños reduce las pérdidas en la inversión.

La valoración forestal anterior solo se ve condicionada por los intereses privados del propietario. Entonces, las decisiones productivas recaen en el propietario particular sin tener en cuenta el bienestar social. Por tanto, la valoración forestal se amplía con el fin de incluir la producción de servicios ambientales que beneficien a la sociedad. De esta manera se obtiene la rotación óptima para el propietario y la sociedad. Ambas no tienen por qué coincidir, pues una no está influyendo sobre la otra. Por lo tanto es necesario desarrollar mecanismos que influyan en el propietario para que éste considere las necesidades sociales en sus decisiones. Uno de esos mecanismos es el pago por la producción de servicios ambientales. Esto genera un ingreso para el propietario y un gasto para la sociedad, lo que supone que ambos agentes sean partícipes de la rotación forestal y que las posibles diferencias entre la rotación forestal de ambos intereses se pueda ver reducida. Uno de los incentivos puede ser el pago total o parcial de la prima del seguro anteriormente planteada. Con este pago se involucran las dos partes, es decir la sociedad y el propietario, en la producción de servicios medioambientales. Esto implica que si el propietario quiere recibir el incentivo, entonces debe de cumplir una serie de condiciones forestales para favorecer la generación de servicios medioambientales.

Por otro lado, la demanda del actual seguro forestal es muy reducida a pesar de que existen ayudas estatales para fomentar su contratación (Agroseguro, 2011). Sin embargo, este apoyo ayudas no contempla la cobertura del seguro por daños en la madera, solo incluye los costes de reforestación tras el incendio. Por ello, el propietario tiene garantizada la siguiente rotación pero la inversión forestal afectada por el incendio no le genera ningún retorno. Asimismo, la garantía de reforestación supone que la sociedad asegure beneficiarse de servicios ambientales. No obstante, el propietario no tiene garantizadas las posibles pérdidas en su producción actual, solo tiene la expectativa de alcanzar una futura rotación forestal. Por lo tanto un seguro que englobe ambas opciones es un mecanismo de gestión forestal interesante para el propietario y la sociedad.

Dada la poca demanda de seguro forestal en España y en Galicia, esta tesis realiza un *experimento de elección* para analizar la disposición a pagar por parte del propietario por un seguro con las coberturas anteriormente planteadas. A este modelo asegurador también se incluye la opción de que el seguro obligue al propietario a estar certificado como medida de control de su gestión forestal. En ningún estudio previo se empleó este modelo con la finalidad de conocer las utilidades que le reportan al gestor o propietario forestal la contratación de un seguro contra pérdidas causadas por incendio. De esta manera también se estudia la utilidad que las diversas clausulas crediticias le generan al propietario. Por último, también se puede analizar cómo influyen las características socioeconómicas de estos gestores o propietarios con respecto a la opción de contratar un seguro forestal.

Con esto se diseña una encuesta para que los propietarios o gestores forestales seleccionaran las opciones del *experimento de elección* de acuerdo con sus preferencias. En el cuestionario se incluyen preguntas relativas a la gestión forestal y también a las características socioeconómicas del encuestado. Con esta finalidad, se realizó una encuesta en el Distrito

Forestal VI de Galicia ubicado en "A Mariña Lucense". La encuesta contiene nueve tarjetas con tres posibles alternativas, las dos primeras recogen un modelo de seguro conforme a los parámetros establecidos en el estudio, mientras que la última hace referencia al *status quo*. Las opciones del seguro son el coste, la cobertura en daños de la madera, cobertura en restauración y la posible obligación de poseer la certificación forestal para poder contratar el seguro.

Con esto, la tesis se estructura en seis capítulos. En el primer capítulo introduce los temas que se tratarán en la tesis. En el segundo se estudia la causalidad de los incendios en Galicia con el fin de analizar la influencia humana en la ocurrencia de incendios. En los dos siguientes capítulos se elabora y analiza un modelo de seguro forestal para ver su incidencia en la rotación y en la inversión forestal. El quinto capítulo realiza un análisis de la demanda del seguro forestal en el VI Distrito Forestal de Galicia. Para finalizar se ofrece una sección con las principales conclusiones obtenidas en la tesis.

2. PRINCIPALES RESULTADOS OBTENIDOS

Los resultados y conclusiones particulares de esta tesis se encuentran al final de los cuatro principales capítulos que vertebran esta tesis. Además, en esta tesis se incluye un capítulo final que enumera las conclusiones generales. En el segundo capítulo se señala que las variables socioeconómicas, ambientales y climáticas inciden en el riesgo de incendio forestal, tanto en número como en superficie. En este sentido, a través de estadísticos espaciales se logra detectar que el comportamiento de los incendios no es homogéneo entre los distritos gallegos. Empleando modelos econométricos se observa que los incendios pueden explicarse por una serie de variables socioeconómicas, climáticas o forestales. Así, factores como la ordenación forestal, la estructura agro-ganadera, la densidad poblacional o la climatología inciden en la ocurrencia de incendios. De tal manera que las políticas públicas deberían incidir en estos apartados para poder reducir los incendios. Se observa que también existe un factor temporal en la evolución de los incendios en Galicia.

El tercer capítulo muestra que el riesgo de incendio y el seguro forestal pueden implicar cambios en la rotación óptima de los cultivos forestales. Con esto se observa que las producciones forestales en localizaciones de menor riesgo tienen un mayor atractivo para el inversor. Sin embargo, aquellas áreas con mayor riesgo de incendio son atractivas financieramente al reducir la volatilidad de la inversión. En este capítulo también se observa que el ajuste de la prima al riesgo real de incendio supone un factor clave en la valoración forestal. En este sentido, si la prima es inferior al riesgo real, entonces la valoración forestal aumenta.

En el cuarto capítulo se observa que se puede implantar el seguro forestal como un incentivo a la producción de servicios ambientales. Esto implicaría una transmisión de valor entre la sociedad y el propietario, provocando que cambie la independencia del propietario al tomar decisiones productivas. Al igual que en el capítulo anterior, este apartado observa que la riqueza del propietario se ve condicionada por el riesgo de incendio y que existe una reducción en la volatilidad de su inversión. Este hecho también se traslada a la producción de servicios ambientales. Sin embargo, la presencia del seguro como un incentivo reduce los resultados económicos sociales al producirse un traspaso de éstos recursos hacia el productor. Tal pérdida económica por parte de la sociedad supone una garantía de que la producción de servicios ambientales continuará en el futuro.

Por último, los resultados del quinto capítulo señalan que el seguro forestal reporta al propietario una utilidad en función de las coberturas e incluso de la obligación de estar certificado. Asimismo, se obtiene la disposición al pago para el seguro forestal, alcanzando un valor de 3.64 €/Ha. También se observa que factores como la edad o ser quien efectúa la actividad forestal son elementos condicionantes en la contratación del seguro forestal.

3. DISCUSIÓN

Esta tesis logra identificar una serie de factores que afectan a la gestión forestal. Entre éstos destaca la implicación del riesgo de incendio, el seguro forestal y los incentivos en la gestión forestal. Esto contribuye a identificar empíricamente una serie de variables socioeconómicas que inciden en el riesgo de incendio, por lo que éste se puede controlar y reducir mediante la formulación de políticas públicas. De la misma manera, se identificó una serie de variables climáticas, espaciales y ambientales que influyen conjuntamente en la ocurrencia y afección de incendios. De ello se deduce que la capacidad predictiva de los factores climatológicos tiene un factor importante. Igualmente, se observa que la ordenación agro-ganadera y forestal incide significativamente en la ocurrencia de incendios. Asimismo, se puede observar que existe un comportamiento espacial y estacional dependiendo del año. Por ello las administraciones públicas deberían desarrollar modelos predictivos más fiables para reducir el riesgo de incendio. Esto favorecería la creación de más fiables políticas preventivas contra incendios.

La existencia de incendio forestal provoca que el propietario pueda asegurarse contra este riesgo. Así, la gestión forestal está condicionada por la existencia de un seguro que contemple esta amenaza. Empleando la fórmula de Faustmann, se ha logrado observar la incidencia que tiene el seguro en la inversión forestal, así como el efecto que tiene el riesgo de incendio en la rotación forestal. Aunque este seguro se ha formulado con múltiples coberturas, está encaminado a paliar los efectos económicos y medioambientales de los incendios. El seguro propuesto reduce la volatilidad en la inversión del propietario, y garantiza que la producción forestal no será abandonada, pues la póliza de seguro garantiza la recuperación forestal tras un incendio.

Al emplear el modelo de Faustmann, se incluye de la producción maderera y la generación de servicios ambientales de manera independiente. La primera supone un interés económico para el productor, mientras que la segunda supone un bienestar para la sociedad. En ambos casos se observa que el riesgo de incendio afecta a su *Valor Actual Neto* (VAN). Sin embargo, se observan diferencias de valoración y de rotación forestal entre ambas perspectivas, públicas y privadas. Dado que la decisión de rotación recae sobre el productor forestal, se plantea la inclusión de un incentivo para relacionar ambos intereses. La transferencia de riqueza supone que ambos intereses se relacionen y equilibren, provocando que la diferencia de períodos óptimos de rotación se acorte.

Por último, la demanda del seguro forestal está condicionada por diversos factores, como pueden ser las coberturas o las condiciones para suscribir un seguro forestal. En este sentido, la cobertura por daños en la madera y para restauración de la propiedad tras incendio, supone características demandadas por los encuestados; ellos desean asegurar lo producido, al mismo tiempo que asegurar la siguiente rotación. Por otro lado, una cláusula que establezca que la producción forestal asegurada debe estar certificada se puede incluir en la póliza del seguro. Esta característica del estudio destaca el interés del propietario por la inclusión de dicha cláusula en la póliza. Esta situación implica que el propietario y la sociedad garantizan un mayor ingreso por su respectiva producción, mientras que para la aseguradora supone un mecanismo de control del riesgo. Por otro lado, para el estudio de la demanda del seguro forestal se tiene en cuenta las características socioeconómicas del mercado objetivo, pues se observa que la demanda se clasifica según la edad y las características personales. Por ello, se deben establecer parámetros con los que la aseguradora llegue al público interesado en contratar el seguro forestal. Del mismo modo que la aseguradora podría adaptar el seguro a las necesidades de cada grupo de clasificación.

4. CONCLUSIONES GENERALES

La gestión forestal se ve condicionada por el riesgo de incendio, por la política forestal y por la posibilidad de contratar un seguro. En el riesgo de incendio influyen una serie de variables ambientales, climáticas y socioeconómicas. Estos factores pueden ser utilizados en las políticas públicas para prevenir y mitigar la ocurrencia de incendios. De esta manera, la gestión forestal se enfrentaría a un menor riesgo de incendio, lo que provocaría que la inversión forestal tuviera una menor incertidumbre.

El seguro forestal es otro mecanismo que ayuda a reducir el riesgo en la inversión forestal. Sin embargo, esto condiciona la gestión forestal al realizar el esfuerzo que determine la póliza aseguradora. Este seguro confiere al gestor forestal el derecho a recibir una compensación en caso de incendio a cambio de realizar la gestión forestal suscrita en el contrato. Las compensaciones pueden ir orientadas a sufragar las pérdidas ocasionadas en la producción maderera y en la recuperación de la generación de servicios ambientales. De esta, manera los intereses privados y públicos están incluidos en la póliza de seguro. Para relacionar estos intereses, la administración podría decidir realizar un pago al propietario por la generación de servicios ambientales. La proposición de esta tesis es que sea la parte proporcional de la prima de seguro en función de la producción de servicios medioambientales. De esta manera el productor vería garantizado su interés económico y la sociedad tendría seguridad en la continuación de los servicios ambientales tras un incendio. La rotación forestal estará vinculada tanto a los intereses del productor como de la sociedad mediante la transferencia de riqueza de la sociedad al propietario. Esto equilibra los intereses en la rotación forestal de ambos agentes. Esto sucedería siempre y cuando se produzca una transferencia de acuerdo con la producción de servicios medioambientales.

Por último, la utilidad que reporta a los propietarios y gestores forestales la contratación del seguro contra incendio dependerá de las cláusulas que se presenten en la póliza. En este sentido, las coberturas son uno de los principales factores que afectan la utilidad que reporta el seguro al propietario forestal, aunque dicha utilidad depende de las características del propietario o gestor forestal. También se destaca que el propietario o gestor tenga una utilidad positiva ante el requerimiento obligatorio de estar certificado para asegurar la producción forestal. Esto muestra que el propietario reconoce que esta condición supone una declaración del riesgo de incendio y un beneficio para su explotación forestal. Así, la compañía aseguradora conoce el riesgo al que se enfrenta el asegurado y podrá discriminar precios de acuerdo con dicho riesgo. Por otra parte, el requerimiento de este sello de calidad productiva repercute económicamente en el propietario al incrementar el precio de su producción forestal. Con todo esto, la compañía aseguradora debería diseñar un seguro forestal centrado en las coberturas que ofrece, en las obligaciones contractuales que establece y en las características socioeconómicas de la zona.

5. FUTURAS INVESTIGACIONES

La temática de este trabajo de investigación podría ampliarse con nuevos datos y herramientas teóricas. Por ello, las futuras investigaciones se centrarán en aplicar nuevos modelos econométricos en los que se logre una mayor comprensión de los factores que afectan al riesgo de incendio. Del mismo modo, se profundizará en los mecanismos de valoración forestal y en la utilidad del seguro forestal de acuerdo con las percepciones de riesgo del propietario. La demanda del seguro será influenciada por este condicionante socioeconómico; por ello, nuevas variables deberán incluirse en los modelos empleados por este estudio.

El segundo capítulo podría ampliarse con más detalle, usando la metodología propuesta por los modelos de econometría espacial para muestras temporales. Con esto se lograría identificar y estimar las relaciones espaciales entre entidades que determinan la ocurrencia de incendios. Esto debe hacerse sin olvidar la inclusión de variables socioeconómicas en el modelo, así como aquellas de carácter ambiental o climático. En el tercer y cuarto capítulo se podría emplear métodos actuariales para valorar el riesgo de la aseguradora. Con apoyo en estos capítulos, también se podría estudiar la influencia de incentivos públicos en la gestión forestal para observar su mutua influencia.

Por último, el quinto capítulo podría incluir un estudio sobre la percepción de riesgo del propietario/gestor forestal. Para ello se podría estudiar la utilidad del seguro forestal en función de aptitudes del entrevistado al riesgo de incendio. Además, se podrían emplear modelos más sofisticados para identificar las distintas clases de demandantes. De esta manera se podría refinar el estudio sobre la demanda del seguro forestal planteado.

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APPENDIX 2: LANDOWNER QUESTIONNAIRE

This survey is addressed to forest owner as well as to forest managers. This people are in charge of activities such as: maintenance, reforestation or cleanings in other forest owners its lands. An individual questionnaire was applied to this focus group and is the source of our confidential and anonymous data. Your implication and time responding this questionnaire is appreciated as well as your sincere and honest responses. There are not correct or incorrect responses, all are valid. The obtained data will be used to a PhD Thesis development and under any circumstances this data will be released to thirds. Cross X to answer the current questionnaire. Thanks for your attention; we hope that you will be pleased by this questionnaire.

1. Approximately, how many hectares and/or plots of rustic and/or forest ownership are you owner and/or manager?

	Mark X	Type of land	Number of plots	Number of hectares
Landowner		Agricultural land (pastures, farms, ...)		
		Forestry areas		
Manager		Agricultural land (pastures, farms, ...)		
		Forestry areas		

1.1. **At lands that you are not the owner but you do manage,** who is the owner of this lands?

1.2. **If you are the forestlands owner and you have a manager in charge of maintenance or reforestation, among other activities,** who is the manager?

□ It is not performed by anyone. □ The management is ceded to ________ □ Others: ________

2. Which activities do you develop in your rural lands and how much area involves each activity?

Mark X	Market	Mark X	Type	Area (Hectares)
	Livestock		Bovine	
			Caprine	
			Ovine	
			Equine	
			Porcine	
			Others:_____________	
	Woodstock		Pine	
			Eucalyptus	
			Oak	
			Chestnuts	
			Others:_____________	
	Agriculture			
	Harvest (mushrooms, truffle, etc.)			
	Fruit production			
	Hunting			
	Energy production (solar, wind, etc.)			
	Apiculture (bees breeds and honey production)			
	Other (specify): ___________________________			

2.1. Have you sold wood stock during the last ten years at lands that you own or manage?

□ Yes □ Non □ Dk/Da

2.1.1. **If previous response is affirmative,** when have you did the last cutting and aproximately how much profit do you record?

The last cutting was made at ___________ and the profit was aproximately:

- □ Lower than 3.000€
- □ From 3.000€ to 6.000€
- □ From 6.001€ to 12.000€
- □ More than 12.000€

2.2. Are the forest land activities or management your main source of income?

- □ Yes, forest land activities support my family and I.
- □ No, the forest only gives me an extra-income during the year, but it is not my main income.
- □ No, I only obtain occasional income depending on the year.
- □ No, nowadays, I have no income from forest land activities.

3. **If you are forest owner:**

3.1. Do you live at the same municipality of your main forest land area?

□ Yes □ No □ Dk/Da

□ **If previous response is negative,** what is the main council of your forest land?

3.2. How do you get the forest land?

- □ Familiar heritage
- □ Land purchase
- □ Donation
- □ Other: ___________

4. Do you know about the Forest Certification?

□ Yes □ No □ Dk/Da

4.1. **If you do not know about Forest Certification:**

Forest certification is obtained from an independent agency; it certifies that forest production is managed according to a set of standards and criterions. The type and requirements of each certification depends on their supervisory agency. These requirements define a suitable forest management according to actual regulations. Forest certification implies a timber price increment; however, the landowner should pay for red tape and administrative costs for certifying the forest production. A forest management plan of cleanings, forest structure, fertilizing, etcetera, should be also applied in order to fulfil the certification requirements.

4.2. **If question 4 is affirmatively answered:**

4.2.1. What forest certification do you know? (Choose as many options as you need)

□ PEFC □ FSC □ Other:______

4.2.2. Have you certified any of your forest lands?

□ Yes □ No □ Dk/Da

- Why do you decide whether to certified or not your forest lands?

- If you have not certified your forest lands, would you be able to certified you lands in case of **(choose one option only)**:
  - □ Simplify the red tape.
  - □ Subsidy (almost in part) the cost of being certified.
  - □ If the timber price will be increased over its habitual cost because of being certified.
  - □ If in case of being certified, the timber price could increase over the cost of achieve the certification.
  - □ Is not interested by any circumstance.
  - □ Dk/Da

5. What familiarity rate do you have about forest insurance? If 1 represents that you have not any knowledge and 5 represents that you know very well this insurance.

1	**2**	**3**	**4**	**5**

5.1. **If the familiarity rate is lower or equal to 3:**

The forest insurance involves the coverage of wildfire, flood or storm damages caused in the forest plantation. An insurance premium should be paid in order to be covered by previous damage risks. If forest insurance is contracted, the compensation could be received by insured when the coverage damages occurs. In Spain, forest insurance premium is subsidized from 14% to 44% of its cost. This percentage depends on the kind of landowner and the insured antiquity.

1.1. **If the familiarity rate is lower or equal to 3:**

1.1.1. How did you know it?

1.1.2. Have you contracted a forest insurance policy?

□ Yes □ No □ Dk/Da

- **If question 5.5.2. is negatively answered,** why have you not contrated any forest insurance?
  - □ I do not know it.
  - □ I do not need it.
  - □ Forest insurance is expensive than its cover offered.
  - □ Other:__________________

- **If question 5.5.2. is affirmatively answered,**
  - How do you describe the forest insurance experience?

  □ Positive □ Neutral □ Negative

- Do you receive a forest insurance subsidy?
  - □ Yes, with a ____ percentage.
  - □ No
  - □ Dk/Da

2. The next question shows some possible insurance policy. Different costs, coverage and requirements are included in this policy. Three bids are proposed to cover the possible wildfire damages. You must choose one of the proposed options in each choice card. You should consider that either the unmentioned features or the external risk effect not vary between policies.

FOREST INSURANCE PREMIUM represents the expense of being insured against the possible forest damages. This payment should be made in Euros per insured hectare. The **TIMBER COVERAGE** and **RESTORATION COSTS COVERAGE** are defined as the damage percentage that insurance company covers. The **FOREST CERTIFICATION REQUIREMENT** is a mandatory condition to get the insurance; without this certification any property could be insured.

2.1. From previous insurance attributes, which are the most important? Choose the feature according its increase importance. Select 1 to the most important, 2 to the second, 3 to the third…

Forest insurance premium	
Timber coverage	
Restoration cost coverage	
Mandatory Forest Certification	

2.2. Choose an insurance policy from each choice card. You could decide not to choose any insurance policy when both policy options are not of your interest.

CHOICE CARD 1

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 2

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	0%	100%	
Restoration coverage	100%	50%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

CHOICE CARD 3

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	100%	50%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

CHOICE CARD 4

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	0%	100%	
Restoration coverage	50%	100%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 5

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	4.20 €/Ha.	5.04 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 6

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	0%	100%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 7

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	100%	50%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 8

	Option A	Option B	Neither A or B: Without forest insurance
Forest insurance premium	5.04 €/Ha.	3.36 €/Ha.	
Timber coverage	100%	50%	
Restoration coverage	50%	100%	
Mandatory forest certification	Yes	No	
Mark X in your election:			

CHOICE CARD 9

	OPTION A	**OPTION B**	**NEITHER A OR B: WITHOUT FOREST INSURANCE**
Forest insurance premium	3.36 €/Ha.	4.20 €/Ha.	
Timber coverage	50%	0%	
Restoration coverage	50%	100%	
Mandatory forest certification	No	Yes	
Mark X in your election:			

2.2.1. If you mainly mark the option “Not to choose forest insurance” (then you have chosen, at least, a half choice cards), how do you explain this main decision?

3. If you manage the maintaining, reforestation or cleaning, among other activities in forestlands:

3.1. Mark the activities that you develop:

Activity	**My family or me**	**Contracting services**	**Is not performed**	**Dk/Da**
Plantation				
Cleanings				
Pruning				
Cutting				

3.2. Do you consider that the adjacent forestlands to yours are property cleaning?

□ Yes □ No □ Dk/Da

3.3. Do you consider the adjacent forestlands of influence to your own forestlands cleaning decisions?

- □ Yes, my forestland is cleaner when the adjacent forestlands are also clean.
- □ Yes, my forestland is less cleaned when the adjacent forestlands are clean.
- □ The adjacent forestlands do not influence my cleaning decisions.
- □ Dk/Da

3.4. In comparison with the adjacent forestlands landowner/managers, describe your own landforest management:

- □ Lower than the other landowner or manager
- □ Equal to the other landowner or manager
- □ Higher than the other landowner or manager

3.5. What is the risk that your lands being affected by adjacent wildfires?

□ Critical □ Important □ Minor important □ Not important

3.6. Do you support that the cleanings would be regulated by laws?

□ Yes □ No □ Dk/Da

3.6.1. Why?

3.7. The next public policies will be applied in order to increase the cleanings and to punish the landowners of uncleaning's lands. You could value these policies by using the question rate, in which 1 represents that you are disagree with proposed public policy and 5 represent that you are agree with proposed public policy.

Public Policy	**1**	**2**	**3**	**4**	**5**
Administrative penalties (fines, returns subsidies...).					
The public administration charge the cleaning cost to landowners that do not performed this activity.					
Charge the wildfire suppression costs to landowners that do not clean their lands during the previous years.					
Increase the rural land property tax when the forest is not cleaned.					
If the landowner does not clean their forests after being informed several times, the public administration will expropriate these lands.					

3.8. If you are a forest owner, what criteria do you use to cut your forest plantation? (Choose only one option)

□ When the plantation is prepared to be cut.

□ When I need money.

□ When timber price is high.

□ When I decide it.

□ Others: ___________

3.9. Nowadays, if you consider the wildfire risk of your forestlands, what is your perception of the next situations (choose in the next range in which 1 represent lower rate and 5 high rate):

	1	**2**	**3**	**4**	**5**
Your forestland could be burned and a portion of timber production could be recovered					
Your forestland could be burned and anything could be recovered					
Your forestland could not be burned					

3.10. If your forest is affected by wildfire, would you plant again the burned area?
□ Yes □ No □ Dk/Da

3.10.1. **If question 10.12. is negatively answered,**

	Yes	No	Dk/Da
I will replant the burned area if the government subsidize it			
I will replant the burned area if the government subsidize it in exchange of contracting forest insurance			

3.10.2. **If question 10.12. is affirmatively answered,** would you plant again the same specie?
- □ Yes
- □ No, I will plant: ___________________________.
- □ Dk/Da

3.11. If your forest is affected by wildfire, would you manage the forestland in the same way that you previously did?
- □ Yes
- □ No, I will increase the forest cleanings.
- □ No, I will decrease the forest cleanings.
- □ No, I will invest on prevention measures to avoid wildfire occurrence.
- □ No, others:____________

3.12. **Besides cleaning activities,** would you develop another prevention measures to avoid forest fires?
□ Yes □ No □ Dk/Da

3.12.1. **If previous question is affirmatively answered,** what prevention measures would you develop?
- □ Firewalls.
- □ Cleaning forest roads.
- □ Setting and maintaining water points.
- □ Others:_________________

4. Do you know any forestry producers association?
□ Yes, I know:__ □ No □ Dk/Da

4.1. **If previous question is affirmatively answered,** are you member of any forestry producers association?
□ Yes, I know:___ □ No □ Dk/Da

5. Approximately, how many times does your forestland were affected by wildfires during the last 10 years?

The forestlands were burned ______ times during the last ten years.

6. What is your opinion about the influence of next socioeconomic factors in wildfire occurrence? Choose between critical, important, minor importance or not important according to your perceptions:

	Critical	**Important**	**Minor importance**	**Any importance**
Progressive ageing population				
Scatter forest properties				
Lower incidence of agricultural activities on forestland				
Bad firefighting organization				
Climate change				
Lower forest supervision				
Abandon or inefficient forest management				
Lower society importance of forestland				
Personal or neighbourhood dispute				
Soft punishment or legal implications for arsonists				
Natural phenomena (lightening)				
People with mental health problems				
Negligence or carelessness				
Political interests				
Economic interests				

7. Considering the burned areas in the rest of Galician municipalities, what is the relation between your municipality wildfires and another Galicia area?
   - □ In average, wildfires affect LESS hectares in my council than the rest of Galicia.
   - □ In average, wildfires affect the SAME hectares in my council than the rest of Galicia.
   - □ In average, wildfires affect MORE hectares in my council than the rest of Galicia.
   - □ I do not know.

8. Considering the number of wildfires in the rest of Galician, what is the relation between your municipality wildfire and another Galicia area?
   - □ The wildfire number is LOWER recorded in my council than other Galician areas.
   - □ The wildfire number is recorded at SAME level in my council than other Galician areas.
   - □ The wildfire number is HIGHER recorded in my council than other Galician areas.
   - □ I do not know.
   - □

9. **If you are forest owner,** what is your opinion about who will be the forest manager in 20 years?

10. How would you predict that the forest sector will be in 15-20 years?

	Will increase	Actual trend will be maintained	Will diminish	Dk/Da
The forest sector demanding of timber certification				
Forest cleaning				
Forest producers association				
Timber price				
Forest stand production				
Forest management subsidies				
Galician timber certification				
Forestland abandon				

11. **If you are forest owner,** what is the probability rate of this situation in 15-20 years? (Choose in the next range, in which 1 represent lower rate and 5 high rate)

	1	2	3	4	5
My inheritors will ignore where the lands are					
The forestlands will not be distributed in heritage					
The forest production will be certified					
The forestlands will be associated to forest producers in order to obtain better rents					
The forestlands will be sold					
Forest management will be transferred to a relative, neighbour, company, etc.					
All forestlands will be concentrated in one plot					
A forest insurance will be contracted					

12. You could participate in a lottery with 6€, what option do you choose?

		Mark X
Option A	15€ will be received with a 10% probability. Meanwhile, 5€ will be received with a 90% probability.	
Option B	20€ will be received with a 30% probability.	
Option C	Indifferent between both previous options.	

13. If you have 20€ prepared to expend in a raffle, what is your willingness to pay by one raffle ticket in which there are 10 tickets and only one could achieve the prize of 100€?

I will pay ___________ Euros by ticket.

14. To finalize the current questionnaire, personal data are requested (any identification questions are included):

- Gender:
- Residence municipality:
- Post code of your permanent address:
- Born date:
- Occupation:

- Studies:
  - □ Not able to read or write
  - □ Can read and write, but went to school less than 5 years
  - □ Went to elementary school 5 or more years, but secondary education has not been completed (EGB, ESO or Bacharelato Elemental)
  - □ Secondary education degree (Bacharelato Elemental, EGB or ESO completa)
  - □ High school education degree (Bacharelato superior, BUP, Bacharelato LOGSE, COU, PREU)
  - □ First degree of professional training (FPI, FP grado medio, Oficiaría Industrial or equivalent)
  - □ Second degree of professional training (FPII, FP superior, Mestría industrial or equivalent)
  - □ Diploma course degree, Technical architecture or engineering degree. Pass three curses on Architecture, Engineering, Bachelor degree
  - □ Architecture, Engineering, Bachelor degree or equivalent
  - □ Doctorate

- Family annual income:
  - □ Lower than 8.000 €
  - □ From 8.001 € to 16.700 €
  - □ From 16.701 € to 25.900 €
  - □ From 25.901 € to 36.700 €
  - □ From 36.701 € to 52.100 €
  - □ From 52.101 € to 80.800 €
  - □ More than 80.801 €

- What kind of area do you live in?
  - □ Urban area
  - □ Rural area

APPENDIX 3: PUBLICATIONS RELATED WITH CHAPTER 1

Barreal, J., Loureiro, M.L. 2015. Modelling Spatial Patterns and Temporal Trends of Wildfires in Galicia (NW Spain). Forest Systems 24 (2), e022, xx pages. http://dx.doi.org/10.5424/fs/2015242-05713.

Forest Systems
24(2), e022, 19 pages (2015)
eISSN: 2171-9845
http://dx.doi.org/10.5424/fs/2015242-05713
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Modelling spatial patterns and temporal trends of wildfires in Galicia (NW Spain)

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Abstract

Aim of study: The goal of this paper is to analyse the importance of the main contributing factors to the occurrence of wildfires.

Area of study: We employ data from the region of Galicia during 2001-2010; although the similarities shared between this area and other rural areas may allow extrapolation of the present results.

Material and Methods: The spatial dependence is analysed by using the Moran's I and LISA statistics. We also conduct an econometric analysis modelling both, the number of fires and the relative size of afflicted woodland area as dependent variables, which depend on the climatic, land cover variables, and socio-economic characteristics of the affected areas. Fixed effects and random effect models are estimated in order to control for the heterogeneity between the Forest Districts in Galicia.

Main results: Moran's I and LISA statistics show that there is spatial dependence in the occurrence of Galician wildfires. Econometrics models show that climatology, socioeconomic variables, and temporal trends are also important to study both, the number of wildfires and the burned-forest ratio.

Research highlights: We conclude that in addition to direct forest actions, other agricultural or social public plans, can help to reduce wildfires in rural areas or wildland-urban areas. Based on these conclusions, a number of guidelines are provided that may foster the development of better forest management policies in order to reduce the occurrence of wildfires.

Keywords: Cause-effect relationship; climatology; spatial and temporal indicators; fixed effects; random effects; socio-economic factors.

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Introduction

It is estimated that more than 1.3 million hectares of forest are destroyed by wildfires in Europe each year (FOREST EUROPE, UNECE & FAO, 2011). Spain is one of the five southern European countries with the highest level of damage caused by wildfires, with a yearly average of 19,705 wildfires from 1998 to 2007, affecting a total of 130,714 hectares (SECF, 2010). Within Spain, the case of Galicia is particularly relevant. While only representing 6% of national surface area, between 1991 and 2010 Galicia registered an approximate average of 46% of Spanish wildfires and 21% of the total burned surface area (Figure 1), according to MARM (2012) and the regional government

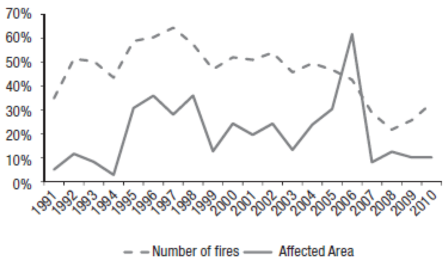

Figure 1. Galician wildfires with respect to the total number of Spanish wildfires (1991-2010).

Barreal, J., Loureiro, M., Picos, J. 2012. Estudio de la causalidad delos incendios forestales en Galicia, Economía Agraria y Recursos Naturales 12(1), 99-114. ISSN: 1578-0732, http://recyt.fecyt.es/index.php/ECAGRN/article/view/earn.2012.01.04/10340

Economía Agraria y Recursos Naturales. ISSN: 1578-0732. e-ISSN: 2174-7350. Vol. 12, 1. (2012). pp. 99-114

Estudio de la causalidad de los incendios forestales en Galicia

Jesús Barreal[1], María Loureiro[1], Juan Picos[2]

RESUMEN: El objetivo de este trabajo es estudiar la relevancia de los múltiples factores socio-económicos, agrarios y ambientales en la ocurrencia de los incendios forestales en Galicia. Los modelos econométricos presentados analizan el número de incendios ocurridos así como el número de hectáreas quemadas, en función de los múltiples factores indicados. A raíz de los resultados obtenidos, se concluye que determinadas políticas públicas preventivas diseñadas hacia una reorientación el sector agro-ganadero, el cuidado de la pirámide poblacional y un mejor aprovechamiento de los usos del suelo, pueden ayudar a disminuir los incendios forestales en Galicia de forma significativa.

PALABRAS CLAVES: Relación causa-efecto, factores socio-económicos, climatología, regresión.

Clasificación JEL: Q23, Q51.

DOI: 10.7201/earn.2012.01.04.

The causality of wildfires in Galicia

ABSTRACT: The goal of this research is to analyze the importance of the main factors contributing to the occurrence of wildfires in Galicia. The econometric models are specified taking into account as a dependent variable the number of fires and affected area, while these depend on a number of explanatory variables, including climatic and socio-economic characteristics. Based on the obtained results, we conclude that public policies should be oriented to re-structuring the agro-livestock sector, considering the evolution of the population pyramid, and new land uses. Such policies can help to reduce wildfires in Galicia.

KEYWORDS: Cause-effect relationship, socio-economic factors, climatology, regression.

JEL classification: Q23, Q51.

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Barreal, J., Loureiro, M. 2012 Análisis espacial de la ocurrencia de incendios en Galicia durante 2006, Actas del V Congreso Forestal Español, ISBN: 978, 6CFE01-323, http://www.congresoforestal.es/fichero.php?t=41725&i=5153&m=2185

Análisis espacial de la ocurrencia de incendios en Galicia durante 2006

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Resumen

Los incendios forestales devastaron amplias áreas forestales en Galicia durante los últimos años, registrándose el episodio más catastrófico en 2006. Ese año destaca por la alta intencionalidad que registró la ocurrencia de incendios, por lo que se plantea la necesidad de localizar los factores espaciales y socioeconómicos que expliquen esa incidencia. Para identificar la relación entre la ocurrencia de incendios y estos factores, se estima preliminarmente un modelo por Mínimos Cuadrados Ordinarios (MCO) en el que se analizará el porcentaje de superficie arbolada que resultó calcinada y el número de incendios en función de características socioeconómicas y climatológicas de las áreas afectadas. Seguidamente, se enriquecerá el análisis mediante el estudio de la relación espacial que presentan las variables dependientes en cada municipio. Para ello se emplearán estadísticos de autocorrelación espacial conjunta e individual. Una vez detectada dicha autocorrelaciónse empleаráel modelo conretardo espacial y el modelo conretardo en la perturbación. De esta manerase estimaráel comportamiento espacial de las variables dependientes teniendo en cuenta las variables independientes incluidas en MCO. A raíz de estos modelos, los resultados preliminares muestran que los factores poblacionales, territoriales, agrarios o forestales influyen en la ocurrencia de los incendios. Por consiguiente, si la política forestal incide en determinadas zonas sobre estas variables, entonces la ocurrencia de incendios se vería modificada.

Palabras clave

Autocorrelación espacial, incendios forestales, política forestal, modelos econométricos espaciales.

1. Introducción

En Galicia durante el 2006 se produjeron numerosos incendios que afectaron amplias extensiones forestales (MOLANO et al., 2007). Esto provocó una gran alarma social y una gran pérdida económica y social. Estas pérdidas afectaron tanto a corto plazo como a largo plazo, viéndose afectada tanto la producción forestal como otros sectores relacionados con ella (BARRIOet al., 2007).Siguiendo datos del Instituto Gallego de Estadística (IGE, 2012) y el Ministerio de Agricultura, Alimentación y Medio Ambiente (MAAMA, 2010) la superficie afectada en 2006 alcanzó un total de 95.948 hectáreas, divididas en 55.533 de superficie arbolada y 40.415 de superficie rasa. Siguiendo los datos facilitados por las anteriores fuentes se puede elaborar el Figura1, en el que se puede observar que 2006 fue el año que más superficie se calcinó en Galicia durante las dos últimas décadas. También se puede destacar que en ese año la superficie forestal calcinada reflejó un incremento considerable con respeto a los otros años. Por otro lado el número de incendios en 2006 es de un total de 6.996. Siguiendo el

APPENDIX 4: PUBLICATIONS RELATED WITH CHAPTER 2

Barreal, J., Loureiro, M., Picos, J. 2014. On insurance as a tool for securing forest restoration after wildfires, Forest Policy and Economics 42, 15-23. ISSN 1389-9341, http://dx.doi.org/10.1016/j.forpol.2014.02.001

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On insurance as a tool for securing forest restoration after wildfires

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ABSTRACT

Quick recovery of the affected areas after a wildfire is important in order to restore the production of the various ecosystem services. We develop a theoretical valuation model that contains a forest insurance policy, in order to protect the landowner against total or partial losses caused by wildfires. Restoration costs of affected areas are explicitly covered. Such model is used to simulate the changes in rotation and profitability of *Pinus pinaster* Aiton. in Galicia (NW Spain). We find that in the areas where the risk of wildfires is higher, forest owners may profit the most from subscribing such insurance. Overall, we conclude that insurance is an effective policy to increase the net present value (NPV) of forest investments, particularly when restoration costs are covered.

1. Introduction

In Europe, forest fires are concentrated in the Southern countries, with Portugal, Spain, Italy, and Greece being the most affected, both in terms of the number of fires recorded and forest area affected (European Commission, 2011). Nevertheless, these Mediterranean countries represent less than 30% of Europe's forestry areas. The case of Spain is even more serious in terms of fire intensity: whilst representing around 10% of Europe's forest area, it suffers about 24% of the total number of wildfires per year, representing approximately 25% of the total amount of burned forest area in Europe. There are also important regional variations within a given country. For example, in the case of Spain, Galicia is the Spanish region with the most wildfires. Galicia represents 15% of the Spanish forest area, whilst in recent years it has experienced around 42% of Spain's total number of wildfires (MAFE, 2012).

Wildfires cause significant damage to both, the forest stand and soil quality, whilst the affected growing stocks may take a long time to recover (Inbar et al., 1997). Therefore, if there are no forest restoration measures in place, the chances of success for a post-wildfire forest depend on its natural regeneration speed and how badly degraded the soil is (Bautista et al., 2009). However, forest restoration is expensive for landowners, who may be interested in covering wildfires losses with insurance in exchange for the payment of an insurance premium. In order to mitigate the significant losses caused by wildfires, some private companies offer the possibility to take out forest insurance. In particular, in countries such as Norway, Germany and France, landowners can contract fire insurance. In general, these policies can cover damage caused by storms, snow, or wildfires. The forest insurance policies in these countries can also cover other restoration costs, including all the damage caused, although different restrictions and conditions may apply. For example, in Germany, the restoration cost is not usually included within the forest insurance policy. Keeping this in mind, it is therefore necessary to assess the impact of forest insurance as a compensation mechanism for the damage caused by wildfires on forest management.

In this study, we look into an experimental Spanish fire insurance programme. Some forest insurance programmes have appeared in this country over the last few decades, and a legal protocol for their implementation is currently underway. These insurance programmes have been designed to cover the costs of replanting affected areas for a wide range of species, whilst wood and other commercial losses are only covered for a limited number of species. The size of the insurable Spanish forest reached 6,224,029 ha in 2010, whilst only 77,103 ha were insured in the same year (Agroseguro, 2011). This implies that only 1.25% of the forests that fulfil the criteria to be insured are covered with a forest insurance policy.

The Spanish Strategic Forestry Plan (Ministry of Environment, 1999) highlights the importance of forest insurance as a mechanism to cover wildfire losses, with a special emphasis on forest restoration. This insurance can have positive implications for the landowner and society, because the forest returns to production faster and provides new environmental and ecosystem services for the community. Consequently, it is necessary to design an insurance model in which these forest restoration costs could be covered in order to improve the forest management. This type of coverage may provide more sustainable forest management strategies, guaranteeing that forest profitability is not depleted and generates higher incentives to invest in forest production. Therefore, insurance may also help to restore and recover forest areas,

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