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Fractional Chebyshev Approximations for the Stochastic Hamilton-Jacobi-Bellman Problem: A Case Study on Resource Extraction

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Abstract

This research focuses on the sustainable management of resource extraction under uncertainty, addressing the trade-off between economic efficiency and long-term environmental sustainability. Fluctuating market prices, depletion dynamics, and ecological impacts make traditional deterministic models inadequate for capturing real-world variability. To overcome these challenges, a stochastic dynamic optimization framework is developed, formulated through a stochastic Hamilton-JacobiBellman (HJB) equation. Since analytical solutions to the HJB equation are generally intractable, an efficient spectral collocation method is proposed, combining Chebyshev polynomials for temporal approximation and fractional-order Chebyshev polynomials for spatial approximation. This hybrid method leverages orthogonality and fractional flexibility to model memorydependent extraction behavior with high accuracy and stability. The results reveal optimal extraction strategies that balance short-term returns with long-term sustainability, aligning with the United Nations

Sustainable Development Goals through resilient and low-impact resource utilization policies. © 2026 IEEE.

Author keywords

fractional-order Chebyshev polynomials; Hamilton-Jacobi-Bellman equation; optimal extraction strategy; spectral collocation method; stochastic dynamic optimization; sustainable resource extraction

Indexed keywords

Engineering controlled terms

Chebyshev polynomials; Environmental impact; Environmental management; Extraction; Optimization; Polynomials; Stochastic systems; Sustainable development; Sustainable development goals

Engineering uncontrolled terms

Chebyshev polynomials; Dynamic optimization; Fractional order; Fractional-order chebyshev polynomial; Hamilton Jacobi Bellman equation; Optimal extraction strategy; Resource extraction; Spectral collocation method; Stochastic dynamic optimization; Stochastic dynamics; Sustainable resource extraction; Sustainable resources

Engineering main heading

Economic and social effects

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Details about financial support for research, including funding sources and grant numbers as provided in academic publications.

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