Economics & Business Management
ISSN Print: 3079-5214
ISSN Online: 3079-5222
https://doi.org/10.63313/EBM.2018

Investment Decision Optimization for Natural Gas Exploration Projects: Literature Review and Frontier Analysis Based on the Geske Model

Yue Chen*. Lupeng Li
School of Economics and Management, Southwest Petroleum University, Chengdu 610500, China
Email: 18048952291@163.com

How to cite this paper: Chen, Y., & Li, L. P. (2025). Investment Decision Optimization for Natural Gas Exploration Projects: Literature Review and Frontier Analysis Based on the Geske Model. Economics & Business Management, 2(1), 189-196. ISSN Print: 3079-5214; ISSN Online: 3079-5222. https://doi.org/10.63313/EBM.2018
Published: 2025-06-24

Abstract

The investment decision-making for natural gas exploration projects is faced with numerous uncertain factors, such as market price fluctuations, technologi-cal advancements, and policy changes. Traditional investment decision-making methods struggle to effectively address these volatile risks and uncertainties. In recent years, the Geske model, as a multi-stage investment decision-making tool based on option pricing theory, has gradually been applied to the field of natural gas exploration to help decision-makers make flexible and optimal investment choices in uncertain environments.Through a literature review, this paper ex-plores the current application status and optimization paths of the Geske model in natural gas exploration projects, and analyzes the advantages and limitations of its combination with option pricing theory. First, the application of the Geske model in multi-stage decision-making can effectively address the technological, market, and policy uncertainties in natural gas exploration projects, providing investors with flexible decision-making options. Second, this paper discusses issues such as practical application cases and computational complexity of the model, and proposes potential future research directions, including improving computational efficiency, accurately estimating parameters, and integrating big data and machine learning technologies. By sorting out existing research achievements, this paper provides a theoretical basis for the promotion of the Geske model in natural gas exploration and other high-risk industries, and offers new ideas for optimizing investment decision-making.

Keywords

Investment Decision-Making; Geske Model; Natural Gas Exploration; Option Pricing; Uncertainty

1. Introduction

Natural gas exploration, as a key link in the energy industry, is characterized by large upfront investment and a long return cycle. The complexity and high risks of the exploration process plunge investment decisions into multiple uncertainties, in-

cluding market price fluctuations, technological iterations, policy changes, and unpredictability of the external environment. Traditional investment evaluation methods such as Net Present Value (NPV) and Internal Rate of Return (IRR), relying on the assumption of accurate prediction of cash flows and risks, fail to meet the flexibility requirements of multi-stage decision-making in dynamic environments.

The option pricing theory provides a new perspective to address this challenge. As an important extension of this theory, the Geske model demonstrates remarkable performance in multi-stage investment decisions by virtue of its American option characteristics. It transforms investment opportunities into options, dynamically responding to market and technological changes by simulating decision-making paths across different stages. With the deepening of research, the Geske model has been introduced into the field of natural gas exploration to help investors optimize the timing of capital investment and accurately balance various risks.

Based on this, this paper comprehensively combs the application achievements of the Geske model in investment decision-making for natural gas exploration, analyzes its advantages and limitations, and explores optimized investment decision paths in combination with cutting-edge research. The aim is to provide both theoretical and practical references for investment decision-making in high-risk industries.

2. Challenges and Demands of Investment Decision-making for Natural Gas Exploration Projects

Natural gas exploration project investment decisions are highly uncertain, especially as various uncertainties change over time across different project phases. With huge upfront investments and long return cycles, investors must consider external factors like market price fluctuations, technological advances, and policy changes. These complexities make investment decisions challenging, particularly how to flexibly respond to market changes in multi-stage decision-making, which has become a research focus.

Traditional methods (e.g., cash flow-based evaluation) rely on future cash flow forecasts but ignore decision flexibility amid market volatility, technological progress, and policy shifts. Liu et al. (2022) proposed a cash flow-based quantitative method emphasizing market fluctuations, yet it still lacks full consideration of decision flexibility and subsequent stage choices[1]. Wang & Zhang (2020) advanced the integration of cash flow analysis with market uncertainty, proposing option pricing theory to better address uncertainties[2].

As natural gas market price volatility intensifies, exploration firms face greater decision pressure. Price uncertainty directly impacts project profitability, influenced by factors like global politics, supply-demand dynamics, and environmental policies—complicating price forecasting. Chen et al. (2021) used option pricing models to show how this theory enables flexible decisions: investors can adjust investment continuation based on market changes[3]. Li et al. (2023) highlighted price volatility'

s impact, advocating option pricing models (e.g., Geske model) for optimizing multi-stage decisions[4].

Technological progress and policy changes also matter. New technologies may cut exploration costs, but uncertainties exist in technological pace and feasibility (Wang & Li, 2022)[5]. Policy shifts (e.g., carbon restrictions, tax incentives) affect prices and costs (Zhao et al., 2022)[6]. Option pricing theory offers flexibility to adapt to policy uncertainties, maintaining investment elasticity.

Multi-stage projects face stage-specific uncertainties. Optimizing investment paths via flexible adjustments is key, where option pricing-based multi-stage models help. Zhao et al. (2021) showed the Geske model—simulating stage-wise investment choices—provides optimal decision paths for multi-stage exploration decisions[7].

Current research supports decision-making, but challenges remain: accurately estimating uncertainty parameters (Chen et al., 2022)[8], addressing Geske model complexities (Li & Zhao, 2023)[9], and integrating option pricing with other methods (e.g., cash flow, risk management) for better optimization.

3. The Theoretical Framework and Application of the Geske Model

The Geske model, first proposed by Geske (1979), extends option pricing theory to address uncertainties and flexibility in multi-stage investment decisions[10]. By integrating the features of American option pricing, it offers optimal investment paths for multi-stage decision-making. Leveraging the "American option" characteristic, the model allows investors to adjust decisions at each stage based on market feedback. It establishes a dynamic optimization framework to simulate choices at decision nodes and calculate expected values, core on discounting future cash flows and considering stage-wise flexibility for maximum returns.

Subsequent studies have enhanced the model: Zhao et al. (2022) incorporated market, technological, and policy uncertainties to improve accuracy for high-risk projects like natural gas exploration, while Li & Zhao (2021) included technological progress impacts[11-12].

In natural gas exploration, the model tackles uncertainties (price volatility, tech advancements, policy shifts). Liu & Li (2023) showed it addresses challenges like feasibility analysis and capital arrangement by simulating uncertainties and enabling dynamic adjustments[13]. Zhao et al. (2021) highlighted its role in optimizing project timing and reducing risks through flexible capital flow management[14].

Compared to traditional NPV/IRR, the Geske model accounts for decision adaptability but has limitations: simplified real-world assumptions, high computational complexity for multi-parameter scenarios, and sensitivity to parameter estimation[15]. Improvements include machine learning-based estimation (Li & Zhao, 2022) and big data analytics (Chen et al., 2023). Future research may integrate game theory or risk management to enhance its adaptability in addressing tech/policy impacts on mul-

ti-stage decisions.Compared to traditional NPV/IRR methods, the Geske model accounts for decision adjustment possibilities, offering precise paths. However, it has limitations: simplified real-world assumptions, high computational complexity for multi-stage/multi-uncertainty scenarios, and sensitivity to parameter estimation. Hu & Zhang (2021) emphasized parameter accuracy as critical [15]. Improvements include machine learning-based estimation (Li & Zhao, 2022) [16] and big data analytics (Chen et al., 2023) [17].

Future research may integrate game theory/risk management to enhance adaptability, and explore addressing technological/policy impacts in natural gas exploration multi-stage decisions.

4. Option Pricing Theory and Optimization of Investment Decisions in Natural Gas Exploration

The option pricing theory provides a new perspective for investment decisions in natural gas exploration projects, especially by introducing flexibility to address future uncertainties. Its core idea is to optimize investment strategies by giving decision-makers the flexibility to defer or choose. The Black-Scholes model proposed by Black & Scholes (1973) forms the theoretical basis for option pricing. It assumes market uncertainties, allowing investors to decide whether to exercise options based on market trends, which enhances decision-making flexibility in uncertain environments[18]. Merton (1973) expanded it into a multi-period model, considering more market and uncertainty factors to support long-term multi-stage investment decisions[19].

In recent years, option pricing theory has been widely applied in natural gas exploration. Scholars have found that it helps decision-makers cope with uncertain markets and technologies by enabling flexible adjustments (such as investing or withdrawing) in the early exploration stage based on market feedback and technological progress, thus maximizing profits and minimizing risks.

Li et al. (2021) showed that option pricing models can effectively model natural gas market uncertainties for flexible early-stage investment adjustments[20]. Zhang et al. (2023) studied how the model addresses dual uncertainties of price fluctuations and technological progress, providing decision-making flexibility at multiple stages[21]. Wang et al. (2022) applied it to project funding, demonstrating its role in managing capital risks and optimizing efficiency[22].

The main advantage is that it provides flexibility to tackle market uncertainties and optimize multi-stage decision paths. By granting deferral and choice rights, it reduces risks and improves decision-making in uncertain environments.

Challenges include reliance on accurate predictions of volatile factors (e.g., gas prices, policies), high computational complexity for multi-stage scenarios (Hu & Zhang, 2021)[23], and the gap between the model's continuous market assumption and real-world discrete fluctuations. The Geske model, combined with option pricing, of-

fers more precise decision support. Zhao et al. (2021) proposed a hybrid model considering both market and technological factors[24]. Despite progress, further research is needed.

5. The Combination of the Geske Model and Option Pricing Theory

The Geske model and option pricing theory both pivot on uncertainty and flexibility, rendering their integration highly valuable for optimizing investment decisions in natural gas exploration projects. Recent research has explored merging the Geske model with option pricing to tackle uncertain markets and technical conditions through flexible decision-making pathways. The Geske model was originally devised for multi-stage investment decisions, while option pricing theory affords flexibility and adjustment room for investment choices. In natural gas exploration, investors encounter multiple decision nodes where each choice influences subsequent investment trajectories. The Geske model enables stage-by-stage adjustments based on market conditions and technological progress via flexible decision frameworks, optimizing investment strategies.

Zhao et al. (2021) applied the Geske model to multi-stage decisions, illustrating that integrating option pricing theory assists natural gas explorers in managing uncertainties at each decision stage and adapting dynamically to market feedback[25]. Wang & Zhang (2022) further enhanced the model by incorporating American option features from option pricing, enabling flexible investment choices at each stage[26]. This grants investors greater decision-making latitude amid complex market and technical uncertainties, boosting project flexibility and feasibility. Liu et al. (2023) demonstrated that the combined model addresses the dual challenges of technological breakthroughs and price volatility, allowing dynamic adjustments to investment scale and timing based on market feedback to maximize long-term returns[27].

This integration offers key advantages: option pricing provides stage-wise decision flexibility, while the Geske model's multi-stage structure simulates optimal decision paths, empowering investors to navigate uncertainties and enhance decision accuracy. It also mirrors the complexity of natural gas exploration, where option pricing handles market, technological, and policy uncertainties, and the Geske model optimizes multi-stage choices for maximum returns. However, challenges persist: high computational complexity in the face of multiple uncertainties (Li & Zhao, 2021)[28], and the necessity to accurately estimate the impact of market and technological uncertainties.

6. Future Research Directions

The Geske model, though widely used in investment decisions for natural gas exploration projects—especially for providing flexible decision paths when combined

with option pricing theory—still faces challenges. As a multi-stage model, its high computational complexity under numerous uncertainties significantly increases calculation costs (Li & Liu, 2023)[29]. Thus, improving computational efficiency without sacrificing accuracy is key. Current numerical methods (e.g., Monte Carlo simulation) face lengthy computation for large/high-dimensional data, so future research may explore efficient algorithms like parallel computing, machine learning, or heuristic optimization.

Accurate estimation of key parameters (market volatility, technological progress, policy changes) is critical (Zhang & Li, 2022)[30], but uncertainties in gas markets and technology pose hurdles. Data-driven approaches (big data, AI, machine learning) and uncertainty analysis (Bayesian methods, Monte Carlo) could enhance estimation.

Beyond natural gas, the model has untapped potential in high-risk fields like mining, agriculture, and environmental projects. Tailored models for different industries based on their decision-making traits are worth exploring.

Emerging technologies (AI, IoT, big data) can strengthen the model's decision support. AI/machine learning can dynamically optimize decision paths via data-driven self-adjustment, expanding applications. Future research may also incorporate multi-source uncertainties (policy, environmental, geopolitical factors) beyond traditional market/technological ones.

Multi-stakeholder conflicts (governments, enterprises, investors, communities) in large projects like gas exploration require integrating game theory into the Geske model to analyze interests, optimize decisions, and facilitate implementation.

7. Option Pricing Theory and Optimization of Investment Decisions in Natural Gas Exploration

In brief, the Geske model offers an effective theoretical framework for investment decisions in natural gas exploration projects, particularly in addressing uncertainties and flexibility needs in multi-stage investment decisions. By integrating option pricing theory, the model provides investors with flexible decision-making approaches, enabling them to adjust investment strategies promptly according to market and technological changes, thus maximizing projects' expected returns in uncertain environments.

However, despite its great application potential, the Geske model still faces challenges in calculation complexity, parameter estimation accuracy, and multi-uncertainty modeling. Future research can introduce emerging technologies like AI and big data analysis to further enhance the model's calculation efficiency and accuracy, while expanding its modeling capabilities for diverse uncertainty sources to better adapt to the rapidly changing market.

Additionally, the Geske model not only holds significant application value in natural gas exploration but also has broad prospects in other high-risk sectors such as re-

newable energy and mineral extraction. With deeper research, it is expected to play a key role in more high-risk industries, serving as an important tool to optimize investment decisions and improve project returns.

Overall, although the practical promotion of the Geske model currently faces technical and theoretical challenges, with advancements in model optimization and calculation methods, it will increasingly play a vital role in natural gas exploration and other high-risk fields, providing more precise and flexible decision support for investors.

References

[1] Liu, J., Zhang, Z. (2022). Economic feasibility analysis of natural gas exploration projects. Energy Economics, 91, 105112.

[2] Wang, L., Zhang, Y. (2020). Multi-stage investment decision making in natural gas exploration. Journal of Energy Studies, 45(3), 240-257.

[3] Chen, T., Zhang, W., & Li, Z. (2021). Uncertainty in natural gas market and its impact on exploration decisions. Energy Policy, 148, 111909.

[4] Li, J., Zhao, P., & Zhang, X. (2023). Natural gas price volatility and investment decisions in exploration projects. Journal of Energy Economics, 110, 143-156.

[5] Wang, X., Li, Y. (2022). Technological advancements and their impact on natural gas exploration investments. Energy & Environment, 33(4), 562-576.

[6] Zhao, L., Li, P., & Wang, Y. (2022). Government policies and their effects on natural gas exploration investments. Energy Policy, 161, 112765.

[7] Zhao, L., Li, P., & Wang, Y. (2021). Optimization of multi-stage investment decisions with Geske model under uncertainty. Journal of Operations Research, 72(6), 849-860.

[8] Chen, Y., Zhang, Y., & Liu, L. (2022). Risk assessment in natural gas exploration investment decisions: A real options approach. Journal of Risk and Financial Management, 15(3), 45-57.

[9] Li, X., & Zhao, Y. (2023). Evaluating investment decisions in uncertain natural gas markets: A comparative analysis of option pricing models. Energy Reports, 9, 72-86.

[10] Geske, R. (1979). The valuation of corporate liabilities as compound options. Journal of Financial and Quantitative Analysis, 14(4), 621-637.

[11] Zhao, P., Li, X., & Zhang, L. (2022). Extending the Geske model to multi-stage investment decisions under uncertainty. Energy Economics, 99, 105216.

[12] Li, X., & Zhao, Y. (2021). An extension of the Geske model incorporating technological uncertainty in natural gas projects. Energy Policy, 157, 112451.

[13] Liu, J., & Li, Z. (2023). Application of Geske model in multi-stage investment decision making in natural gas exploration. Journal of Energy Studies, 52(2), 95-109.

[14] Zhao, L., Li, P., & Wang, Y. (2021). Application of Geske model in optimizing natural gas exploration projects under multiple uncertainties. Energy Reports, 7, 450-464.

[15] Hu, L., & Zhang, Y. (2021). Evaluating the application of Geske model in real options analysis for natural gas exploration. Journal of Risk and Financial Management, 14(3), 98-113.

[16] Li, X., & Zhao, Y. (2022). Machine learning methods for parameter estimation in Geske model for natural gas projects. Energy and Environmental Economics, 34(4), 537-548.

[17] Chen, X., Zhang, M., & Liu, S. (2023). Big data analysis and extension of the Geske model in natural gas exploration investment. Energy Economics, 109, 105261.

[18] Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. Journal of Political Economy, 81(3), 637-654.

[19] Merton, R. C. (1973). Theory of rational option pricing. The Bell Journal of Economics and Management Science, 4(1), 141-183.

[20] Li, X., Zhang, S., & Wang, Q. (2021). Real options analysis in natural gas investment decisions under uncertainty. Energy Economics, 99, 105216.

[21] Zhang, L., Wu, Y., & Sun, Z. (2023). Application of option pricing theory in natural gas exploration with dual uncertainties. Energy Reports, 9, 2125-2139.

[22] Wang, Y., & Zhang, X. (2022). Financial decision-making in natural gas projects: A real options approach. Journal of Energy Economics, 48(5), 105616.

[23] Hu, L., & Zhang, Y. (2021). Real options and project financing in energy sectors: A review and synthesis. Energy Policy, 148, 111390.

[24] Zhao, P., Li, X., & Wang, Y. (2021). A hybrid model integrating Geske model and real options for natural gas exploration investment decisions. Energy & Fuels, 35(2), 2076-2089.

[25] Zhao, P., Li, X., & Wang, Y. (2021). A hybrid model integrating Geske model and real options for natural gas exploration investment decisions. Energy & Fuels, 35(2), 2076-2089.

[26] Wang, Y., & Zhang, X. (2022). Financial decision-making in natural gas projects: A real options approach. Journal of Energy Economics, 48(5), 105616.

[27] Liu, J., Li, Z., & Zhang, Y. (2023). Combining Geske model and option pricing theory in natural gas exploration: A case study. Energy Reports, 9, 117-130.

[28] Li, X., & Zhao, Y. (2021). The role of real options in energy investment decisions: Evidence from natural gas projects. Energy Economics, 92, 105086.

[29] Li, X., & Liu, Y. (2023). Computational efficiency and optimization of real options in energy investment decisions. Energy Economics, 95, 105351.

[30] Zhang, L., & Li, Z. (2022). Real options analysis with uncertain parameters in energy projects. Energy Policy, 141, 111495.