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Assessing drought risk in Mediterranean Dehesa grazing lands

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ABSTRACT

Extensive grazing activities in the Mediterranean area will have to confront an increasing risk of drought. This threat poses a challenge to the long-term viability of these activities that play an important role in rural development and have traditionally shaped highly valued ecosystems such as the *Dehesa* landscape in the Iberian Peninsula. The aim of this research is to assess the economic impact of drought on this extensive livestock farming system and evaluate the potential of adaptation strategies such as reducing the stocking rate. A dynamic and stochastic bioeconomic model is developed to account for the complex climatic, ecologic and economic relationships at play during drought.

We simulate the 1999–2010 weather time series to characterize seasonal patterns and evaluate the risk caused by drought spells. We assess the consequences of drought in terms of duration, frequency and intensity, finding that economic losses increase at an increasing rate with long lasting droughts. Our findings reveal different patterns between climate and economic risk variables. The risk of a climate shock concentrates in spring and the beginning of autumn while the risk of suffering economic losses occurs with a 3–4 weeks delay and lasts for a longer period of time. We integrate Monte Carlo routines in our simulation model to assess risk exposure and propose the use of Value-at-Risk to capture downside risk at different thresholds. Our simulation results show that the farmer may have to confront annual economic losses above 22.9% with a 5% probability in the current or baseline scenario. Finally, we use the model as a tool to evaluate the potential of adaptation strategies such as increasing or reducing the stocking rate. We find that the former has rather limited impact on average income as compared to the later but both show significant impacts on risk exposure, which may entail important economic consequences. In particular, we find that increasing the stocking rate by 20% decreases the probability of incurring moderate losses, from 45.0% to 40.6%. Furthermore, it also increases the probability of favourable outcomes, from 50.0% to 52.0%. However, this comes at the expense of a significant increase in the chance of experiencing severe economic impacts, from 5 to 6.9%. On the contrary, reducing the stocking rate by 20% reduces the chance of severe impacts from 5% to 3.7%, but also entails an increase in the probability of moderate losses and a significant drop in the probability of experiencing a favourable outcome.

1. Introduction

The assessment of drought risk on agricultural systems is a research area of main interest given that frequency and severity of drought is expected to increase in the coming decades (IPCC, 2014). Vulnerability to drought in pastures in semi-arid areas can lead to considerable socio-economic and environmental losses in the absence of mitigation and adaptation strategies (Ares, 2007; Morton and Barton, 2002). Practices such as nomadism or transhumance, that once conformed adaptation strategies in the Mediterranean are now in decay (Carmona et al., 2013). Highly variable rainfall patterns is an intrinsic characteristic of Mediterranean grazing lands and has been identified as a major threat to grazing activities. These activities play a key role in the sustainability of highly valued silvo-pastoral ecosystems, which provide a broad array of environmental, cultural and economic services. Surprisingly, despite the relevance of grazing lands at global and local scale, the body of literature that assesses drought risk and analyses the impact of climate variability on grazing ecosystems is relatively limited. Several authors claim that a better understanding of the relationships between climate, ecologic and socioeconomic factors is needed to support decision-making and adaptation strategies (Asner et al., 2004; Iglesias et al., 2007; Thornton et al., 2009 and Jakoby et al., 2014).

The aim of this work is to assess the risk of drought in *Dehesa* grazing activities, which conform a silvo-pastoral ecosystem that extend

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throughout some 3.6 million hectares in the Southwestern part of the Iberian Peninsula. We address questions such as what is the probability of incurring economic losses and which are the most critical periods of risk. In addition, we evaluate to what extent farm adaptation strategies, such as reducing stocking rate, have an impact on economic risk exposure.

The assessment of drought impact and risk in grazing livestock systems faces several challenges. On the one hand, drought is signalled as a covariate event involving complex spatial and seasonal patterns (Thornton et al., 2009; Tiejten and Jeltsch, 2007; Yurekli and Kurunc, 2006). Yurekli and Kurunc (2006) use an autoregressive moving average (ARIMA) model to estimate weather seasonal patterns and highlight that agricultural drought includes consideration of complex variables that make it impracticable to accurately predict the duration and intensity of agricultural drought. On the other hand, drought is also recognized as a complex socio-environmental phenomenon. Although it is perceived as a climate threat, its effects may be worsened or mitigated by the interaction of various environmental and socioeconomic factors (Kallis, 2008; Thornton et al., 2009; Iglesias et al., 2003, among others). The difficulty of finding a universal definition for drought is highlighted by Zargar et al. (2011) who review 76 different drought indices in the literature. Due to its simplicity, rainfall deficit is the most widely used indicator of drought (Yurekli and Kurunc, 2006; Pratt et al., 1997). Much less frequent is the use of indices or measures involving economic criteria. Among them stands the work of White et al. (1998) who report six core criteria, including farm income and the spatial distribution of the phenomenon together with other biophysical criteria, to assess the extent and severity of drought in grazing lands in Australia.

The review by Thornton et al. (2009) highlights that the interactions of climate variability and climate change in grazing lands is a neglected area of research and pinpoint the lack of data to calibrate and validate bio-economic models as an important backdrop. In the last decade, an emerging body of bio-economic models looked into the sustainability of different grazing management strategies in relation to the phenomenon of drought and the stochastic nature of rainfall (Baumgärtner and Quaas, 2009; Díaz-Solís et al., 2009; Müller et al., 2011; Weikard and Hein, 2011). In this strand, the work of Quaas et al. (2007) analyse farmers' incentives to establish a sustainable grazing management system. Also, Beukes et al. (2002) develop a dynamic bio-economic model that identifies annual rainfall as a key determinant in the decision of whether or not to invest in the implementation of grazing management strategies. These authors advocate more research is needed on the effect of management and structure of the herd stock on farm income. The work of Jakoby et al. (2014) highlights that the first-best strategy in rangeland management differs depending on farmers' characteristics and risk preferences. Their simulation-modelling framework incorporates seasonal weather patterns to evaluate different grazing management options under climate variability. In their work, seasonal patterns are simulated assuming a constant weekly precipitation during the rainy season. In other strand, the work of Lybbert et al. (2004) and Martin et al. (2014) show that risk management behaviour in poor pastoralist populations is clearly influenced by wealth dynamics consideration. While this aspect has received very little attention in the literature on drought and pastoralism, their findings have important policy implications to avoid the poverty trap in vulnerable communities. An innovative approach to risk valuation is the work of Lybbert et al. (2010), who explore the potential of field experiments to better understand how poor valuate drought risk mitigation options in a dynamic context. Linking famers' decision-making and biophysical models in a stochastic context is a computational challenge highlighted by Freier et al. (2011). These authors adopt a Markovian approach and develop an optimization decision-making model in order to identify economic and environmental effects of long persistent drought on extensive livestock systems. Their results show the after-effects of drought last far longer than the meteorological phenomenon itself. To this respect, Wilhite and Glantz (1985) also contend that agricultural drought does not always coincide with periods of meteorological drought.

We contribute to the literature with a stochastic and dynamic bioeconomic model that focuses on the multifaceted nature of drought spells and integrates seasonal weather patterns in order to gain a deeper understanding of the complex relations at play during drought. In addition, we use Monte Carlo techniques to assess economic drought risk at the farm level based on three key elements: (i) probability (ii) potential economic losses and (iii) timeframe being considered. We propose the use of Value-at-Risk, a widely used measure in financial risk assessment to capture downside risk. The methodological approach is presented in the next section where we describe fieldwork, summarize the characteristics of the study site and lay down the bio-economic model. In the third section we present and discuss results while in the final section we establish the main conclusions of the research.

2. Methodology

2.1. Study site: grazing livestock in Iberian Dehesa ecosystem

The production system under analysis is that of a traditional *Dehesa* farm, in the Southwestern part of the Iberian Peninsula (see Fig. 1). The region has a continental Mediterranean climate with mild winters and very hot summers. The annual rainfall is between 600 and 650 L/m^2 and usually peaks in autumn and spring.

The model was parameterized, calibrated and validated using face-to-face field survey, a review of technical information and local studies, satellite data and in situ field data obtained in a representative *Dehesa* grazing farm located in Pozoblanco (Pedroches Valley). Field work was conducted between May 2010 and June 2012 on two plots of land, 60 m × 60 m in size, with grazing and no grazing activities respectively. Pasture growth was measured at monthly intervals, with wet weight and dry matter measured in three random sample cuts on each plot. Soil water content was also measured[1] at three random points and at three cumulative depths (20 cm, 40 cm and 60 cm) during the vegetation activity period. Meteorological daily data on air temperature, rainfall and solar radiation was obtained from the closest weather station,[2] while rainfall was also measured in situ.[3]

A face-to-face survey was conducted with experts and farmers in the area to characterize farm management and strategies to mitigate drought impacts. This information was also complemented with a review of local studies and technical information. The extensive grazing farm has a livestock density of 0.3 livestock units (LSU) per hectare and is focused on the rearing of beef cattle. Management of livestock is heavily dependent on pasture availability and the breeding calendar of the herd is the main adaptation strategy to confront highly variable seasonal weather patterns. The breeding calendar is illustrated in Table 1 in supplementary material. The mating period usually runs from January to May and calving takes place between the months of October and February to coincide with the main pasture growth period, which reaches its peak in spring.[4] The usual fertility ratio of a livestock farm in the area is 0.85 and farmers sell young at approximately 6 months of age when the animal has reached the required weight. Grazing provides the main component of the herd's diet on the farm and livestock usually graze for the whole year, except for the months of August and September when there is not enough pasture growth and their diet must therefore be supplemented. The increase in

[1] Soil water content in volume percentage was determined using a direct measure taken with TDR (Time Domain Reflectance) sensor (Soil moisture Equipment Corp 6050 × 1 Trase System I).

[2] Hinojosa del Duque (38° 29′ 53″ N, 5° 6′ 51″ W, 543 masl).

[3] Measures were recorded with an automatic pluviometer HOBO-200.

[4] Beef cattle go through different physiological stages during the production cycle resulting in different nutritional needs for each period t. The breeding calendar of the herd is detailed in Table 1 in the supplementary material.