Financial Instruments' valuation for climate and energy

The main objective of this project is to advance research in modeling and pricing financial instruments such as futures and options, and, more in general, derivatives. We will focus on three types of derivatives: 1) "purely financial" derivatives related to stocks, bonds, currencies, interest rates, and market indexes; 2) energy derivatives; and 3) weather derivatives.

Purely financial derivatives can be priced using a variety of models. Among them, the most renowned is the Black-Scholes model, which has been extended in various directions, leading to diverse approaches. These include models with stochastic volatility and/or stochastic interest rates, models with jumps driven by Lévy processes, fractional models, non-linear models (such as those incorporating transaction costs and incomplete market models), and other variations.

The models used for pricing energy derivatives are often very similar, and in many cases, identical to those employed for valuing purely financial derivatives. Common approaches include the Black-Scholes model, stochastic volatility models, models with multiple factors, and jump-diffusion models.

Weather derivatives are priced based on models that, in most cases, closely resemble or are even identical to the aforementioned approaches. Despite the relatively extensive literature on the subject, modeling and pricing derivatives still pose significant challenges, particularly when the goal is to accurately and efficiently value them. In fact, several models proposed in the literature fail to consider all the significant sources of risk that can impact derivative pricing. Factors such as the correlation between interest rates and the volatility of asset and energy prices, the stochastic behavior of long-run energy price means, and the volatility variability of temperature are often neglected. Furthermore, when dealing with multi-factor models, derivatives on multiple underlying assets, or non-linear pricing methods, numerical approximation becomes necessary. However, in many instances, the computational techniques developed thus far remain relatively inefficient.

In this "Assegno di Ricerca" project we plan to develop new tools for accurately modeling the risk of asset and energy prices and weather indices and for efficiently valuing purely financial, energy, and weather derivatives. To accurately model the risk associated with derivatives and efficiently compute their prices, we will follow two main methodologies:

- Methodology 1: we will model the various sources of risk that may impact the value of the derivatives using stochastic processes in continuous time. Specifically, the goal is to develop accurate multi-factor models capable of accounting for all the variables that may significantly affect the prices of financial assets and energy and weather-related quantities. In doing this, the following empirical features and stylized facts will be accounted for:

- the stochastic volatility of asset returns: to incorporate it, we will use stochastic volatility models such as the Heston's model;

- the mean reversion of interest rates and weather-related variables;

- the fact that the long-run mean of commodity prices vary over time;

- the fact that asset and energy prices often experience large and sudden variations due to financial crises, political instability, or unexpected news;

- the possible correlation among the volatility of returns, interest rates, and energy prices;

- the possible occurrence of long-range dependence in the time series);

- the convenience yield from holding storable commodities;

- the fact that the markets of weather derivatives, energy derivatives (and, in some circumstances, also purely financial derivatives) are incomplete.

Next, we will compute the prices of the derivatives by numerically solving the partial differential equations associated with the stochastic models developed, resembling the Black-Scholes equation. To accomplish this, we will develop new computational methods utilizing finite-difference and spectral approaches, which can be further enhanced by Richardson extrapolation. Through these innovative techniques, we aim to achieve higher levels of accuracy compared to traditional Monte Carlo simulation methods, particularly when the number of stochastic factors is not excessively high (e.g., four or fewer).

However, when dealing with a larger number of factors, we will adopt a novel approach that combines the efficiency of radial basis function discretization techniques with the flexibility of Monte Carlo simulation. This approach enables us to effectively handle high-dimensional problems and maintain computational efficiency despite the increased complexity.

- Methodology 2: In the second methodology, we employ Zadeh's possibility theory as it proves effective in handling incomplete information, represented by fuzzy sets, and in evaluating uncertainty. Possibility theory offers valuable insights into modeling and presents promising applications, particularly in contexts such as weather forecasting. In this domain, conceptual and practical limitations often hinder the applicability of density-based interpretations of models. Our objective is to utilize the average cumulative function (ACF) as a possibilistic representation of fuzzy sets, which shares several properties with the cumulative distribution function. Given the complex nature of decision-making processes in energy transition and climate change, characterized by limited or incomplete knowledge (such as time or space gaps in weather and energy data) and heterogeneous datasets from various sources, observed features may possess both probabilistic and possibilistic nature. To preserve both hard and soft information sources, we will develop hybrid decision-making models that appropriately integrate stochastic variables and fuzzy numbers in a well-founded theoretical framework. Additionally, in the multi-dimensional case, we will leverage suitable depth functions and copulas to construct hybrid models capable of accommodating stochastic, interval-valued, and membership-valued variables.

Activity plan:

In the first six months, the research associate will formulate one or more multifactor models to describe the risk and uncertainty associated with energy prices and the behavior of climatic variables. In the remaining 12 months, the research associate will proceed with the estimation and validation of the proposed models and will construct efficient numerical methods for the evaluation of derivatives based on these models.