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‘Weather Value at Risk’: A uniform approach to describe and compare sectoral income risks from climate change

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HIGHLIGHTS

- We extend the ‘*Weather Value at Risk*’ concept to assess climate change (CC) impacts.
- The extended concept captures CC-impacts on an indicator's mean and variability.
- We apply the concept to agricultural and tourism incomes in (parts of) Sardinia.
- Rain-fed wheat cultivation shows a higher weather risk than summer tourism.
- However, summer tourism is more susceptible to climate change.

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ABSTRACT

We extend the concept of ‘*Weather Value at Risk*’ – initially introduced to measure the economic risks resulting from current weather fluctuations – to describe and compare sectoral income risks from climate change. This is illustrated using the examples of wheat cultivation and summer tourism in (parts of) Sardinia. Based on climate scenario data from four different regional climate models we study the change in the risk of weather-related income losses between some reference (1971–2000) and some future (2041–2070) period. Results from both examples suggest an increase in weather-related risks of income losses due to climate change, which is somewhat more pronounced for summer tourism. Nevertheless, income from wheat cultivation is at much higher risk of weather-related losses than income from summer tourism, both under reference and future climatic conditions. A weather-induced loss of at least 5% – compared to the income associated with average reference weather conditions – shows a 40% (80%) probability of occurrence in the case of wheat cultivation, but only a 0.4% (16%) probability of occurrence in the case of summer tourism, given reference (future) climatic conditions. Whereas in the agricultural example increases in the weather-related income risks mainly result from an overall decrease in average wheat yields, the heightened risk in the tourism example stems mostly from a change in the weather-induced variability of tourism incomes. With the extended ‘*Weather Value at Risk*’ concept being able to capture both, impacts from changes in the mean and the variability of the climate, it is a powerful tool for presenting and disseminating the results of climate change impact assessments. Due to its flexibility, the concept can be applied to any economic sector and therefore provides a valuable tool for cross-sectoral comparisons of climate change impacts, but also for the assessment of the costs and benefits of adaptation measures.

1. Introduction

Weather affects almost every aspect of the economy to a greater or lesser extent in a variety of ways (Subak et al., 2000; Changnon, 2005; Lazo et al., 2011; Dell et al., 2014). For example, a winter with below-average temperatures and above-average snow amounts may harm the economy by pushing up snow removal and heating costs, while stimulating the economy through an enhanced attendance at ski resorts (Falk, 2010; Shih et al., 2009; Toeglhofer et al., 2011). High temperatures can reduce labour productivity (Ramsey and Morrissey, 1978; Niemelä et al., 2002; Cachon et al., 2012), while increasing the number of visitors to lakes and outdoor swimming pools or sales of mineral water and ice cream. An extended dry period may cause agricultural losses (Lin et al., 2013; Nagarajan, 2010; Neuwirth and Hofer, 2013), while helping construction projects to keep on schedule. Principally, the economic impacts of weather variations may arise from effects on both the supply of and the demand for products or services of a particular industry. Extraordinary hot conditions, for instance, may reduce electricity supply (Pechan and

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Eisenack, 2014; Sathaye et al., 2013), whereas simultaneously increasing cooling energy demand (Hekkenberg et al., 2009; Moral-Carcedo and Vicéns-Otero, 2005).

Overall, even normal weather variations may show noticeable impacts on a nation's economy, let alone extreme weather events. Lazo et al. (2011), for instance, estimate the annual impact of normal weather variations on the U.S. economy to amount to 3.4% of U.S. gross domestic product, with the impact on single industries ranging to as much as 14.4% of their value-added. Economic sectors generally thought to rank among the most weather sensitive include agriculture, energy, tourism, retail, transport, insurance and construction. A careful understanding of the impacts and risks that weather variability poses on various branches of the economy seems essential for the effective design of contemporary economic policies and risk management strategies. Toeglhofer et al. (2012) introduced a simple concept for measuring the economic risks related to fluctuations in the weather, called '*Weather Value at Risk*' or just '*Weather-VaR*'. They used it to exemplarily quantify the current weather risks faced by the Austrian winter tourism industry. However, with the climate expected to change (or to keep on changing) noticeably in the decades ahead (IPCC, 2013), understanding the economic implications and risks of weather variability does not only represent an important task for optimizing current risk management, but may also be of crucial help in assessing the potential economic impacts of future climate change and in developing adequate adaptation strategies.

The objective of this present paper is to test and discuss, whether the Weather-VaR concept of Toeglhofer et al. (2012) represents (i) an adequate approach to describe and compare sectoral income risks due to climate change and (ii) a useful tool to present impact and risk information to stakeholders and decision makers. To this end, we extend the Weather-VaR concept's initial area of application – i.e. weather risks faced by (winter) tourism under current climatic conditions – with respect to both the sectoral and the temporal dimension. That is, regarding the sectoral dimension we apply the Weather-VaR concept not only to the tourism industry, but also to the agricultural sector. In the temporal dimension, we extend the application of the Weather-VaR concept from current climatic conditions to a comparison of current (or reference) and future climatic conditions. These concept extensions are illustrated using data from the river basin 'Rio Mannu di San Sperate' (Sardinia) and its surrounding province Cagliari as well as from Sardinia as a whole. The mentioned river basin and its surroundings is one of the seven study sites investigated within the EU-FP7 project CLIMB[1] (Ludwig et al., 2010), in the context of which the present study has been elaborated. Using climate scenario data from four different Regional Climate Models (RCMs) to account for climate signal uncertainties, we also present a simple strategy of how to incorporate uncertainty information into the Weather-VaR measure.

2. Materials and methods

2.1. The concept of 'Weather-VaR'

The concept of '*Weather Value at Risk*' or just '*Weather-VaR*', introduced by Toeglhofer et al. (2012), represents a method to measure non-catastrophic economic weather risks. It captures both a socio-economic indicator's sensitivity and exposure towards weather variability. Weather-VaR (α) denotes '*the Value at Risk resulting from adverse weather conditions, and represents – for a given level of confidence [α] over a given period of time – the maximum expected loss*' (Toeglhofer et al., 2012, p. 191). Weather-VaR (0.95), by way of example, represents the weather-induced loss, which won't be exceeded with a probability of 95% within the considered time horizon — or put the other way around, which will be exceeded with a probability of 5%. Alternatively, the risk measure 'Weather-VaR' can also be interpreted in terms of return periods, i.e. Weather-VaR (0.95) expresses the lower bound of the weather-induced loss associated with an average recurrence interval of once in 20 periods.

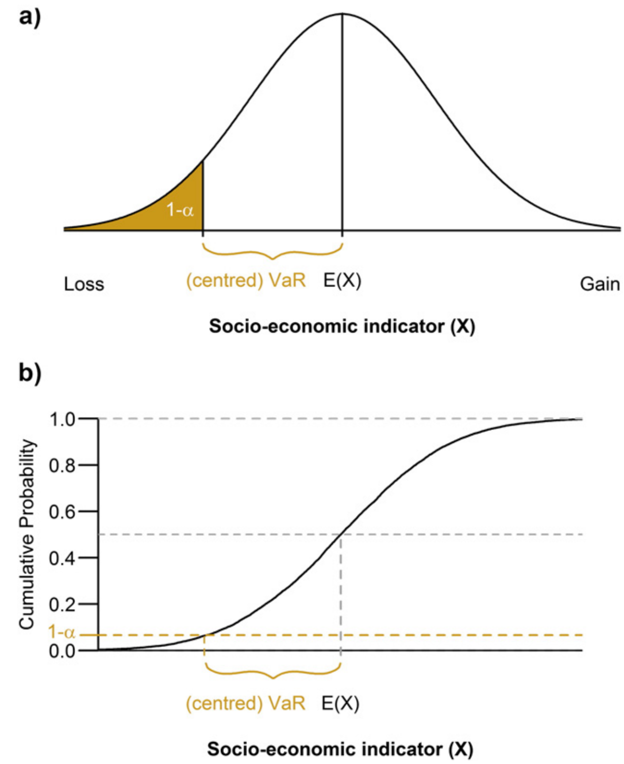

Fig. 1. Illustration of the Weather-VaR concept (based on Toeglhofer et al., 2012).

Fig. 1 provides a graphical illustration of the Weather-VaR concept. Plot a) in the upper part of the figure shows the probability density function of some weather-dependent socio-economic indicator, resulting from the variability of weather conditions. Alternatively, plot b) in the lower part of Fig. 1 illustrates the indicator's cumulative distribution function (CDF), again resulting from the variability in weather. As shown in both plots, the risk measure Weather-VaR (α), or more precisely the centred Weather-VaR (α), simply represents the difference between the value of the considered socio-economic indicator expected under average weather conditions and the value of the considered socio-economic indicator expected under 'adverse' weather conditions as occurring with a probability of $(1 - \alpha) * 100\%$. This difference can be measured in absolute terms or in relative terms, i.e. in percentages of the value under average weather conditions. Note that in this context the term 'adverse' just means 'harmful'. Hence, depending on the socio-economic indicator considered and its relation to weather, different weather conditions may be defined as harmful or adverse. If, for instance, income from snow-based winter tourism is the socio-economic indicator being considered, adverse weather conditions will most likely be defined as unusually high temperatures and/or abnormally low precipitation (resulting in a lack of snow cover). If, by contrast, income from beach tourism is the socio-economic indicator being studied, unusually low temperatures and/or high precipitation will most probably characterize adverse weather conditions.[2]

Considering plot b) in Fig. 1 once again, it is quite obvious that the size of the centred Weather-VaR (α) depends on the steepness of the illustrated curve, i.e. the steepness of the weather-dependent CDF. Roughly spoken, the flatter the curve the higher the indicator's variability due to changing weather conditions and hence the higher the risk emanating from adverse weather conditions. In addition to the risk measure 'Weather-VaR' itself, such illustrations of the indicators'

[1] CLIMB — Climate Induced Changes on the Hydrology of Mediterranean Basins (www.climb.fp7.eu).

[2] Extremely hot temperatures may as well represent harmful conditions in the case of beach tourism (see e.g. Rutty and Scott, 2010).