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Mathematical Modeling and Numerical Methods for Pricing Emission and Renewable Energy Certificates in Energy Markets

The transition to low-carbon energy systems has fostered the development of market-based instruments, such as CO_2 emission allowances (EAs) and renewable energy certificates (RECs), to reduce greenhouse gas emissions and incentivize renewable energy production. This project explores the mathematical modeling, analysis, and numerical solution of these instruments, contributing both theoretical and computational advances.

EAs are central to cap-and-trade systems, where firms trade allowances under a regulatory cap on emissions. Their price dynamics depend on multiple uncertain factors-in particular, electricity demand and cumulative emissions-and are modeled using forward-backward stochastic differential equations (FBSDEs) and related nonlinear partial differential equations (PDEs). We aim to extend existing models by incorporating feedback mechanisms and jump processes, leading to more complex semilinear partial integro-differential equations (PIDEs). Rigorous mathematical analysis ensures the well-posedness of these models, while novel numerical schemes improve computational efficiency.

A less mature but growing area of study is RECs, which are issued to renewable energy producers. Here, the certificate price depends on stochastic renewable generation and certificate accumulation. The project investigates FBSDE formulations where the existence of solutions remains an open question due to full coupling. We extend the modeling of REC dynamics and analyze the pricing of both standard (European) and advanced (American, exotic) derivatives using PDEs, complementarity problems, and expectation-based formulations. Efficient solution techniques, including finite difference, semi-Lagrangian, and Monte Carlo methods, are developed and tested.

This interdisciplinary work bridges applied mathematics, finance, and energy economics, providing valuable insights into sustainable energy market design and risk management. The models and methods developed have broad applicability in quantitative finance, policy modeling, and computational science.

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