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Optimizing Value-Based Healthcare Pricing Through Actuarial Science: A Theoretical Approach

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Abstract
Value-based healthcare (VBHC) seeks to align healthcare spending with outcomes, yet implementation has been constrained by challenges in risk adjustment, cost measurement, and incentive design. This paper explores the integration of actuarial science into VBHC pricing models, drawing on established concepts such as utility theory, cost-effectiveness analysis, and principal–agent theory. Literature on payment reform and actuarial modeling highlights how actuarially informed approaches can strengthen outcome measurement, reduce inefficiencies, and improve equity in care delivery. Challenges remain, including patient heterogeneity, ethical concerns in pricing, and regulatory barriers. Future research should expand the use of predictive analytics, explore actuarial approaches to personalized pricing, and incorporate social determinants of health. A hybrid framework combining actuarial methods, health economics, and data science offers a promising pathway to more sustainable and equitable healthcare financing.

Keywords: Value-Based Healthcare (VBHC); Actuarial Science; Risk Adjustment; Cost-Effectiveness; Health Financing

1. Introduction

Over the past one to two decades, healthcare systems worldwide have been experiencing a shift away from purely volume-based or fee-for-service (FFS) payment models toward value-based healthcare (VBHC). Under the FFS model, providers are reimbursed for each service (visit, test, procedure) regardless of outcome, which can lead to overuse, inefficiencies, and misaligned incentives. In contrast, VBHC frameworks aim to tie payment to patient outcomes, quality, and cost effectiveness. A recent scoping review of VBHC initiatives globally found that while many initiatives have adopted elements of value-based care, their implementation is often limited to institutional or departmental levels rather than full-system adoption (Douglas et al., 2025).

The importance of aligning healthcare costs with quality outcomes arises from the dual pressures of rising expenditures and increasing demands for accountability. For example, the United States spends a higher percentage of GDP on health than almost any peer country, yet in many studies, higher spending does not consistently lead to better outcomes. A systematic review titled “The Association Between Health Care Quality and Cost” concluded that the correlation between cost and quality is inconsistent and of small to moderate magnitude, depending on the spending type; some expenditures improve quality, others may

represent waste (Hussey et al, 2013). Similarly, cases of price increases without corresponding improvements in quality or cost control have been observed in hospital integration and consolidation studies. For example, a review of horizontal and vertical integration in US health systems found that many integration arrangements have increased prices (for payers or patients) while often failing to deliver consistent improvements in quality (Satiani et al., 2023).

However, pricing healthcare services in a value-based model involves several key challenges. First, balancing affordability (to patients and system/funders), sustainability (long-term financial viability), and health outcomes is difficult when health needs vary across populations. Data limitations, about outcomes, patient risk, cost of services, and real-world effectiveness, can impede accurate measurement and benchmarking. Second, provider behaviour and incentive structures, if poorly designed, may lead to risk selection (avoiding high-cost patients), under-treatment, or unintended consequences. Third, operational challenges such as information systems, measurement of quality, delays in outcome realization, and regulatory/policy constraints often make implementation difficult. Studies in lower-middle-income contexts, for instance, Ghana, show that stakeholders see considerable potential in value-based payment (VBP) but flag weak data systems, limited human and financial resources, and resistance from providers as barriers (Issahaku et al., 2021).

To address these challenges, actuarial science offers tools and methods for managing uncertainty, risk, and financial sustainability in insurance and health financing. Actuarial science is broadly defined as the discipline that uses mathematical and statistical methods to assess and quantify financial risks associated with uncertain future events. These uncertain events include morbidity, mortality, utilization of medical services, and other health states. Traditional uses include life tables, premium setting, reserve calculation, and risk pooling (Investopedia, 2025).

Risk pooling refers to combining individuals in one financing pool so that the high costs of some are offset by the lower costs of others. The structure and size of pooling (single pool vs multiple pools; mandatory vs voluntary membership) have important implications for financial risk, sustainability, and equity. A classification of pooling arrangements shows that mandatory, large pools offer greater redistributive capacity and financial sustainability than voluntary, small, risk-segmented pools (Mathauer et al., 2019).

In health insurance and managed care settings, actuarial models have historically been used to assess the financial risk to providers under alternative payment agreements. For example, capitation contracts require projecting expected utilization and cost; actuarial risk models have been used to assess risks under managed care and capitation, including identifying diagnosis-related groups, estimating per capita cost, and adjusting for patient risk factors (Pyenson, 1997; Okumu, & Assan, 2025b).

The methods of actuarial science can enhance value-based healthcare (VBHC) in several important ways. First, risk adjustment ensures that payments account for differences in patient health status, comorbidities, and socio-economic factors, thereby reducing incentives for adverse selection; substantial literature highlights the design and trade-offs of such models (Juhnke et al., 2016). Beyond this, actuarial models are widely used to project costs and assess the long-term sustainability of healthcare financing arrangements. For example, Wu et al. (2024) [Wu et al., 2024] employed actuarial modelling to evaluate China's reform of pooled health insurance funds, demonstrating potential balance gaps under prevailing trends. Actuarial approaches are also critical for setting fair payment weights that balance efficiency and quality, whether in episode-based reimbursement, outcome-linked incentives, or broader performance metrics. Finally, dealing with uncertainty is a core actuarial function: stochastic modelling, sensitivity analyses, and scenario planning enable policymakers and providers to anticipate how variations in

utilization, risk factors, or cost trends may affect both provider solvency and patient outcomes. Collectively, these methods provide a robust framework for embedding transparency, sustainability, and fairness into VBHC pricing structures.

Thus, actuarial science can contribute to fairness (ensuring providers are not unfairly penalized for serving high-risk populations), efficiency (minimizing waste, aligning payment with value), and sustainability (ensuring that payer pools, insurance funds, or health systems do not become bankrupt or unbalanced over time because of adverse risk or mis-priced payments).

Given the growing interest in value-based healthcare (VBHC) and the persistent challenges of pricing and payment design, this review pursues three interrelated aims. First, it synthesizes the existing literature on VBHC pricing, drawing together definitions and conceptual frameworks, as well as empirical evidence on reforms such as accountable care organizations, bundled payments, and shared savings models. In doing so, it examines both the observed outcomes and the associated cost trade-offs, while highlighting gaps in practice and evaluation. Second, the review explores how actuarial principles can serve as theoretical tools for optimizing VBHC pricing structures. This includes the application of risk adjustment models, pooling arrangements, payment weights, incentive mechanisms, and forecasting or scenario analysis techniques. Finally, it identifies key knowledge gaps and outlines directions for future research, with particular attention to underexplored contexts such as low- and middle-income countries, the integration of diverse data sources including real-world evidence and socio-demographic risk factors, and the development of models that incorporate non-linear risk, equity considerations, and social determinants of health.

2. Conceptual Foundations: VBHC & Actuarial Science

2.1 Value-Based Healthcare (VBHC)

Value-Based Healthcare (VBHC) has emerged as a prominent paradigm in health policy and health economics. The core principle of VBHC is to maximize patient health outcomes relative to the costs of delivering care (Porter, 2010). This focus distinguishes VBHC from traditional fee-for-service (FFS) models, which primarily incentivize the quantity of services provided rather than their quality or efficiency (Eijkenaar, 2012; Chikovani et al., 2020).

Internationally, VBHC has gained significant traction across diverse healthcare systems. In the United States, initiatives by the Centers for Medicare & Medicaid Services (CMS), such as bundled payment programs and Accountable Care Organizations (ACOs), have sought to link provider reimbursement to patient outcomes and efficiency (Rajkumar et al., 2014). In Europe and other OECD countries, policymakers have increasingly emphasized value-based reforms to improve health system efficiency and fiscal sustainability. OECD reports highlight how aligning spending with outcomes can help countries achieve better value for money in health care while ensuring equity and sustainability under budgetary pressures (OECD, 2019).

VBHC implementation frequently relies on innovative payment models that link reimbursement with performance and outcomes. One approach is bundled payments, in which providers receive a single, comprehensive payment for all services related to a treatment episode (Dummit et al., 2016). Another is pay-for-performance, which rewards providers for meeting pre-specified quality or efficiency benchmarks (Eijkenaar, 2012). Shared savings programs also play a role, allowing providers to retain a portion of the savings when actual costs fall below benchmarks, provided quality standards are maintained (McWilliams et al., 2016). Capitation models take a different form, offering fixed payments per enrolled individual, often expressed as per member per month (PMPM), with adjustments for risk factors to account for

variations in patient health status and expected costs (Toward, 2019; UHF, 2016). Collectively, these models are designed to encourage efficiency, accountability, and patient-centered outcomes. However, their effectiveness depends on accurate outcome measurement, robust risk adjustment, and the development of pricing mechanisms that equitably allocate resources across diverse populations. These challenges underscore the potential role of actuarial science in strengthening VBHC by embedding risk modeling, uncertainty analysis, and predictive analytics into pricing structures.

2.2 Actuarial Science and Healthcare Financing

Actuarial science applies mathematical, statistical, and financial techniques to evaluate and manage risks in contexts where future events (e.g. illness, claims) are uncertain. In healthcare financing, actuarial methods play a central role in ensuring that payment systems are financially sustainable, equitable, and responsive to heterogeneity across patient populations.

Core Actuarial Principles

Actuarial practice in health is grounded in several foundational principles that guide the design of financing and payment models. Risk assessment and risk scoring are central, involving the estimation of the probability and severity of healthcare expenditures, morbidity, and transitions in health states; such scoring is widely used to generate adjustment factors that normalize differences across populations (SOA, 2016; Duncan, 2011). Building on these assessments, actuaries engage in premium setting and pricing, where expected claims are combined with administrative cost loadings and margins for uncertainty to calculate premiums or unit payments that ensure financial viability. Mortality and morbidity modeling also play a critical role, as projecting death rates or disease incidence and progression is essential when payments or reserves extend over time. In addition, loss modeling distinguishes between the frequency with which health events occur and their severity, with the combined expectation serving as the basis for accurate pricing and adequate provisioning.

Role in Health Insurance Pricing and Financial Sustainability

Actuarial methods play a critical role in health insurance pricing and financial sustainability by enabling payers and insurers to align revenues with liabilities and to absorb variations in risk. Risk adjustment mechanisms, such as those applied in U.S. insurance markets, redistribute payments according to enrollee health risks to discourage risk selection. A notable example is the Affordable Care Act (ACA) risk adjustment program, which applies actuarial risk modeling to mitigate adverse selection (Kautter et al., 2014). Reviews of these systems, including those conducted by the American Academy of Actuaries, often assess whether proposed payment formulas are “actuarially sound,” meaning that they compensate for risk in a way that is both stable and fair (Bluhm et al., 1999). In capitation-based health systems, actuaries also estimate capitation weights adjusted for age, comorbidities, and demographic characteristics to ensure equitable budget allocation across providers. Recent applications, such as the use of modern actuarial and statistical techniques to calculate the Capitation Payment Unit (CPU) in Colombia, demonstrate how these models are applied to balance financial sustainability with fairness in provider reimbursement (Espinosa et al., 2023).

Traditional vs. Modern Actuarial Methods

Historically, actuarial models in health were largely deterministic, relying on point estimates and fixed assumptions. But the complexity and heterogeneity in healthcare have driven the adoption of more advanced techniques:

- **Stochastic modeling**: Models that represent uncertainty explicitly (distributions rather than point estimates), enabling scenario analysis, stress testing, and resilience planning.
- **Predictive analytics/machine learning**: Using large volumes of claims, demographic, clinical, and behavioral data, modern actuarial approaches increasingly rely on algorithms (e.g. regression, tree-based models, neural networks) to improve prediction accuracy. For example, Shouri et al. (2025) propose a hybrid model that uses machine learning (XGBoost) plus incentive structures to design risk-based premiums (Shouri et al., 2025).

These modern methods allow finer stratification of risk, reduced error in payment predictions, and dynamic adjustment as new data become available.

2.3 Intersection of VBHC and Actuarial Science

How Actuarial Modeling Enhances Transparency, Fairness, and Efficiency

Actuarial modeling enhances transparency, fairness, and efficiency in value-based healthcare (VBHC) by embedding rigorous risk sensitivity into payment design. In value-based arrangements such as bundled payments or accountable care organizations (ACOs), risk adjustment is essential to ensure that providers caring for patients with higher morbidity receive commensurate payments, thereby reducing incentives for risk selection or "cream-skimming" (Kautter et al., 2014). Beyond risk adjustment, actuaries draw on historical claims data, readmission rates, and utilization patterns to establish fair target prices and capitation weights, often integrating outcome metrics that are weighted to capture both clinical impact and cost implications (Espinosa et al., 2023).

Actuarial forecasting also provides tools for managing financial risk by simulating the probability of cost overruns and informing the design of risk-sharing contracts, including upside-only models, reinsurance, or stop-loss provisions. Equally important, stochastic modeling, sensitivity testing, and scenario analysis allow policymakers and payers to assess the robustness of pricing structures under alternative assumptions, such as changing morbidity incidence, shifting utilization rates, or inflationary pressures (SOA, 2016).

Collectively, these methods provide a quantitative foundation for VBHC models that are not only financially sustainable but also equitable and adaptable to diverse patient populations.

Theoretical Synergies: Aligning Risk-Based Pricing with Outcome-Based Reimbursement

VBHC emphasizes rewarding outcomes, while actuarial science provides rigorous tools for estimating expected costs and allocating risk. A theoretically sound payment structure can integrate:

- Base payments that reflect actuarially estimated expected costs for a given risk pool,
- Outcome adjustments (bonuses or penalties tied to quality/outcome indicators), and
- Risk-sharing provisions to balance incentives and protect providers from catastrophic losses.

Modern actuarial practice further incorporates predictive analytics and machine learning to stratify patients by risk of poor outcomes or high costs, thereby enabling more precise resource allocation and advancing the efficiency goals of VBHC (Shouri et al., 2025).

3. Literature Review

3.1 Evolution of Healthcare Pricing Models

Healthcare pricing models have evolved substantially over recent decades in response to rising costs and concerns about quality and efficiency. Historically, many health systems relied on **fee-for-service (FFS)** reimbursement, which pays providers for each service delivered. FFS is widely documented to create incentives that can lead to higher service volume and contribute to overuse and fragmented care delivery; regional studies of Medicare spending and systematic reviews of overuse both document substantial variation in utilization that is not consistently associated with better outcomes (Fisher et al., 2003; Keyhani et al., 2013).

Beginning in the late 20th century, policymakers in the United States and other OECD countries experimented with managed care and prospective payment methods to better control spending and encourage efficiency. The introduction of Diagnosis-Related Groups (DRGs) and prospective payment for hospitals, and the growth of Health Maintenance Organizations (HMOs), shifted incentives toward prepayment and utilization management, but not without controversy (Hsiao et al, 1986). Empirical reviews indicate that HMOs tended to reduce inpatient and high-cost resource use while producing broadly comparable quality measures in many studies, though critics raised concerns about restricted choice and potential underprovision of care (Miller & Luft, 2002).

Building on lessons from FFS and managed care, the more recent value-based healthcare (VBHC) movement reorients payment toward patient health outcomes per unit cost rather than sheer volume. VBHC aims to align incentives to improve quality, coordination, and efficiency. However, experience from earlier payment reforms highlights the need to carefully balance incentives to avoid both the overprovision associated with FFS and the underprovision risks that can occur under tightly managed prepayment systems, an argument articulated in the VBHC literature and in reviews of pay-for-performance schemes (Porter, 2010; Eijkenaar et al., 2013).

3.2 Current Evidence on Value-Based Pricing

Empirical evidence assessing value-based payment reforms is growing, but results remain heterogeneous across settings, clinical areas, and program designs.

- **Bundled payments.** Studies of Medicare's bundled payment initiatives provide some of the clearest empirical evidence. In the Bundled Payments for Care Improvement (BPCI) initiative, hospitals that participated in early BPCI models for lower-extremity joint replacement experienced greater reductions in episode payments than comparison hospitals, without detectable declines in measured quality during the early follow-up period. However, effects vary by clinical area and follow-up period, and longer-term impacts require additional study (Dummit et al., 2016; Navathe et al., 2018).
- **Shared savings and ACOs.** Evaluations of Medicare Shared Savings Program (MSSP) ACOs have shown modest reductions in Medicare spending and improvements on some quality measures during the early years, though results are variable across cohorts and program designs. McWilliams et al. (2016) reported early spending reductions for some ACO entrants, while subsequent evaluations note heterogeneous performance depending on model features and risk sharing (McWilliams et al., 2016; Trombley et al., 2019).

- **Pay-for-performance (P4P).** Large P4P implementations (e.g., the UK Quality and Outcomes Framework) produced improvements in several targeted clinical process and intermediate outcome measures, yet evidence on sustained improvements in hard health outcomes and cost containment is mixed. Design features (reward vs penalty, choice of metrics, baseline performance) and context matter substantially (Roland & Campbell, 2014; Minchin et al, 2018).
- **Outcome-based contracts / managed entry agreements.** European payers have increasingly experimented with outcome-oriented managed entry agreements for high-cost drugs. Systematic reviews and consortium reports indicate these agreements can improve alignment of payment with real-world benefit but face operational hurdles, data collection, outcome definition, and administrative complexity remain barriers to wide adoption (Bouvy et al., 2018; Pauwels et al., 2017).
- **Key performance indicators (KPIs).** Across studies, commonly used KPIs include total episode or per-capita spending, readmission rates, mortality, procedure-specific complication rates, and patient-reported outcome measures (PROMs) when available. The ability to interpret KPI changes meaningfully depends on robust risk adjustment and data completeness (Dummit et al., 2016; McWilliams et al., 2016).
- **Synthesis / lessons.** The literature suggests value-based pricing can reduce some categories of spending and improve targeted quality metrics, but success depends on (1) careful specification of episodes/outcomes, (2) strong data and measurement systems, (3) appropriate risk adjustment to avoid cream-skimming, and (4) contractual design that balances incentives and protects providers from excessive downside risk (Dummit et al., 2016; McWilliams et al., 2016; Roland & Campbell, 2014).

3.3 Actuarial Applications in Healthcare Literature

Actuarial methods underpin many technical aspects of modern health financing and are directly relevant to operationalizing value-based pricing.

- **Cost prediction and claims forecasting.** Actuaries model claim frequency and severity to forecast healthcare spending and set payment levels. These methods are central to estimating episode costs for bundled payments and to projecting liabilities under capitation. Contemporary actuarial reports and textbooks outline methods for frequency–severity decomposition, reserve setting, and scenario testing (SOA, 2016).
- **Risk adjustment.** Risk adjustment models (e.g., HHS-HCC / CMS HCC models) are widely used to reallocate payments according to enrollee clinical and demographic risk so that plans/providers are compensated for expected cost differences. The HHS-HCC methodology and companion publications describe both model structure and implementation choices used in U.S. marketplaces and Medicare contexts. Robust risk adjustment is essential for fair value-based payments (Kautter et al., 2014).
- **Actuarial methods in Medicaid/Medicare pricing.** Actuarial reviews and applied studies show how capitation rates, bundled target prices, and ACO benchmarks are often informed by actuarial analysis. For example, actuarial/statistical techniques were used to estimate capitation payment units in systems such as Colombia, illustrating how actuaries translate claims data into per-member payments adapted to local contexts (Espinosa et al., 2023).

- **Advances in predictive modeling and big data.** The actuarial profession and academic literature document increased use of predictive analytics and machine learning to improve risk scoring and cost forecasting. The Society of Actuaries reports and research agendas summarize how predictive models (GLMs, tree-based methods, ensemble/boosting algorithms) can enhance explanatory power for risk scores and identify high-cost patients, though implementation requires attention to data quality, interpretability, and fairness (SOA, 2016; Diana et al., 2016).
- **Practical implications for VBHC.** Combining actuarial risk adjustment with predictive stratification enables more accurate base payments and targeted interventions (e.g., care management for patients predicted to be high-cost). Actuarial scenario analysis (stochastic modeling, stress testing) also informs contract design—deciding when to include downside risk, reinsurance, or stop-loss provisions to maintain provider solvency while preserving incentives for quality (SOA, 2016; Espinosa et al., 2023).

Collectively, the literature shows that actuarial approaches provide the technical foundation for fair and sustainable pricing in VBHC. By combining traditional actuarial tools with modern predictive analytics, health systems can design payment models that balance cost containment, provider incentives, and patient outcomes.

4. Theoretical Framework: Actuarial Models for Value-Based Pricing

4.1 Risk Adjustment and Outcome-Based Contracts

One of the core challenges in value-based healthcare (VBHC) pricing is ensuring that payments reflect differences in population health rather than differences in patient selection. **Actuarial risk adjustment models** are designed to mitigate this by predicting expected healthcare costs based on demographic and clinical characteristics. Widely used examples include the **Hierarchical Condition Categories (HCC)** models applied in U.S. Medicare Advantage and ACA marketplaces, which adjust payments to plans according to enrollees' risk scores (Kautter et al., 2014). These models rely on regression-based methods to translate morbidity patterns into predicted expenditures, ensuring that providers or payers serving sicker populations are not unfairly penalized.

Risk adjustment forms the theoretical backbone of outcome-based contracts. By incorporating outcome measures, such as readmission rates, mortality, or patient-reported outcomes, into actuarial pricing, payments can be explicitly tied to health improvements rather than service volume. The linkage between outcomes and pricing is supported by contract theory, which emphasizes aligning incentives under information asymmetry (Ellis & McGuire, 1990). In practice, outcome-based contracts for pharmaceuticals and chronic disease management often use actuarially informed benchmarks to set payment levels contingent on realized outcomes (Bouvy et al., 2018).

4.2 Cost–Outcome Optimization

Beyond risk adjustment, actuarial science draws on formal economic tools to optimize how health care costs and outcomes are balanced. Cost-effectiveness analysis (CEA) is a foundational framework, as originally described by Weinstein & Stason (1977), which values health interventions in terms of incremental costs per unit of health gain such as quality-adjusted life years (QALYs) (Weinstein & Stason, 1977).

Contemporary discussions (e.g., Neumann & Cohen, 2018) emphasize both the utility and the limitations of QALYs as outcome measures, especially with respect to how quality of life is measured and how

different stakeholders perceive these metrics (Wouters et al., 2015; Neumann & Cohen, 2018). While formal incorporation of CEA into pricing contracts is not yet widespread, actuarial models increasingly use cost-utility analyses or incremental cost per health outcome metrics to inform benchmarks, target payment rates, or to decide which interventions represent "value for money." Simulation models, sensitivity analyses, and stochastic models further help to account for uncertainty in cost and outcome estimates, enabling more robust pricing design under variability (Pandya et al., 2018; Russell,1999; O'Hagan, & Stevens, 2001).

In addition, stochastic modeling is an essential tool for simulating the variability of healthcare costs and outcomes. Monte Carlo methods and other probabilistic approaches allow actuaries and health economists to estimate the distribution of potential spending under different patient risk profiles and clinical practice patterns (O'Hagan & Stevens, 2001; Briggs et al., 2006). These methods are particularly relevant for value-based payment models that expose providers to financial downside risk. In bundled payment design, for instance, stochastic simulations can inform the use of risk corridors and stop-loss provisions to stabilize provider participation and protect against excessive losses.

4.3 Incentive Structures and Behavioral Economics

The design of VBHC pricing models not only allocates financial risk but also shapes provider and patient behavior. Actuarial methods intersect with behavioral economics by structuring incentives to promote desired actions while accounting for bounded rationality, risk aversion, and response to financial signals.

On the provider side, actuarially calibrated payment adjustments can discourage both "over-treatment" (common under fee-for-service) and "under-treatment" (a risk under capitation). Models of optimal payment design draw on principal–agent theory, which addresses how to align provider effort with patient welfare when monitoring is imperfect (Ellis & McGuire, 1990; Eijkenaar, 2012).

On the patient side, actuarial benefit design can incorporate behavioral insights such as value-based insurance design (VBID), where copayments are reduced for high-value services (Chernew et al., 2007). By embedding these principles, actuarial pricing models go beyond cost prediction to actively influence choices in ways that enhance efficiency and equity.

Integrating actuarial science with behavioral economics thus provides a richer theoretical framework for VBHC, where payment models are not only financially sustainable but also behaviorally effective in steering both providers and patients toward high-value care.

5. Challenges and Limitations

5.1 Data limitations: outcome measurement, quality reporting, patient heterogeneity

A persistent barrier to implementing actuarial-driven VBHC pricing is data quality and completeness. Outcome-based pricing requires reliable, timely measures of clinical outcomes and patient-reported outcomes (PROMs), but outcome measurement is heterogeneous across settings and often limited by incomplete registry coverage, inconsistent coding, and lack of interoperability between electronic health records and payer claims systems. Recent reviews and empirical studies highlight substantial variation in how outcomes are defined and recorded, which complicates cross-provider comparisons and calibration of actuarial models. Efforts to improve structured real-world data quality and standardize PROMs are ongoing, but weaknesses remain a key limitation for actuarial pricing (Lighterness et al., 2024).

Patient heterogeneity also undermines straightforward pricing. Differences in comorbidity, social determinants of health (SDOH), and unobserved frailty create wide variation in realized costs and

outcomes even for similar clinical episodes. Thus, actuarial models may systematically underpredict costs for subgroups if relevant predictors are missing or poorly measured. Work on integrating SDOH into risk adjustment shows potential to reduce volatility and better reflect population needs, but the gains are often modest and raise questions about data availability and stability across programs (Phelos et al., 2022).

5.2 Uncertainty in long-term health outcome valuation

VBHC often requires placing monetary or utility values on outcomes that accrue over long horizons (e.g., survival gains, QALYs). Extrapolating short-term trial or observational results to long-term outcomes introduces substantial uncertainty. Health technology assessment (HTA) literature emphasizes that alternative extrapolation methods and assumptions can materially change cost-effectiveness estimates and implied value prices; actuarial models used for pricing must therefore incorporate uncertainty analysis (probabilistic sensitivity analysis, scenario testing) to avoid overconfidence in point estimates. Recent papers and guidance stress rigorous uncertainty quantification for long-term effect estimates used in economic models (Versteeg et al., 2024).

5.3 Ethical considerations in actuarial-based pricing (equity for underserved populations)

Actuarial pricing that closely ties payment to predicted risk and expected costs can improve technical fairness (matching payments to expected expenditures) but can also entrench or exacerbate inequities if not designed carefully. Classic critiques of risk-rating note that actuarially "accurate" prices can make care unaffordable for high-risk or low-income groups and may reduce access. Contemporary actuarial and policy discussions emphasize equity concerns: risk adjustment must be designed to avoid creating perverse incentives (e.g., under-treatment of complex patients), and supplemental measures may be needed to support providers serving disadvantaged populations. Actuarial professional bodies have published briefs noting both the promise and the risks of actuarial approaches for health equity (Light, 1992, Okumu & Assan, 2025a).

5.4 Implementation barriers (regulatory, administrative, and provider buy-in)

Operationalizing actuarial underpinnings of VBHC faces real-world barriers. Regulatory constraints (data sharing rules, privacy legislation), administrative costs (establishing measurement systems, claims reconciliation), and the need to renegotiate contracts across payers and provider organizations slow adoption. Provider buy-in is fragile: many providers fear financial downside, increased administrative burden, or unreliable benchmarking. Systematic reviews and policy analyses identify these implementation hurdles and recommend phased pilots, transparent methodology for risk adjustment, and reinsurance/stop-loss arrangements to reduce provider reluctance (Leao et al., 2025).

6. Future Research Directions

6.1 Integrating advanced predictive analytics into actuarial VBHC models

There is strong momentum for combining traditional actuarial practice with machine learning and AI to improve risk prediction and pricing. Reviews document how predictive analytics (gradient boosting, neural networks, ensemble methods) can improve identification of high-cost patients and refine claims forecasting, but they also caution about concerns related to interpretability, fairness, and overfitting. Future work should focus on robust, explainable models that integrate clinical, claims, and social data while validating out-of-sample performance across populations (Dixon et al., 2024).

6.2 Exploring actuarial approaches for personalized healthcare pricing

Advances in data (genomics, longitudinal EHRs, wearable sensors) make personalized pricing or more granular risk-based payments technically possible. The literature on personalized/value-based pricing for precision medicine discusses methods for aligning price to real-world effectiveness (value-based pricing) but also highlights ethical and regulatory concerns. Research should evaluate feasible personalization scopes (e.g., stratified bundles, subgroup risk adjustments), their equity implications, and governance frameworks required to prevent discrimination (Garrison & Towse, 2017).

6.3 Comparative studies of actuarial-based VBHC pricing models across countries

Cross-country comparative work can illuminate how institutional design, data ecosystems, and regulatory regimes affect the feasibility and outcomes of actuarial VBHC models. OECD and country case studies can be paired with actuarial analyses to assess how capitation, bundles, or outcome-based contracts performed under different governance arrangements. Such comparative studies would help identify generalizable design principles and context-specific caveats (Smith et al., 2023).

6.4 Incorporating social determinants of health (SDOH) into actuarial risk models

Empirical analyses and actuarial pilots indicate that adding SDOH markers (income, housing instability, education) can modestly improve model fit and reduce unexplained financial volatility for plans serving disadvantaged populations. Ongoing Society of Actuaries and industry reports provide initial roadmaps; future work must test which SDOH measures are most predictive, how to collect them ethically and reliably, and how to recalibrate models to avoid perverse incentives (SOA, 2025).

6.5 Developing hybrid frameworks (actuarial science + health economics + data science)

The most promising avenue is hybrid frameworks that unite actuarial rigor (frequency/severity modeling, solvency testing), health economic valuation (CEA, utility theory), and data-science advances (ML, causal inference). Recent methodological work and applied studies propose hybrid pipelines for pricing that combine predictive accuracy with economic valuation and uncertainty quantification, allowing pricing to be both technically sound and policy-relevant. Future research should prototype these hybrids in pilot payment programs, with pre-specified evaluation metrics for cost, outcomes, equity, and robustness (Shouri et al., 2025; Espinosa et al., 2025).

7. Conclusion

This study has examined how actuarial science can enrich value-based healthcare (VBHC) pricing models by introducing rigorous methods of risk adjustment, cost–outcome optimization, and incentive alignment. The conceptual foundations show that actuarial principles provide structured approaches for balancing costs, outcomes, and risks in healthcare financing. The literature further demonstrates both the promise and complexity of implementing VBHC reforms, highlighting issues of measurement, equity, and system-level constraints. By integrating actuarial science with health economics and behavioral insights, VBHC frameworks can evolve into models that are not only financially sustainable but also equitable and behaviorally effective. Nonetheless, challenges remain in terms of data limitations, ethical considerations, and regulatory implementation. Future research should focus on predictive analytics, cross-national comparisons, and the incorporation of social determinants of health into actuarial models. Together, these directions will help shape a more resilient and inclusive foundation for healthcare financing reform.

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