



## Decision Support

## Robust portfolio selection problem under temperature uncertainty

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## ABSTRACT

In this paper, we consider a portfolio selection problem under temperature uncertainty. Weather derivatives based on different temperature indices are used to protect against undesirable temperature events. We introduce stochastic and robust portfolio optimization models using weather derivatives. The investors' different risk preferences are incorporated into the portfolio allocation problem. The robust investment decisions are derived in view of discrete and continuous sets that the underlying uncertain data in temperature model belong. We illustrate main features of the robust approach and performance of the portfolio optimization models using real market data. In particular, we analyze impact of various model parameters on different robust investment decisions.

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## 1. Introduction

Weather plays a significant role in determining revenue of some industries and market players. National Science Foundation estimated the annual economic impact of weather risk to the US economy as \$485 billion in 2011. Various business sectors such as agriculture, retail, tourism and energy are directly affected by exceptional weather conditions (Svec & Stevenson, 2007). For instance, a warm winter may cause excess supplies of oil or natural gas for the utility and energy companies or may incur significant losses in earnings of a winter resort. Similarly, an exceptionally cold summer can affect tourism sector in various aspects. Even big construction companies, especially in Northern Europe, with tight deadlines and costly penalty clauses, consider derivatives to hedge the risk of delays due to weather conditions (The Economist Magazine, 2012).

Weather derivatives were first introduced by Enron in 1997 as financial instruments to minimize effects of climatic events in the US energy industry. Since then, the unregulated market for temperature derivatives has been constantly growing. The standardized contracts are also available in Chicago Mercantile Exchange (CME) for the major cities in the USA, Europe, Australia and Japan. The most common weather derivatives are written on temperature indices that form about 80% of weather contracts to manage weather related risk (Cao & Wei, 2004). There are also weather contracts written on other weather events such as levels of rain, snow, wind, frost and hurricanes.

The pricing problem for weather derivatives has been widely studied in the literature; for instance see Jewson and Brix (2005), Benth and Saltyte-Benth (2007) and Benth and Saltyte-Benth (2011), Dorfleitner and Wimmer (2010), Schiller, Seidler, and Wimmer (2012), and Hardle, Lopez-Cabrera, and Ritter (2012). The underlying indices or degree days are modeled under an assumption of various stochastic processes. Garman, Blanco, and Erickson (2000) and Svec and Stevenson (2007) modeled the underlying indices of weather derivatives using both time series and stochastic approaches. Brody, Syroka, and Zervos (2002) characterized temperature dynamics by a fractional Ornstein–Uhlenbeck process to price contingent claims based on heating and cooling-degree-days. Hamisultane (2010) studied utility based pricing of weather derivatives. Recently, Elias, Wahab, and Fang (2014) compared regime-switching temperature modeling approaches for applications in weather derivatives. The reader is referred to Saltyte-Benth and Benth (2012) for a critical review on temperature modeling.

Weather derivatives have been extensively used as an attractive asset class for hedging and risk management purposes. As Jewson (2004) pointed out, insurance companies, reinsurance companies, banks, hedge funds and energy companies have set up trading desks that are dedicated to weather derivatives. Weather derivatives are traded on different locations for the purpose of insurance over various weather events. Broadly speaking, insurance is designed for low probability extreme events, like hurricanes and tornadoes, whereas weather derivatives are structured for high probability events like a dryer-than-expected summer or warmer-than-expected winter. An insurance payout is only received after a significant loss is proved. On the other hand, a holder of

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weather derivative contracts receives the payout based on the realization of indices whether they have suffered a loss or not. Turvey (2001) considered weather derivatives as a form of agricultural insurance. Woodard and Garcia (2008) suggested that the potential for weather derivatives in agriculture may be greater, particularly for aggravators of risk such as reinsurer of the agriculture products. Musshoff, Hirschauer, and Odening (2008) investigated portfolio effects and the willingness to pay for weather insurances. Ellithorpe and Punman (2000) stated that participants in the power industry hold a portfolio of weather positions. Brockett, Wang, and Yang (2005) examined the hedging strategies from the credit risk and the basis risk perspectives. Bank and Wiesner (2011) empirically investigated the advantages of using weather derivatives in tourism industry.

The role of weather derivatives within portfolio management has also been recognized by the investment community due to mainly diversification purposes. According to Brockett, Wang, Yang, and Zou (2006), investors have seen the potential in weather derivatives as a tool for portfolio diversification since the derivatives are not expected to correlate significantly with the financial markets. Jewson (2004) highlighted several trading strategies for profitable investment portfolios of weather derivatives. Cao, Li, and Wei (2004) showed that as an alternative class of financial instruments, weather derivatives can improve the risk-return trade-off in asset allocation decisions. Recently, Bertrand, Brusset and Fortin (2015) investigated how to assess and hedge the cost of unseasonal weather in the apparel sector. Barth, Benth, and Potthoff (2011) studied optimal positions in market-traded temperature futures to hedge spatial risk. The optimal portfolio of futures contracts traded in different locations minimizes the variance with a certain temperature index. In this paper, we introduce a robust optimization approach to portfolio management of weather futures under uncertain temperature. To the best of our knowledge, robust optimization has not been applied to portfolio construction of weather futures and options. The framework laid out in the paper might be of interest to the practitioners for the insurance and risk management purposes.

Robust optimization is considered as an alternative approach to stochastic programming and deals with data uncertainty. Since it was independently developed by Ben-Tal and Nemirovski (1998) and El Ghaoui and Lebret (1997), it has been widely used for solving various stochastic programming problems arising in different sectors such as defense, agriculture, energy, supply chain, healthcare, and finance. The reader is referred to Gorissen, Yanikoglu, and Den Hertog (2013) for a detailed overview of robust optimization and its applications in various fields. In particular, it has been applied for robust investment decisions within the single period mean-variance portfolio allocation framework to handle uncertainty arising due to misspecification and estimation errors for (mainly means and covariance matrices of) random asset returns: for instance see Ceria and Stubbs (2006), Goldfarb and Iyengar (2003), Kawas and Thiele (2009) and Gülpınar, Katata and Pachamanova (2011). Moon and Yao (2011) showed that effective portfolio allocation strategies can be obtained by careful selection of the uncertainty sets over which the worst-case is considered. Soyster and Murphy (2013) introduced a framework for duality and modeling in robust linear programs and applied to the classic Markowitz portfolio selection problem. Oguzsoy and Guven (2007) studied robust portfolio planning problem in the presence of market anomalies. In addition, there exists several successful applications of the robust optimization approach within the multi-period portfolio allocation framework; for instance, see Ben-Tal, Nemirovski and Roos (2002) and Bertsimas and Pachamanova (2008).

Robust optimization considers the worst-case decision criteria unlike the expected value criteria is used as a standard approach

for decision making problems under uncertainty. It possesses modeling and computational advantages over the stochastic programming (Ben-Tal, Ghaoui, & Nemirovski, 2009). The data uncertainty is taken into account during modeling stage of the problem without an assumption on specific distribution of the underlying random variables. The uncertain parameters take their worst-case values within a set (so-called an uncertainty set). An uncertainty set consists of general restrictions (representing different forms of rules or factors) on the realizations of the uncertainties of the underlying stochastic program. The robust counterpart of the stochastic program is derived in view of the pre-specified uncertainty set. This is a deterministic model that does not involve an uncertain parameter (Bertsimas, Pachamanova, & Sim, 2004). Most importantly, the robust model becomes computationally tractable. The main drawback of the robust optimization methodology is that specific choice of uncertainty sets and budget of robustness may lead to a conservative strategy (Gulpınar & Rustem, 2007). The recent studies showed that data driven robust approaches to design uncertainty sets utilizing data can overcome this issue and avoid overly conservative strategies; see for instance, Bertsimas, Gupta, and Kallus (2013).

In this paper, we are concerned with a portfolio management problem under temperature uncertainty using weather derivatives. A robust optimization approach to portfolio allocation of weather derivatives is introduced to investigate impact of temperature noise on the investment strategies. We are particularly interested in the effect of robust investment strategies for insurance purposes, that is, whether robust optimization strategies perform better than traditional strategies in extreme scenarios. We present robust formulations of the portfolio allocation problem under different uncertainty sets to incorporate risk preferences of the investor. We therefore consider discrete (scenario-based) as well as continuous (symmetric and asymmetric) uncertainty sets for modeling temperature uncertainty. Specifically, we introduce Conditional Value-at-Risk (CVaR) constraints using scenario-based uncertainty set in the context of portfolio selection problem under weather uncertainty. The symmetric and asymmetric uncertainty sets in view of certain conditions determine a risk measure on the uncertainty arising in the underlying problem. For further information on the use of risk measures in financial applications, the reader is referred to Rockafellar and Uryasev (2000) and Natarajan, Pachamanova, and Sim (2008). The numerical experiments are conducted to analyze performance of different investment strategies determined in view of different risk preferences and to investigate impact of various model parameters on the performance of robust investment decisions using real data.

The rest of the paper is organized as follows. Section 2 presents a brief introduction to weather derivatives and Section 3 focuses on modeling temperature uncertainty. The stochastic portfolio selection problem under temperature uncertainty is introduced in Section 4. In Section 5, we derive robust portfolio formulations using different uncertainty sets. Section 6 summarizes design of numerical experiments, implementation issues and data analysis. We present an empirical analysis of robust weather investment strategies using real market data and computational results in Section 7. Section 8 concludes the paper with a short summary of findings and future research directions.

## 2. Weather derivatives

Weather derivatives are traded as financial instruments between two parties. The seller agrees to bear risk for a premium and makes profit if nothing happens. However, if the weather turns out to be bad, then the buyer claims the agreed amount. Broadly speaking, futures (forward) and options are main types of weather derivatives that are written on temperature indices.

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