

A Narrative Review of Multi-Scenario Financial Modeling Techniques for Optimizing U.S. Technology Investment Decisions

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Abstract

Technology investment decisions under uncertainty are poorly served by deterministic financial methods that undervalue flexibility and sequential information arrival. This narrative review synthesizes 30 studies published between 2020 and 2026 to examine how multi-scenario financial modeling techniques are applied to U.S. technology investment decision-making and what integrated understanding emerges regarding their capabilities, limitations, and practical value. The literature reveals structured pluralism, strong agreement on the value of contingent decision rights and sequential structure, alongside persistent differences in uncertainty representation, computational philosophy, and organizational applicability. Four contributions are advanced. First, fragmented literature is consolidated into a coherent account of the field. Second, an integrative classification differentiates techniques by assumptions, capabilities, and contextual suitability. Third, unresolved debates are translated into a focused research agenda. Fourth, evidence-informed principles guide technique selection according to uncertainty type, sequential structure, organizational capacity, and institutional context. Effective multi-scenario support depends on diagnostic alignment rather than universal preference for any single method.

Keywords: multi-scenario financial modeling, real options analysis, technology investment, uncertainty, sequential decision-making, Monte Carlo simulation

1. Introduction

Technology investment decisions increasingly confront multi-source uncertainty that deterministic financial methods handle poorly. Capital-intensive projects in digital infrastructure, clean energy, advanced manufacturing, and research-intensive domains face rapid innovation cycles, short technology life spans, volatile demand, policy shifts, and sequential information arrival (Ginbo et al., 2020; Rempel, 2026). When future cash flows are assumed to follow a single expected trajectory, managerial flexibility is systematically undervalued, and the contingent character of optimal commitment is obscured (Maier, 2020; Savchuk, 2023).

Traditional discounted cash flow analysis remains widely used, yet it treats investment as largely irreversible once initiated and offers limited guidance on the value of waiting, staging, expanding, abandoning, or switching as uncertainty resolves. Multi-scenario techniques, including scenario analysis,

Monte Carlo simulation, decision trees, real options analysis, and hybrid computational methods, have therefore gained prominence as means of incorporating uncertainty and adaptive decision rights into technology investment appraisal (Carozzani & D'Alpaos, 2025; Belz et al., 2025; Savolainen & Knudsen, 2025).

Even so, the literature remains fragmented across finance, operations research, strategic management, energy systems, and innovation studies. Techniques are frequently examined in isolation, uncertainty is represented inconsistently, and comparative understanding of when alternative approaches are most suitable is still limited (Gorupec et al., 2022; Alinasab & Hunt, 2025). What is missing is an integrated scholarly account of how multi-scenario methods are applied to technology investment, what collective insights emerge about their capabilities and limitations, and what practical principles follow for decision makers.

This narrative review addresses that gap. Its primary question asks: How are multi-scenario financial modeling techniques being applied to optimize technology investment decision-making within the United States, and what integrated understanding emerges from the existing body of knowledge regarding their capabilities, limitations, and practical value under conditions of uncertainty? Secondary questions examine the techniques most commonly applied, the forms of uncertainty they address, the comparative strengths and limitations of alternative approaches, and the conditions under which different methods prove most effective.

After defining scope and approach, the manuscript traces the evolution of multi-scenario modeling, conducts a systematic comparative analysis of principal techniques, synthesizes the mechanisms that make such modeling effective, identifies current limitations and research priorities, and derives evidence-informed practical implications for technology investment decision-making.

2. Review Rationale

This review examines multi-scenario financial modeling techniques used to support technology investment decisions under uncertainty. Multi-scenario modeling refers to analytical approaches that evaluate investment outcomes across alternative future states, probabilistic distributions, or contingent decision pathways rather than a single deterministic forecast. The focus is restricted to technology-related capital allocation, including digital infrastructure, clean energy, advanced manufacturing, research and development, and related intangible or platform assets, within U.S. decision contexts.

Techniques considered include scenario analysis, sensitivity analysis, Monte Carlo simulation, decision tree analysis, real options analysis, and hybrid or emerging computational methods. The intended audience comprises finance and technology investment researchers, strategic management scholars, and practitioners responsible for capital allocation under uncertainty. The review does not address pure financial portfolio theory unrelated to technology assets, nor does it extend to non-U.S. institutional settings except where methods are transferable.

3. Review Methodology

A narrative review approach was adopted because the field encompasses diverse analytical methods, theoretical perspectives, and application domains not readily amenable to quantitative synthesis. This approach provides the flexibility required to integrate heterogeneous evidence, critically evaluate the evolution of financial modeling techniques, and develop an overarching understanding of how multi-scenario approaches can inform technology investment decisions. Literature research was performed

across major academic databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, Wiley Online Library, MDPI, Taylor & Francis Online, and Google Scholar, covering peer-reviewed studies published between 2020 and 2026. Additional reference screening identified relevant studies not retrieved in the initial searches. Inclusion required explicit treatment of multi-scenario or real-options methods applied to technology-related investment decisions. Studies focused solely on pure financial portfolio theory or non-technology contexts were excluded. After deduplication, 30 studies formed the validated corpus. Although the review emphasizes U.S.-relevant evidence, studies from other settings were included when their methods or findings were transferable. Editorials, conference abstracts lacking methodological detail, duplicates, and unrelated studies were excluded. The selected literature was examined for methodological transparency, conceptual relevance, and contribution to understanding investment decision-making under uncertainty. Evidence was synthesized narratively to compare modeling techniques, identify recurring patterns, examine methodological differences, highlight strengths and limitations, and reveal emerging research directions.

4. Evolution of Multi-Scenario Financial Modeling in Technology Investment

Technology investment decisions have long been evaluated through deterministic financial methods, most notably discounted cash flow analysis and net present value calculations. These approaches assume that future cash flows can be projected with reasonable confidence and that a single expected scenario adequately represents investment outcomes. While computationally straightforward, they systematically undervalue managerial flexibility and fail to capture the multi-source uncertainty that characterizes contemporary technology investments, including rapid innovation cycles, market volatility, policy shifts, and technical learning (Maier, 2020; Savchuk, 2023).

Recognition of these limits prompted the gradual incorporation of scenario-based planning into capital budgeting practice. Early scenario approaches expanded the decision frame by constructing alternative future states, typically organized around optimistic, base, and pessimistic outlooks. Although awareness of downside and upside potential improved, the scenarios often remained static. They were treated as discrete and equally weighted possibilities rather than as evolving information sets that could trigger adaptive responses (Caputo et al., 2023; Pawlak, 2024). Scenario analysis therefore marked an important transitional step but stopped short of embedding sequential decision rights into the valuation calculus.

Probabilistic financial modeling advanced the field further by replacing discrete scenarios with continuous distributions of key value drivers. Monte Carlo simulation, in particular, enabled analysts to propagate input uncertainty through financial models and to generate distributions of net present value, internal rate of return, and related metrics (Pawlak, 2024; Zhang, 2020). Risk could now be expressed in probabilistic terms rather than as simple sensitivity ranges. Classical probabilistic models, however, still treated the investment decision as largely irreversible once initiated. They quantified uncertainty more rigorously without necessarily valuing the option to wait, expand, abandon, or switch as new information arrived (Maier, 2020; Compennolle et al., 2021).

The recognition that many technology investments contain embedded flexibility elevated real options analysis to a central multi-scenario paradigm. By drawing on the analogy with financial options, real options methods formalize the value of managerial discretion under uncertainty. Early applications focused on natural resource and capacity expansion problems, employing continuous-time optimal stopping frameworks to derive investment thresholds (Compennolle et al., 2021; Jeon, 2023). Later work extended these models to multi-factor uncertainty, time-to-build lags, and learning effects, showing that

construction delays and information gathering can materially alter both the timing and the scale of irreversible commitments (Jeon, 2023; Maier, 2020). Parallel developments in binomial and lattice methods made real options more accessible for practical strategic risk management, including the use of project value-at-risk metrics (Savchuk, 2023).

As modeling ambitions grew, pure closed-form solutions proved insufficient for many technology investment problems. Path dependence, American-style exercise features, compound sequential options, and high-dimensional state spaces drove the adoption of simulation-based techniques, particularly least-squares Monte Carlo methods (Villani, 2021; Pawlak, 2024). Hybrid approaches that combine analytical insights with numerical simulation improved reliability, especially in portfolio decomposition and multi-factor sensitivity analysis (Maier, 2020). Neural network surrogates trained on simulation outputs have more recently been shown to accelerate the valuation of complex research and development compound options while retaining acceptable accuracy (Villani, 2021). Surveys of modern Monte Carlo methods further highlight multilevel and multifidelity techniques that reduce computational cost without sacrificing statistical rigor (Zhang, 2020).

A parallel thread concerns the representation of uncertainty itself. Classical real options models typically assume probabilistic risk governed by known stochastic processes. Growing recognition of deeper forms of uncertainty has led to the incorporation of parameter uncertainty through Bayesian methods, ambiguity, and hybrid fuzzy-stochastic formulations that accommodate both randomness and vagueness. Real learning options that explicitly value information gathering under fuzzy-stochastic conditions illustrate this expansion (Bauder et al., 2020; Zmeškal et al., 2026). Exact distributional propagation methods have also emerged to map full input probability distributions into financial metrics such as net present value and levelized cost, moving beyond moment-based approximations (Wieland & Gürsal, 2026). The quality of multi-scenario analysis, these developments suggest, depends critically on whether the chosen uncertainty representation matches the dominant sources of uncertainty in the decision context.

Strategic flexibility has likewise broadened beyond pure project-level timing decisions. Multi-stage portfolio selection frameworks now address sequential research and development funding under both economic and non-economic criteria (Belz et al., 2025). Machine replacement problems have been reformulated as sequences of execution, delay, and cancel options evaluated under stochastic demand and cost conditions (Momani et al., 2024). Competitive interactions appear in multi-volatility real option games (Chandra & Hartley, 2026). At the organizational level, real options reasoning is increasingly understood not only as a formal valuation technique but also as a heuristic of staged commitment employed by resource-constrained firms (Alinasab & Hunt, 2025). Integration with strategic foresight allows numerical uncertainty to be treated quantitatively while structural or radical uncertainty is explored through qualitative scenario methods (Savolainen & Knudsen, 2025).

Taken together, these strands explain why modern technology investment decisions increasingly require multi-scenario decision support. Technology assets are typically capital intensive, subject to rapid obsolescence, exposed to policy and market volatility, and characterized by sequential information arrival. Deterministic methods ignore the value of adaptive decision rights. Static scenario analysis improves awareness but does not formalize those rights. Probabilistic simulation quantifies risk yet often retains an irreversible decision framing. Real options, sequential portfolio models, hybrid computational methods, and expanded uncertainty representations address these successive limitations. The literature's trajectory therefore reveals a progressive movement toward modeling architectures that treat flexibility, learning, and multi-source uncertainty as first-order features of technology investment rather than as residual

adjustments to conventional discounted cash flow analysis. This evolutionary context establishes the foundation for a systematic comparative evaluation of the principal multi-scenario techniques now employed in technology investment decision-making.

5. Comparative Analysis of Multi-Scenario Financial Modeling Techniques

Multi-scenario financial modeling techniques differ systematically in their assumptions about uncertainty, the decision rights they formalize, their computational demands, and their suitability for particular technology investment contexts. A comparative evaluation clarifies these differences and reveals the trade-offs decision makers confront when selecting an analytical approach.

The principal techniques examined in the validated literature fall into three broad classes. Class I comprises analytical closed-form approaches, most prominently classical real options models that yield investment thresholds under specified stochastic processes. Class II encompasses simulation and computational methods, including Monte Carlo simulation, least-squares Monte Carlo, and related numerical procedures. Class III includes hybrid and non-classical uncertainty approaches that incorporate ambiguity, fuzzy-stochastic representations, Bayesian parameter uncertainty, or the integration of quantitative valuation with strategic foresight (Cao et al., 2025; Zmeškal et al., 2026; Savolainen & Knudsen, 2025; Bauder et al., 2020). Heuristic real options reasoning functions as a parallel mode of staged commitment under resource constraints rather than as a formal valuation class (Alinasab & Hunt, 2025).

Table 1 summarizes the comparative characteristics of the main techniques along dimensions of uncertainty treatment, analytical capabilities, principal strengths, key limitations, and contextual suitability for U.S. technology investment decisions.

Table 1 Comparative Characteristics of Multi-Scenario Financial Modeling Techniques for U.S. Technology Investment Decisions

Technique	Uncertainty Representation	Core Capabilities	Principal Strengths	Key Limitations	Contextual Suitability
Scenario Analysis	Discrete alternative futures	Exploration of plausible states	Transparency; strategic conversation	Static; limited formal flexibility value	Early-stage framing; high structural uncertainty
Sensitivity Analysis	Local parameter variation	Identification of value drivers	Computational simplicity	Does not value flexibility or joint uncertainty	Preliminary screening
Monte Carlo Simulation	Full probabilistic distributions	Risk metrics;	Handles multiple	Often retains irreversible	Risk quantification when

		distributional outputs	correlated inputs	decision framing	flexibility is secondary
Decision Tree Analysis	Discrete sequential states	Explicit staging of decisions	Intuitive sequential logic	State-space explosion; discrete approximation	Multi-stage projects with limited branches
Real Options (Analytical)	Continuous stochastic processes	Optimal thresholds; flexibility valuation	Transparent economics; comparative statics	Limited scalability in multi-factor or path-dependent settings	Timing decisions under well-specified market or policy risk
Real Options (Simulation/Computational)	Flexible probabilistic, path-dependent	American features; compound options; portfolios	Handles complexity and early exercise	Reduced transparency; computational cost	Sequential R&D; multi-stage portfolios; complex exercise
Hybrid / Non-Classical	Ambiguity, fuzzy-stochastic, Bayesian, foresight integration	Expanded uncertainty fidelity; learning options	Matches deeper or hybrid uncertainty	Calibration demands; varying implementability	Deep uncertainty; learning; policy ambiguity; Industry 5.0 transitions

Different techniques optimize different aspects of investment decision-making, including flexibility valuation, computational tractability, uncertainty representation, and organizational usability. What emerges from Table 1 is structured specialization rather than universal superiority. Scenario analysis and sensitivity analysis remain useful for problem framing and for identifying critical value drivers, yet they do not formalize the option to adapt as uncertainty resolves (Caputo et al., 2023). Monte Carlo simulation substantially improves risk quantification by propagating input distributions into output metrics such as net present value or levelized cost; exact distributional methods refine this capability further (Pawlak, 2024; Wieland & Gürsal, 2026; Zhang, 2020). Many probabilistic implementations, however, still treat the underlying investment as irreversible once initiated and thereby understate the value of timing and staging rights (Maier, 2020).

Analytical real options methods address this limitation by deriving optimal investment thresholds that embed the value of waiting, expanding, abandoning, or switching (Compennolle et al., 2021; Jeon, 2023;

Alvarez-Herault et al., 2022; Nishihara, 2023; Zambujal-Oliveira & Duque, 2026). Their strength lies in economic transparency and comparative statics. That strength diminishes when the problem involves multiple stochastic drivers, path dependence, American-style exercise, or portfolio interactions. In such settings, pure closed-form solutions can become unreliable or intractable; hybrid analytical-simulation validation has been shown to improve robustness (Maier, 2020).

Simulation-based real options and related computational methods extend the feasible model class. Least-squares Monte Carlo, nested simulation, stochastic optimization, and neural-network surrogates enable valuation of compound sequential options, multi-stage research and development portfolios, and complex exercise features (Villani, 2021; Belz et al., 2025; Giannelos et al., 2024; Momani et al., 2024). The corresponding trade-off is reduced analytical transparency and higher computational cost, although multilevel and multifidelity techniques mitigate the latter (Zhang, 2020).

Hybrid and non-classical approaches expand representational fidelity still further. Ambiguity models alter both investment thresholds and financing implications relative to pure risk frameworks (Cao et al., 2025). Fuzzy-stochastic real learning options explicitly value information gathering under combined randomness and vagueness (Zmeškal et al., 2026). Integration of real options with strategic foresight assigns numerical uncertainty to quantitative valuation and structural or radical uncertainty to qualitative exploration (Savolainen & Knudsen, 2025). Multi-criteria frameworks that combine sustainability assessment with real options illustrate another hybrid direction (Deng et al., 2023). These methods improve the match to deeper uncertainty regimes but introduce additional demands on calibration, data, and organizational capacity.

Contextual suitability follows from these differences. Analytical real options align most closely with the evidence when the dominant decision is one of timing under relatively well-specified market or policy processes (Alvarez-Herault et al., 2022; Zambujal-Oliveira & Duque, 2026). Computational and multi-stage methods fit sequential research and development, portfolio selection, and path-dependent technology problems more closely (Belz et al., 2025; Villani, 2021). Hybrid and foresight-integrated approaches are indicated when structural uncertainty or organizational learning is first-order (Savolainen & Knudsen, 2025; Zmeškal et al., 2026). Heuristic staged reasoning remains relevant for resource-constrained firms that cannot sustain full formal valuation (Alinasab & Hunt, 2025). Regulated or asymmetrically informed settings further require attention to quantity as well as timing distortions (van Oosterhout & Zwart, 2023). The techniques are therefore complementary rather than mutually exclusive. Their comparative value depends on the alignment between uncertainty representation, sequential structure, computational ambition, and organizational capacity. This comparative foundation supplies the structured evidence required for higher-order synthesis of what makes multi-scenario financial modeling effective in technology investment decision-making.

6. Evidence Synthesis: What Makes Multi-Scenario Financial Modeling Effective?

Comparative differences among techniques become most informative when read against the cross-study patterns that determine effective decision support. Effectiveness is not located in any single method but in a set of recurring mechanisms and principles that align modeling structure with the distinctive features of technology investment under uncertainty (Ginbo et al., 2020; Rempel, 2026; Savolainen & Knudsen, 2025).

One such mechanism is the explicit valuation of contingent decision rights. Studies consistently show that the capacity to delay, stage, expand, abandon, switch, or learn improves investment appraisal relative to

irreversible commitment rules (Carozzani & D'Alpaos, 2025; Jeon, 2023; Momani et al., 2024; Belz et al., 2025). Effectiveness rises when these rights are formalized rather than left to informal managerial judgment. The same logic appears in heuristic form among resource-constrained firms that employ staged commitment as real options reasoning even without full quantitative valuation (Alinasab & Hunt, 2025). Sequential structure constitutes a second mechanism. Technology investments frequently unfold as multi-stage processes in which later outlays depend on intermediate information. Models that represent compound options, time-to-build with learning, multi-gate portfolio selection, or phased replacement capture value sources that single-stage formulations omit (Jeon, 2023; Belz et al., 2025; Villani, 2021; Zmeškal et al., 2026). Sequential structure is therefore not an optional refinement; it is a defining characteristic of effective multi-scenario support for technology decisions.

Uncertainty management forms a third principle. Effective approaches match the representation of uncertainty to its dominant sources. Probabilistic risk models perform well when market or load processes are reasonably well characterized (Alvarez-Herault et al., 2022; Wieland & Gürsal, 2026). Ambiguity, fuzzy-stochastic hybridity, and parameter uncertainty become material when information is sparse, subjective, or structurally incomplete (Cao et al., 2025; Zmeškal et al., 2026; Bauder et al., 2020). Integration of quantitative real options with strategic foresight further allows numerical uncertainty and structural uncertainty to be treated through complementary tools rather than forced into a single representation (Savolainen & Knudsen, 2025; Smit & Moraitis, 2026). Misalignment between uncertainty type and modeling representation remains a recurring source of limited decision relevance.

Effective modeling also integrates financial and strategic variables. Purely financial metrics understate the role of non-economic criteria in public research and development portfolios, sustainability objectives, competitive positioning, and digital platform strategy (Belz et al., 2025; Nishihara, 2023; Deng et al., 2023; Trigeorgis & Miller, 2025). Approaches that accommodate strategic narratives, multi-criteria assessment, or portfolio interactions among growth, switching, and abandonment options produce more complete appraisals (Smit & Moraitis, 2026; Trigeorgis & Miller, 2025). Financial flexibility and strategic flexibility appear jointly constitutive to robust technology investment decisions.

Organizational and informational conditions further shape effectiveness. Learning-induced uncertainty affects expected returns after capacity construction, while explicit real learning options value information gathering under hybrid uncertainty (Aretz & Kagkadis, 2024; Zmeškal et al., 2026). Policy and regulatory processes, including stochastic carbon taxes and asymmetric information, alter both timing and quantity decisions and cannot be treated as secondary adjustments (Zambujal-Oliveira & Duque, 2026; van Oosterhout & Zwart, 2023; Nishihara, 2023). Organizational capacity, understood here as the availability of analytical expertise, computational resources, data, and decision-support infrastructure, varies across firms; heuristic staged reasoning remains effective where data, bandwidth, or modeling resources are constrained (Alinasab & Hunt, 2025; Rempel, 2026).

These mechanisms together yield a higher-order characterization of effectiveness. Multi-scenario financial modeling supports technology investment most successfully when it formalizes contingent decision rights, respects sequential structure, aligns uncertainty representation with dominant uncertainty sources, integrates financial and strategic considerations, and remains sensitive to organizational capacity and policy embeddedness. The principles cut across modeling classes and technology domains. They explain why the same technique can prove highly effective in one context and limited in another, and they supply the integrative foundation for identifying current limitations and research opportunities.

7. Current Limitations, Knowledge Gaps, and Emerging Research Opportunities

Despite substantial progress, the validated literature reveals persistent limitations and unresolved debates that constrain the cumulative strength of current knowledge. The limitations are not merely technical; they reflect deeper disagreements about uncertainty representation, model scope, organizational applicability, and the reliability of competing computational philosophies.

One cluster of limitations concerns the representation of uncertainty itself. Classical real options and simulation models predominantly treat uncertainty as probabilistic risk governed by known stochastic processes. A smaller set of studies incorporates ambiguity, fuzzy-stochastic hybridity, or Bayesian parameter uncertainty and shows that these representations can alter both investment thresholds and financing conclusions (Cao et al., 2025; Zmeškal et al., 2026; Bauder et al., 2020). Systematic head-to-head comparisons that hold the decision context fixed while varying only the uncertainty representation are, however, largely absent. It therefore remains unclear under what conditions the choice among risk, ambiguity, and hybrid formulations produces materially different technology investment recommendations.

A second limitation involves the scope of the decision variables examined. Most real options applications focus on investment timing. Only limited work jointly models timing and quantity under asymmetric information, showing that optimal regulation can distort both dimensions (van Oosterhout & Zwart, 2023). Extension of this joint treatment to broader technology investment and regulatory settings remains underdeveloped. Conflicting results on the role of debt in innovation, where ambiguity models suggest debt can accelerate investment while sustainability-oriented models indicate debt may discourage longer-lived projects, have not been reconciled within a common modeling frame (Cao et al., 2025; Nishihara, 2023).

Methodological robustness constitutes a third area of concern. Pure closed-form solutions can become unreliable in portfolio or multi-factor settings, while pure simulation methods trade transparency for flexibility (Maier, 2020; Villani, 2021). Hybrid analytical-simulation procedures, neural-network surrogates, multilevel Monte Carlo methods, and exact distributional propagation techniques have been proposed as remedies (Maier, 2020; Zhang, 2020; Wieland & Gürsal, 2026). Systematic assessment of their bias, reliability, and decision-relevant accuracy across technology investment problem classes remains limited.

Organizational contingency represents a further gap. Formal valuation models generally assume that decision makers can implement the modeled flexibility. Evidence on heuristic real options reasoning in resource-constrained firms indicates that organizational capacity, data availability, and managerial bandwidth condition the feasible form of multi-scenario analysis (Alinasab & Hunt, 2025; Rempel, 2026). The relationship between formal modeling and simplified staged reasoning is recognized but insufficiently theorized across different organizational scales.

Policy processes, finally, are typically treated as exogenous stochastic drivers. Models of carbon taxes or regulatory tariffs rarely incorporate the possibility of endogenous policy responses or structural breaks (Zambujal-Oliveira & Duque, 2026; Alvarez-Herault et al., 2022). The assumption limits the realism of policy uncertainty analysis for long-lived technology investments.

These limitations translate into a focused research agenda. Comparative evaluations of alternative uncertainty representations on identical technology investment problems are needed to isolate the decision consequences of representational choice. Joint modeling of timing and quantity under asymmetric information should be extended beyond the limited regulatory settings currently examined. The conflicting

implications of debt for innovation under varying ambiguity, project duration, and tax assumptions require systematic reconciliation. Research linking organizational capacity to the appropriate form of multi-scenario reasoning would clarify when formal valuation, heuristic staging, or hybrid approaches are warranted. The reliability of hybrid analytical-computational methods should be assessed across representative technology investment problem classes. Incorporation of endogenous policy dynamics and structural breaks would strengthen the treatment of policy uncertainty in long-horizon technology decisions.

Emerging opportunities also arise from advances in artificial intelligence, digital twins, and adaptive analytics. While the validated corpus already includes neural-network acceleration of complex option valuation and exact uncertainty propagation methods (Villani, 2021; Wieland & Gürsal, 2026), the integration of explainable AI, foundation models, and real-time scenario updating into multi-scenario investment frameworks remains largely prospective within the 2020–2026 evidence base. These directions should build on, rather than bypass, the unresolved debates identified above.

The current state of knowledge is therefore characterized by strong agreement on the value of flexibility and sequential structure, alongside substantive and unresolved differences in uncertainty representation, model scope, methodological reliability, and organizational applicability. Addressing the six priorities outlined here would materially strengthen the cumulative contribution of the field to technology investment decision-making under uncertainty.

8. Practical Implications for Technology Investment Decision-Making

The synthesized evidence carries direct implications for corporate finance managers, technology executives, venture capital professionals, investment analysts, and strategic planning teams responsible for allocating capital under uncertainty. Technique selection is not a matter of universal preference; it depends on the alignment between the characteristics of the investment problem and the assumptions embedded in alternative multi-scenario approaches.

Five evidence-informed principles follow from the comparative and synthetic findings. Uncertainty representation should match the dominant sources of uncertainty. When market, load, or cost processes are reasonably well characterized, probabilistic and classical real options methods provide transparent and decision-relevant thresholds. When ambiguity, sparse data, subjective judgment, or structural change predominate, hybrid, Bayesian, fuzzy-stochastic, or foresight-integrated approaches offer a closer match to the decision environment. Sequential structure should be respected: investments that unfold in stages, incorporate learning, or contain compound decision rights are poorly served by single-stage formulations; multi-stage, compound-option, and learning-option architectures better capture the value at stake. Computational ambition should be calibrated to both problem complexity and organizational capacity. Closed-form methods retain advantages in transparency when complexity remains tractable; simulation, surrogate, and hierarchical methods become necessary as path dependence, early exercise, or portfolio interactions increase; heuristic staged reasoning remains appropriate where formal modeling resources are constrained. Policy and informational factors should be treated as first-order when they are present. Regulatory processes, carbon pricing, and asymmetric information alter both timing and scale decisions and cannot be relegated to secondary sensitivity tests. Finally, quantitative and qualitative tools should be treated as complementary. Numerical uncertainty and structural or radical uncertainty address different facets of the technology investment problem; forcing both into a single representation reduces rather than increases decision quality.

These principles can be organized into a practical selection pathway. Figure 1 synthesizes the reviewed evidence into an evidence-based decision pathway for selecting multi-scenario financial modeling techniques in U.S. technology investment settings. The pathway begins with diagnosis of the dominant uncertainty type and the sequential character of the investment, proceeds through assessment of organizational modeling capacity and the presence of material policy or informational distortions, and culminates in the identification of technique classes most consistent with the diagnosed conditions. It is not offered as a rigid algorithm or as a new theoretical framework. It is a structured summary of the conditions under which the literature indicates that alternative approaches are most coherent with the evidence.

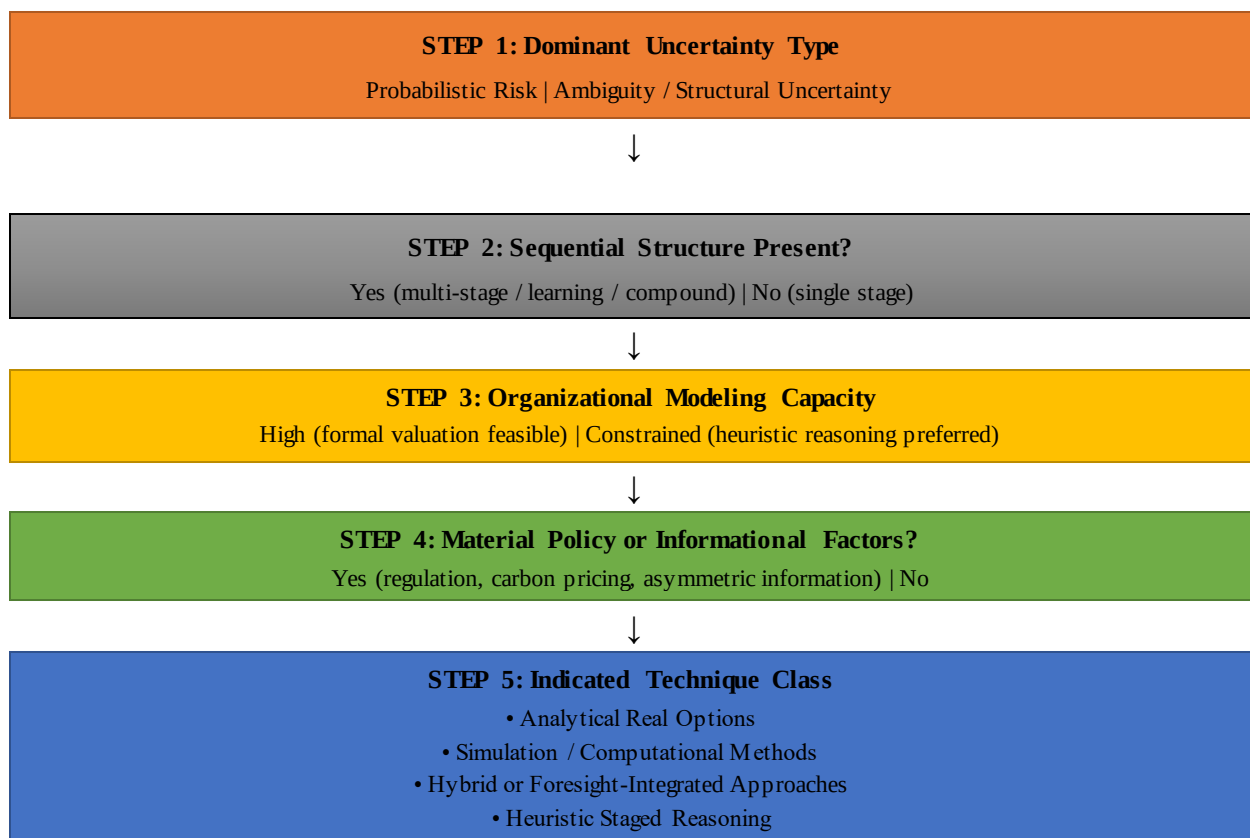


Figure 1

Evidence-Based Decision Pathway for Selecting Multi-Scenario Financial Modeling Techniques in U.S. Technology Investment Decisions

Consider a U.S. firm evaluating a multi-phase investment in utility-scale renewable energy technology with uncertain future policy support, learning effects in construction, and staged capital outlays. Following the pathway, the dominant uncertainty is recognized as a mixture of probabilistic market/policy risk and structural policy ambiguity; the investment is clearly sequential; organizational modeling capacity is high; and material policy factors are present. The diagnosis therefore points toward a hybrid approach that combines multi-stage real options (to value timing, expansion, and learning) with scenario or foresight elements (to explore structural policy shifts), rather than a single-stage analytical model or pure Monte Carlo simulation.

Application of the pathway varies with investment characteristics. Large, irreversible, and highly uncertain commitments with sequential information arrival favor formal multi-stage or hybrid methods when

organizational capacity permits. Smaller or resource-constrained decisions may be better supported by simplified staged reasoning. Early-stage technologies with high structural uncertainty benefit from the combination of quantitative flexibility valuation and qualitative foresight. Mature technologies operating under relatively stable probabilistic risk may be adequately served by analytical real options or well-specified simulation. In all cases, the central practical implication is diagnostic: effective multi-scenario support begins with accurate characterization of uncertainty, sequence, capacity, and institutional context rather than with default reliance on any single technique.

9. Limitations of the Review

This review is limited to English-language publications from 2020 to 2026 and focuses on U.S. technology investment contexts. Findings may not transfer fully to other jurisdictions or earlier periods. The narrative design prioritizes depth of synthesis over exhaustive coverage of every related modeling tradition. In addition, the reviewed literature may reflect publication bias toward successful or well-specified modeling applications, which could underrepresent unsuccessful or inconclusive attempts.

10. Conclusion

This narrative review examined how multi-scenario financial modeling techniques are applied to optimize technology investment decisions under uncertainty. The evidence shows that effective support depends on formalizing contingent decision rights, respecting sequential structure, matching uncertainty representation to dominant uncertainty sources, integrating financial and strategic considerations, and remaining sensitive to organizational capacity and policy context.

The review delivers four contributions. It consolidates a fragmented literature into a coherent account of structured pluralism. It provides an integrative classification of techniques by assumptions, capabilities, and contextual suitability. It translates unresolved debates into a focused research agenda. And it offers evidence-informed principles for technique selection.

Future research should prioritize comparative tests of uncertainty representations, joint timing and quantity modeling, reconciliation of debt-innovation results, organizational contingency, hybrid method reliability, and endogenous policy dynamics. Practitioners benefit most by diagnosing uncertainty type, sequence, capacity, and institutional setting before selecting a modeling approach. Multi-scenario financial modeling will remain central to technology investment as uncertainty, sequential information, and adaptive decision rights continue to define the problem.

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