

A Sustainable Health System Financing Model: An Approach Based on Sustainable Supply Chain Performance and Artificial Intelligence

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Abstract: Financing is one of the most important functions of a health system and plays a critical role in achieving universal health coverage and promoting societal well-being. Countries increasingly seek to protect their populations from excessive healthcare expenditures while ensuring equitable access to healthcare services. This study aimed to validate and assess the fit of a sustainable health system financing model, with particular emphasis on the roles of sustainable supply chain performance and artificial intelligence (AI). The proposed model examined the relationships among sustainable health system resources, AI, sustainable supply chain performance, innovative financing methods, and the optimal financing portfolio. The study was applied in terms of purpose and employed a quantitative, descriptive-survey design. Structural equation modeling (SEM) was used to examine the proposed relationships. The study population consisted of experts and specialists familiar with sustainable health system financing. Based on Cohen's formula, a sample of 350 experts was selected at a 95% confidence level. Data were analyzed using SmartPLS. Assessment of the measurement model using Cronbach's alpha, composite reliability, and convergent validity indicators generally supported the reliability and validity of the study constructs. In addition, the overall model fit index indicated a strong fit for the proposed model according to the criterion adopted in the study. The findings suggest that innovative financing methods, together with AI technologies and sustainable supply chain management, can contribute to improving the effectiveness and sustainability of health system financing. The integrated application of these approaches may facilitate more effective resource allocation, improved financial risk management, and the development of a more resilient health system.

Keywords: sustainable financing; health system; innovative financing methods; artificial intelligence; sustainable supply chain performance; financing portfolio; structural equation modeling

1. Introduction

Health-system financing is a fundamental component of health-system performance because it determines the extent to which financial resources can be mobilized, pooled, allocated, and transformed into accessible, equitable, efficient, and high-quality health services. Sustainable financing is particularly important in contemporary health systems, where rising healthcare expenditures, demographic transition, technological change, epidemiological shifts, economic volatility, and increasing public expectations place persistent pressure on limited financial resources. From a system perspective, financing should not be understood merely as the generation of revenue; rather, it constitutes an integrated

managerial function through which financial protection, resource allocation, service continuity, organizational resilience, and long-term system performance are coordinated. The World Health Organization's health-system performance framework emphasizes that financing interacts with other system functions and ultimately influences health outcomes, responsiveness, fairness, and efficiency [1]. Accordingly, the sustainability of financing arrangements has become a strategic concern for governments and healthcare organizations seeking to maintain service provision without transferring excessive financial burdens to households. This concern is particularly relevant in health systems characterized by fragmented revenue sources, growing expenditure obligations, constrained fiscal capacity, and substantial reliance on out-of-pocket payments. Evidence from Iran has shown that catastrophic health expenditure remains an important challenge for financial protection and equitable access to healthcare [2], while broader assessments of Iranian health-system performance have identified persistent structural challenges affecting efficiency, equity, and achievement of health-system objectives [3, 4]. These conditions make the development of a more sustainable and diversified financing architecture a managerial and policy priority.

Financial sustainability refers to the capacity of an organization or system to secure, maintain, and manage financial resources in a manner that supports current operations while preserving the ability to meet future obligations. In healthcare, this concept is multidimensional because financial sustainability depends not only on the volume of financial resources but also on their stability, diversity, flexibility, predictability, and alignment with health-system priorities. The growing literature on sustainable finance emphasizes the need to move beyond short-term funding decisions toward financing models that incorporate long-term economic, social, institutional, and environmental considerations [5]. In organizational contexts, revenue diversification has similarly been viewed as a mechanism for reducing dependence on a narrow set of revenue sources and increasing resilience to financial shocks [6]. This logic is directly applicable to health systems, where excessive reliance on a limited number of financing channels can increase vulnerability to recessions, fiscal constraints, public emergencies, and fluctuations in governmental revenues. International experiences also demonstrate that health systems require coherent financial strategies rather than isolated funding interventions. For example, analysis of financial sustainability in the Saudi healthcare system underscores the importance of reforming financing structures, improving resource use, and establishing long-term mechanisms capable of supporting expanding healthcare needs [7]. Moreover, the experience of the COVID-19 pandemic demonstrated that sustainable financing is indispensable not only for routine healthcare delivery but also for supporting innovation, emergency preparedness, and coordinated implementation of health interventions during crises [8]. Sustainable health financing therefore requires a portfolio-based approach in which multiple financing mechanisms are assessed collectively according to their contribution to stability, risk diversification, affordability, and strategic health-system objectives.

The design of such a financing portfolio requires accurate identification of the variables that influence healthcare expenditure and financial demand. Health expenditures are shaped by complex interactions among demographic, epidemiological, economic, institutional, and technological factors, making conventional single-factor approaches insufficient for long-term financial planning. Research examining determinants of health expenditure across OECD countries has shown that expenditure patterns can be investigated using advanced analytical techniques capable of identifying complex relationships among explanatory variables [9]. Similarly, predictive methods have increasingly been applied to estimate healthcare expenditures at both population and household levels. Machine-learning techniques have been used to predict out-of-pocket health expenditures, demonstrating the potential of computational models to support financial-risk assessment and resource planning [10]. Predictive approaches have

also been developed for populations with coexisting medical conditions, in which expenditure forecasting becomes especially important because multimorbidity can generate substantial and difficult-to-predict resource requirements [11]. These developments suggest that sustainable financing should incorporate not only retrospective financial analysis but also prospective forecasting capabilities. The emergence of online machine learning and other dynamic modeling approaches in financial prediction further illustrates the broader potential of adaptive analytical systems for managing environments characterized by volatility and uncertainty [12]. For healthcare managers, the integration of predictive intelligence into financing decisions may improve the ability to anticipate expenditure pressures, identify funding gaps, and adjust the composition of financing portfolios before financial imbalances threaten service sustainability.

The importance of such capabilities is particularly evident in Iran, where the financing system faces multiple structural and managerial challenges. Qualitative evidence concerning Iranian health financing has identified problems related to resource mobilization, allocation, pooling, purchasing, governance, and the alignment of financing arrangements with health outcomes [13]. These challenges are also reflected in broader assessments of health financing indicators, which emphasize the importance of evaluating revenue collection, pooling mechanisms, financial protection, expenditure patterns, and the efficiency of resource use when assessing the performance of health financing systems [14]. At the same time, comparative evidence from other regions demonstrates that financing problems often extend beyond insufficient funding and involve imbalances in the financing of different health-system components. A scoping review of health-system financing in Africa showed that the financing of system elements is heterogeneous and that weaknesses in the distribution and organization of resources can impair system functionality even when financing is available [15]. Thus, the sustainability of health-system resources depends on both the quantity and the configuration of available financial resources. In this context, innovative financing methods can contribute to diversification by creating alternative or complementary mechanisms for mobilizing capital, distributing financial risk, supporting investment, and reducing excessive dependence on traditional budgetary sources. However, the effectiveness of innovative financing mechanisms depends on how they are integrated into the institutional, technological, and operational architecture of the health system.

Artificial intelligence (AI) represents one of the most important technological developments capable of reshaping this architecture. AI has expanded rapidly within healthcare and is now applied across clinical decision-making, diagnosis, prediction, administrative processes, resource management, and service delivery [16, 17]. Its strategic significance extends beyond clinical medicine because AI can enhance the capacity of organizations to process large volumes of heterogeneous information, recognize complex patterns, predict outcomes, automate repetitive tasks, and support evidence-based managerial decisions. In healthcare, AI has been described as a potentially transformative technology capable of contributing to a more sustainable global healthcare paradigm by improving efficiency, accessibility, decision quality, and the use of scarce resources [18]. Evidence across World Health Organization regions also indicates increasing use of AI in the delivery of essential health services, although implementation remains uneven and dependent on technological infrastructure, governance, workforce capability, and contextual readiness [19]. At a broader organizational level, AI-driven sustainable development requires alignment among technological infrastructure, organizational processes, managerial capabilities, and strategic objectives rather than the isolated adoption of digital tools [20]. Therefore, AI should be viewed as an enabling organizational capability that can influence the effectiveness of financial and operational mechanisms within healthcare systems.

The application of AI to health financing is particularly relevant because financing decisions involve complex datasets, uncertainty, forecasting, fraud detection, prioritization, risk assessment, and resource-allocation problems. A dedicated review of AI applications in health financing has demonstrated that AI can support several financing functions, including expenditure prediction, revenue management, insurance-related decisions, fraud detection, and strategic resource allocation [21]. At the health-governance level, however, the effective application of AI requires an explicit research and governance agenda addressing data, institutions, ethical considerations, regulation, transparency, accountability, and implementation capacity [22]. Similar considerations have emerged in accounting and auditing, where AI has been associated with enhanced analytical and decision-making capabilities but also with ethical challenges concerning transparency, responsibility, and the quality of algorithmic decisions [23]. AI applications in tax auditing further demonstrate the capacity of intelligent systems to identify patterns, improve monitoring, and support financial control in environments involving large and complex datasets [24]. Likewise, AI-based modeling has been applied to the prediction of financial recovery, suggesting that intelligent analytical techniques can improve the assessment of financial conditions and support forward-looking managerial decisions [25]. In sustainable finance specifically, AI has been proposed as a tool for strengthening sustainable financial development and supporting sustainability-related financial decision processes [26, 27]. Collectively, these developments suggest that AI may strengthen the relationship between innovative financing mechanisms and sustainable financing outcomes by improving the quality, speed, adaptability, and predictive accuracy of financial decisions.

Nevertheless, financial sustainability in a health system cannot be achieved exclusively through financial technologies or analytical intelligence; it is also dependent on operational performance throughout the healthcare supply chain. Healthcare supply chains encompass the coordinated flow of pharmaceuticals, medical equipment, supplies, information, financial resources, logistics services, and other inputs required for continuous health-service delivery. Disruptions, inefficiencies, excessive inventories, shortages, fragmented procurement, and poor coordination can generate substantial financial losses and undermine the benefits of otherwise well-designed financing arrangements. Sustainable supply chain performance therefore provides an essential operational interface between financing decisions and service outcomes. From a management perspective, financial sustainability and supply chain sustainability are mutually reinforcing: predictable financial resources support purchasing and inventory stability, while efficient supply chain operations reduce unnecessary expenditures and improve the productivity of financial resources. Corporate sustainability research similarly suggests that sustainability performance is closely related to financial policies and the distribution of organizational financial resources [28]. Although the healthcare setting differs from the corporate environment, the underlying principle remains relevant: financing decisions cannot be separated from the operational system through which resources are converted into organizational outputs. A sustainable health financing model should therefore account for the extent to which the supply chain can absorb, allocate, and transform financial resources efficiently and resiliently.

The relationship between financing and supply chain performance becomes even more important under conditions of uncertainty. Public-health emergencies, supply disruptions, inflation, sanctions, fiscal instability, and rapid technological changes can simultaneously affect revenues, procurement costs, access to imported medical goods, and the availability of critical health resources. The COVID-19 experience demonstrated that innovation without coordinated financing and implementation is insufficient to ensure health-system resilience [8]. A sustainable supply chain requires not only operational efficiency but also financial flexibility, information visibility, risk management, and the ability to adapt procurement and distribution decisions to changing conditions. Big-data

environments can strengthen such adaptive capacity by improving real-time monitoring and allowing policymakers to adjust fiscal and financial measures during public-health emergencies [29]. AI can further contribute by integrating financial and operational information, anticipating shortages, predicting expenditure patterns, supporting demand forecasting, and improving the timing and targeting of resource allocation. Consequently, sustainable supply chain performance may function not only as an outcome of adequate financing but also as a contextual condition affecting whether innovative financing methods ultimately improve the health system's financing portfolio.

Within this framework, the concept of an optimal financing portfolio becomes especially important. A financing portfolio can be understood as the combination of funding sources and financial mechanisms through which a health system seeks to balance revenue generation, financial stability, cost, risk, accessibility, and long-term sustainability. Portfolio optimization implies that decision makers should not simply maximize financial inflows but should construct a configuration of financing sources capable of maintaining service continuity under different economic and operational scenarios. Such a portfolio may include conventional public funding, insurance contributions, earmarked revenues, innovative financial instruments, private-sector participation, and other mechanisms appropriate to the institutional setting. Diversification can reduce exposure to specific revenue shocks, but excessive fragmentation may also increase administrative complexity and coordination costs. The managerial challenge is therefore to determine a financing mix that is sufficiently diversified to enhance resilience while remaining governable, equitable, and aligned with health priorities. The relevance of diversification for institutional sustainability is supported by research linking diversified revenue structures with financial resilience in other organizational settings [6]. Furthermore, sustainable-finance scholarship highlights the importance of evaluating financial instruments in relation to long-term sustainability goals rather than short-term returns alone [5]. In health systems, this implies integrating financial, social, technological, and operational criteria into financing portfolio decisions.

A comprehensive financing model must also recognize that sustainable resources are an intermediate strategic asset connecting financing innovation to long-term financial stability. Innovative financing methods may generate new resources or improve access to existing ones, but these resources become sustainable only when they are reliable, effectively governed, efficiently allocated, and compatible with long-term system needs. The capacity to transform financing innovation into sustainable resources may therefore determine whether financing reforms generate temporary liquidity or enduring financial resilience. In the Iranian context, where financial protection, resource constraints, and financing-system fragmentation remain important concerns [2, 13], identifying mechanisms that stabilize the resource base is especially important. Similarly, the performance analyses of the Iranian health system demonstrate that improving health outcomes requires coordinated reforms across system components rather than isolated interventions [3, 4]. Sustainable resources should consequently be conceptualized not merely as accumulated funds but as a strategic capacity reflecting the durability, predictability, and effective deployment of financial inputs.

Despite the growing literature on sustainable finance, AI, healthcare management, and health-system financing, these research streams remain insufficiently integrated. Existing studies have examined sustainable finance and its future research agenda [5], health-financing indicators and challenges [13, 14], AI applications in healthcare and essential health services [16, 19], AI in health financing and governance [21, 22], expenditure prediction through machine learning [10, 11], and AI-supported financial analysis in accounting, auditing, and financial recovery [23-25]. At the same time, research on AI and sustainable development suggests that technological value is realized

only when organizational, technical, and process dimensions are jointly aligned [20]. What remains less developed is an integrated management framework explaining how innovative financing methods contribute to sustainable resources and an optimal financing portfolio while accounting for the enabling or conditioning roles of AI and sustainable supply chain performance. Developing such a framework is theoretically important because it connects financial innovation with technological capability and operational sustainability, and it is practically important because healthcare managers require integrated decision models rather than isolated recommendations concerning finance, technology, or supply chain management.

The need for such integration is strengthened by the increasing complexity of contemporary healthcare systems. Financial pressures can no longer be addressed effectively through incremental budget adjustments alone, because financing sustainability depends on the interaction of resource diversification, forecasting capability, digital intelligence, operational efficiency, risk management, and institutional governance. AI can enhance prediction and financial decision support, sustainable supply chain management can improve the efficiency with which financial resources are transformed into health services, and innovative financing mechanisms can expand and diversify the resource base. However, the effectiveness of these mechanisms depends on their configuration within a coherent financing architecture. Studies emphasizing sustainable financial development through AI [26], sustainability reporting and sustainable financing [27], financial sustainability through diversified funding structures [6], and predictive financial modeling using intelligent methods [12] collectively indicate a movement toward data-driven, diversified, and sustainability-oriented financial management. In healthcare, translating this movement into an empirically validated structural model can provide a stronger basis for managerial decision-making, policy design, and the prioritization of digital and operational investments.

Accordingly, the aim of this study was to develop and validate a sustainable health system financing model by examining the relationships among innovative financing methods, sustainable resources, and the optimal financing portfolio, while assessing the roles of artificial intelligence and sustainable supply chain performance within the proposed structural framework.

2. Methods and Materials

The present study is applied in terms of its purpose and employs a descriptive-survey research design. The study follows a quantitative methodological approach, and the relationships among the study constructs and their indicators are examined within a correlational framework. Structural equation modeling (SEM) was performed using the partial least squares (PLS) approach. Data were collected through documentary research and a questionnaire survey.

The theoretical and conceptual foundations of the study were developed through a review of Persian- and English-language books, scholarly articles, and relevant research literature. To test the research hypotheses and assess respondents' views regarding the effects of innovative sustainable financing methods on the sustainable financing portfolio of health system units, a questionnaire was developed based on items identified in relevant previous studies, while taking into account the financial policies and contextual characteristics of Iran.

The questionnaire was further refined based on findings from multiple academic studies and the opinions of the academic supervisors and other experts in the field. Following assessment of its reliability and validity, the finalized questionnaire was administered to the study participants, and the required data were collected. The questionnaire items were organized according to the main study constructs and the dimensions associated with each construct.

The study population consisted of experts and professionals with knowledge and experience in the field of sustainable health system financing. Based on Cohen's formula, a sample size of 350 respondents was determined at a 95% confidence level.

SmartPLS software was used to develop and validate the conceptual model presented in Figure 1. The proposed model was evaluated in terms of construct reliability, validity, and overall model fit. Structural equation modeling was subsequently used to examine the hypothesized relationships among the study constructs.

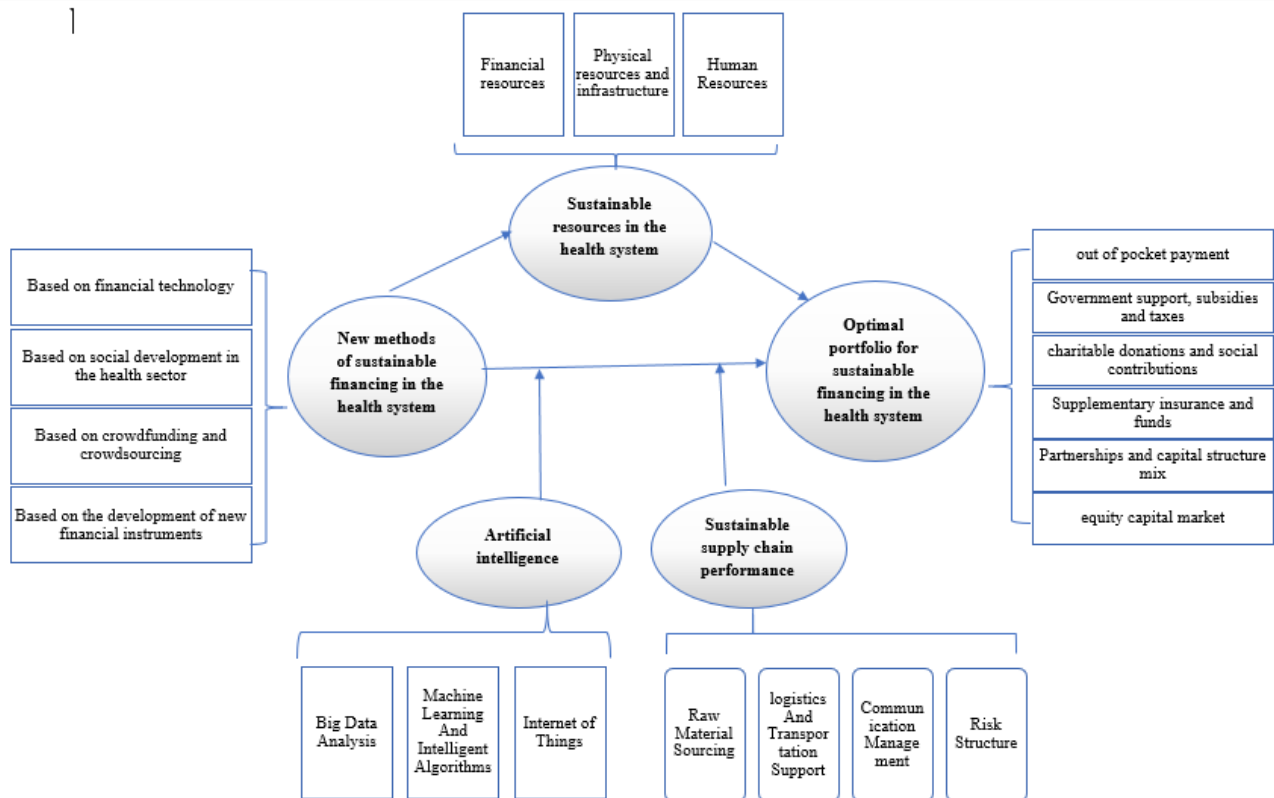


Figure 1. Conceptual Model of the Study

3. Findings and Results

Based on the questionnaire data, a total of 350 respondents participated in the study. The descriptive findings indicated that 259 respondents were women, representing 74% of the sample, whereas 91 respondents were men. Thus, women constituted the majority of the study participants.

Regarding educational attainment, among the 350 respondents, 184 participants (52.57%) held a master's degree, representing the largest proportion among the educational groups.

An examination of respondents' occupational status showed that 254 participants (72.57%) were employed in government positions. This group constituted the largest proportion of respondents in terms of occupational status.

To assess the initial characteristics and distributions of the study data, descriptive statistical indices, including the mean, first quartile, median, third quartile, standard deviation, skewness, and kurtosis, were calculated for the study variables. The results are presented in Table 1.

Table 1. Descriptive Statistics for the Study Variables

Dimension	Mean	SD	Minimum	Q1	Median	Q3	Maximum	Skewness	Kurtosis
Innovative financing methods (score_IFM)	4.02	0.45	4.00	3.79	4.29	2.50	4.93	-0.37	0.66
Sustainable resources (score_SR)	4.05	0.64	4.09	3.64	4.55	2.36	5.00	-0.48	-0.36

Artificial intelligence (score_AI)	3.64	0.73	3.67	3.17	4.00	1.67	5.00	-0.45	0.62
Sustainable supply chain performance (score_SSCP)	3.73	0.67	3.70	3.30	4.30	1.50	5.00	-0.38	1.18
Optimal financing portfolio (score_OFP)	3.19	0.63	3.13	2.75	3.44	1.75	4.75	0.57	0.05

A comparison of the descriptive statistics shows that innovative financing methods received a relatively high mean score of 4.02449, indicating a favorable assessment of this dimension. The standard deviation of 0.451023 indicates relatively low dispersion and, consequently, a comparatively high degree of consistency among respondents' evaluations of this dimension. Sustainable resources had the highest mean score ($M = 4.045714$, $SD = 0.636671$). Artificial intelligence had a mean score of 3.635714, which was above the midpoint, and the highest standard deviation ($SD = 0.732915$), indicating greater variability in respondents' assessments. Sustainable supply chain performance had a mean score of 3.732286, reflecting a relatively favorable assessment, with a standard deviation of 0.671024. The optimal financing portfolio had the lowest mean score ($M = 3.18625$), indicating that respondents rated this construct lower or perceived it as less developed than the other constructs.

All skewness values fell within the range of -3 to $+3$, indicating the absence of severe skewness. Because the study employed SmartPLS and the PLS-SEM approach does not require multivariate normality as a strict distributional assumption, deviations from normality did not constitute a major limitation for the analyses.

At this stage, the conceptual model of the study was evaluated to assess the relationships among the research constructs and determine the extent to which the observed data were consistent with the proposed conceptual model. The research hypotheses were subsequently tested using structural equation modeling. The results of the hypothesis tests are presented graphically in the corresponding structural model diagrams.

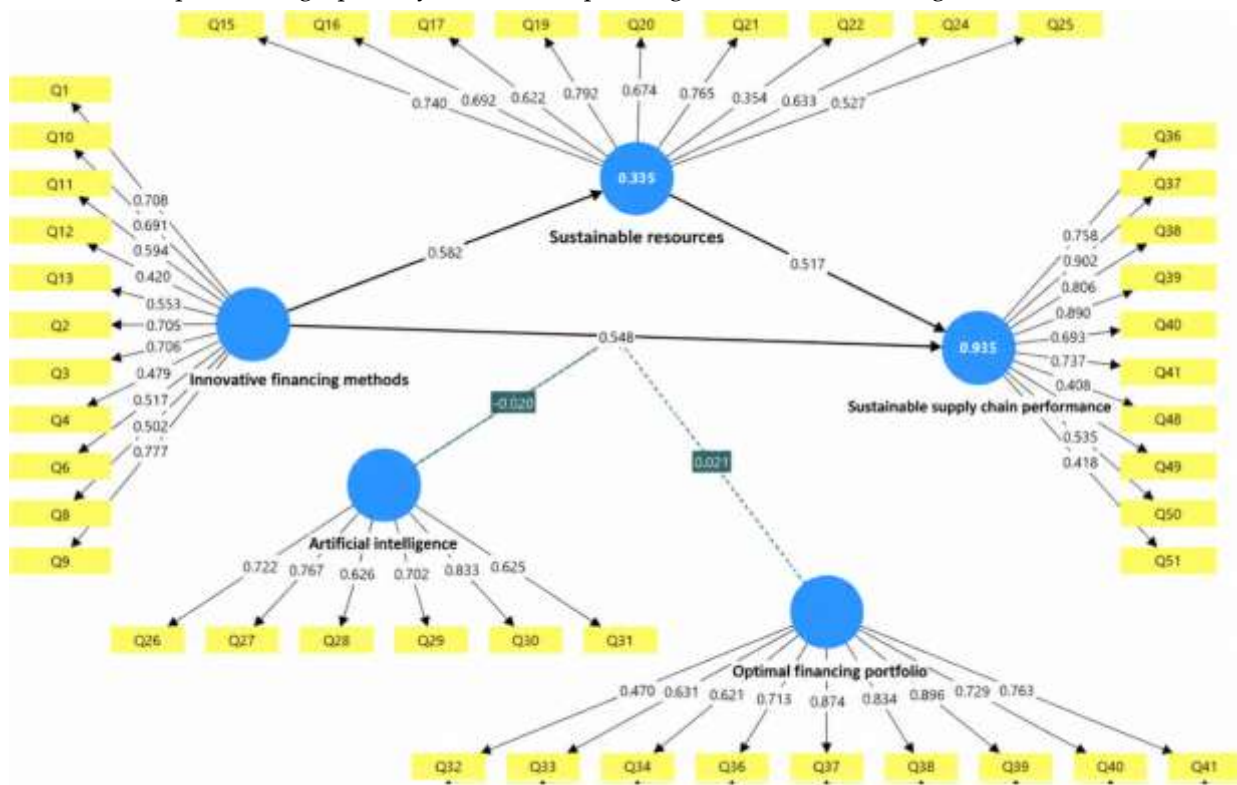


Figure 2. Overall Measurement Model and Hypothesis-Testing Results Based on Standardized Coefficients

Figure 2 presents the overall pattern of relationships among the study variables using standardized coefficients and is therefore useful for understanding the direction and magnitude of the estimated effects. The path between innovative financing methods and sustainable resources is positive and relatively strong, suggesting that diversification of financing instruments may increase the capacity to generate and strengthen sustainable financial resources. The relationship between sustainable resources and the optimal financing portfolio should be interpreted in conjunction with the corresponding significance statistics; conceptually, however, it suggests that the sustainability of financial resources may contribute to improved structuring of the health system financing portfolio. The positions of AI and sustainable supply chain performance within the model further indicate that the effectiveness of innovative financing methods may depend not only on the financial instruments themselves but also on the technological and operational environment in which they are implemented.

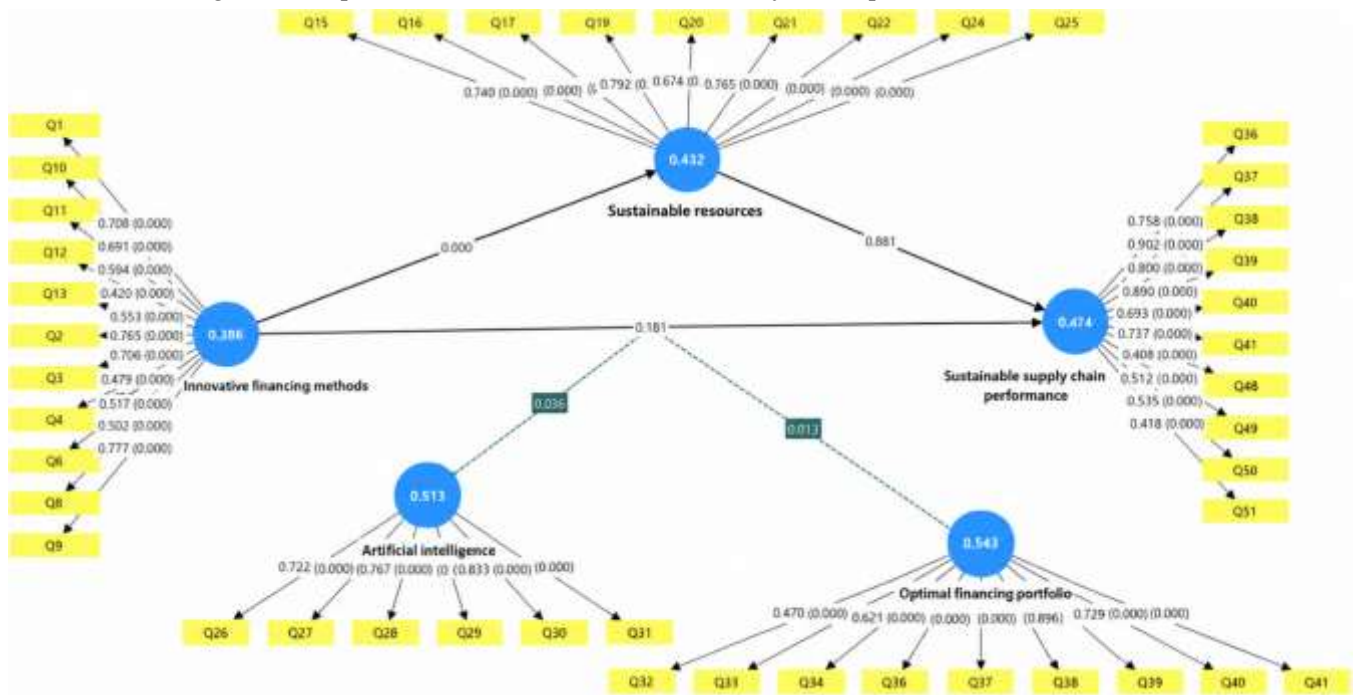


Figure 3. Overall Measurement Model and Hypothesis-Testing Results Based on Significance Statistics

In Figure 3, the principal consideration is not merely the direction of the estimated effects but also the statistical significance of the structural paths. The significance results indicate that several key paths in the model receive adequate statistical support, allowing the corresponding theoretical relationships to be interpreted with greater confidence. In particular, the model suggests that innovative financing mechanisms may function more effectively when accompanied by an appropriate AI infrastructure and strong sustainable supply chain performance.

The measurement model was evaluated using indicators of internal consistency reliability and convergent and discriminant validity. As shown in Table 2, Cronbach's alpha coefficients and composite reliability values for all reported constructs exceeded 0.80, indicating satisfactory internal consistency reliability. Regarding convergent validity, the AVE values for innovative financing methods and sustainable resources were below the conventional threshold of 0.50, whereas the AVE values for artificial intelligence and sustainable supply chain performance exceeded 0.50. Accordingly, the convergent validity of the first two constructs should be interpreted cautiously despite their relatively high composite reliability coefficients. Discriminant validity was additionally examined using the Fornell–Larcker criterion and interconstruct relationships. Overall, the measurement-model results provided the basis for proceeding to structural model assessment and hypothesis testing.

Table 2. Measurement Model Assessment Based on Reliability and Validity Criteria

Construct	Cronbach's Alpha	Composite Reliability	AVE
Innovative financing methods	0.824	0.843	0.327
Sustainable resources	0.860	0.874	0.426
Artificial intelligence	0.834	0.857	0.555
Sustainable supply chain performance	0.900	0.910	0.541

Under the Fornell–Larcker criterion, the square root of the average variance extracted (AVE) for each latent construct is presented on the main diagonal of the correlation matrix. Discriminant validity is generally supported when the square root of the AVE for a given construct exceeds its correlations with the other constructs. The reported values are presented in Table 3 and should be interpreted with reference to this criterion.

Table 3. Fornell–Larcker Criterion After Incorporating the Square Roots of AVE

Construct	Innovative Financing Methods	Sustainable Supply Chain Performance	Artificial Intelligence
Innovative financing methods	0.612		
Sustainable supply chain performance	0.640	0.551	
Artificial intelligence	0.603	0.449	0.686

The reported results were used to assess the discriminant validity of the study constructs.

The average coefficient of determination for the endogenous constructs was $R^2 = 0.339$, whereas the average variance extracted was $AVE = 0.445$. Using the study's reported goodness-of-fit procedure, the resulting overall goodness-of-fit index was approximately $GOF = 0.389$. This value exceeds the adopted threshold of 0.36 and was therefore interpreted as indicating a strong overall fit of the measurement and structural models. This finding suggests that the proposed conceptual framework provides an adequate representation of the relationships among innovative financing methods, sustainable resources, artificial intelligence, sustainable supply chain performance, and the financing portfolio within the health system. Furthermore, examination of the coefficients of determination indicated that the predictor constructs explained 45.4% of the variance in sustainable supply chain performance ($R^2 = 0.454$) and 22.4% of the variance in the optimal financing portfolio ($R^2 = 0.224$), indicating meaningful explanatory capability, particularly with respect to sustainable supply chain performance.

Moreover, the positive Stone–Geisser Q^2 values reported for the two endogenous constructs (0.247 and 0.071, respectively) indicate predictive relevance because values greater than zero generally suggest that the structural model possesses out-of-sample predictive relevance for the corresponding endogenous constructs.

Overall, the evidence indicates that the structural model possesses adequate empirical robustness, explanatory capability, and predictive relevance, thereby providing an empirical basis for hypothesis testing and subsequent policy implications.

Table 4. Structural Model Evaluation

Index	Value	Criterion	Interpretation
GOF	0.389	> 0.36	Overall model fit was interpreted as strong according to the criterion adopted in the study.
Q^2	0.445	> 0.35	The model was interpreted as demonstrating strong predictive capability according to the reported criterion.
R^2	0.339	0.33–0.67	Moderate explanatory power for the endogenous constructs.

Table 5. Hypothesis-Testing Results

Hypothesis	Structural Path	β	SE	t	p	Decision
H1	Innovative financing methods → Optimal financing portfolio	0.3015	0.0592	5.093	< .001	Supported
H2	Innovative financing methods → Sustainable resources	0.6402	0.0384	16.691	< .001	Supported
H3	Sustainable resources → Optimal financing portfolio	0.1764	0.0583	3.028	.003	Supported

Hypothesis 1

The first hypothesis proposed that innovative financing methods have a significant effect on the optimal financing portfolio of the health system. According to the results presented in Table 5, the standardized path coefficient was $\beta = 0.3015$, indicating a positive relationship between the two constructs. The effect was statistically significant ($t = 5.093$, $p < .001$). Therefore, Hypothesis 1 was supported.

Hypothesis 2

The second hypothesis proposed that innovative financing methods have a significant effect on sustainable resources in the health system. According to the results presented in Table 5, the standardized path coefficient was $\beta = 0.6402$, indicating a strong positive relationship between innovative financing methods and sustainable resources. The relationship was statistically significant ($t = 16.691$, $p < .001$). Therefore, Hypothesis 2 was supported.

Hypothesis 3

The third hypothesis proposed that sustainable resources have a significant effect on the optimal financing portfolio of the health system. According to the results presented in Table 5, the standardized path coefficient was $\beta = 0.1764$, indicating a positive relationship between sustainable resources and the optimal financing portfolio. The relationship was statistically significant ($t = 3.028$, $p = .003$). Therefore, Hypothesis 3 was supported.

Hypothesis 4

Hypothesis 4 proposed that AI significantly moderates the relationship between innovative financing methods and the optimal financing portfolio of the health system.

Table 6. Results of Hypothesis 4

Path	Path Coefficient	<i>p</i> Value	Significance
Innovative financing methods → Optimal financing portfolio, moderated by AI	0.0897	.053	Marginal; not significant at $\alpha = .05$

The reported moderation coefficient was $\beta = 0.0897$, with $p = .053$. Because the p value is slightly greater than the conventional significance level of $\alpha = .05$, the moderating effect of AI is not statistically significant at the 5% level. The result may nevertheless be described as marginal or approaching statistical significance. Accordingly, Hypothesis 4 is not supported at $\alpha = .05$ based on the reported results.

Hypothesis 5

Hypothesis 5 proposed that sustainable supply chain performance significantly moderates the relationship between innovative financing methods and the optimal financing portfolio of the health system.

Table 7. Results of Hypothesis 5

Path	Path Coefficient	<i>p</i> Value	Significance
Innovative financing methods → Optimal financing portfolio, moderated by sustainable supply chain performance	0.0772	.092	Significant at the 10% level
Sobel Test Statistic	<i>p</i> Value	Result	
2.977	.0029	The mediating effect was statistically significant at the 1% level.	

The reported moderation coefficient was $\beta = 0.0772$, with $p = .092$. Because this p value is below $\alpha = .10$ but above $\alpha = .05$, the moderating effect is statistically significant only at the 10% significance level. Accordingly, Hypothesis

5 is supported when a 10% significance criterion is adopted, but it would not be supported under the conventional 5% criterion.

The reported Sobel test statistic was approximately 2.98 ($p = .0029$), indicating a statistically significant indirect effect at the 1% significance level. Accordingly, the reported mediating effect is statistically supported. This result suggests that the mediator contributes significantly to transmitting the effect between the corresponding predictor and outcome constructs within the structural model.

4. Discussion and Conclusion

The present study developed and empirically evaluated a sustainable health system financing model integrating innovative financing methods, sustainable resources, artificial intelligence (AI), sustainable supply chain performance, and the optimal financing portfolio. The structural model showed that innovative financing methods had a positive and statistically significant direct effect on the optimal financing portfolio ($\beta = 0.3015$, $p < .001$), indicating that greater use and diversification of innovative financing mechanisms can improve the composition and effectiveness of financing portfolios in health systems. Innovative financing methods also exerted a strong positive effect on sustainable resources ($\beta = 0.6402$, $p < .001$), representing the strongest direct structural relationship identified in the model. In turn, sustainable resources had a positive and significant effect on the optimal financing portfolio ($\beta = 0.1764$, $p = .003$). These findings collectively suggest that innovative financing contributes to health-system financial sustainability through both direct and resource-mediated pathways. The model further showed that AI had a positive but only marginal moderating effect on the relationship between innovative financing methods and the optimal financing portfolio ($\beta = 0.0897$, $p = .053$), whereas sustainable supply chain performance exhibited a positive moderating effect that was significant at the 10% level ($\beta = 0.0772$, $p = .092$). The reported Sobel test also indicated a statistically significant indirect effect ($p = .0029$), supporting the presence of an intermediary mechanism in the model. Taken together, the findings indicate that financing innovation is most likely to produce sustainable outcomes when supported by a stable resource base, effective technological capabilities, and an operationally sustainable supply chain.

The positive direct effect of innovative financing methods on the optimal financing portfolio supports the proposition that health systems can improve their financial resilience by diversifying beyond traditional funding arrangements. An optimal financing portfolio requires a combination of funding sources that can reduce exposure to fiscal volatility, distribute risk, improve liquidity, and maintain continuity of service delivery. This result is consistent with the broader sustainable-finance literature, which emphasizes diversification, long-term financial planning, and the integration of sustainability criteria into financing decisions [5]. The finding also aligns with evidence indicating that revenue diversification can strengthen institutional financial sustainability by reducing dependence on a limited number of funding sources [6]. In healthcare specifically, financially sustainable systems require reforms that expand the available financing base while maintaining affordability, efficiency, and continuity of care [7]. The current result therefore suggests that innovative financing instruments should not be treated merely as supplementary sources of capital but as strategic components of a broader financing portfolio capable of enhancing health-system resilience.

This finding is particularly relevant in the context of health systems that face persistent pressure from rising expenditure, economic instability, demographic changes, and public-health emergencies. Previous studies have shown that healthcare expenditure is influenced by multiple structural, demographic, and economic determinants, creating substantial uncertainty for financial planning [9]. During large-scale shocks such as the COVID-19

pandemic, sustainable financing proved essential for coordinating innovation and preserving health-system functioning [8]. The positive relationship identified in the present study implies that innovative financing methods may provide additional flexibility when conventional public budgets are insufficient or slow to respond. This interpretation is also compatible with evidence from Iran, where financing challenges have included resource mobilization problems, fragmentation, inefficient allocation, and weaknesses in financial protection [13]. Similarly, the continuing burden of catastrophic health expenditure in Iran demonstrates that financing arrangements must be restructured in ways that improve both sustainability and household financial protection [2]. Therefore, an optimal financing portfolio should be assessed not only in terms of revenue generation but also in terms of stability, equity, risk distribution, and its capacity to support system-wide objectives.

The strongest relationship in the model was observed between innovative financing methods and sustainable resources. This finding indicates that financing innovation can substantially contribute to the creation of a more stable and durable resource base for the health system. Innovative financing mechanisms may increase the number and diversity of funding channels, improve access to capital, reduce overdependence on annual governmental allocations, and enhance the flexibility with which resources can be mobilized. The strength of this relationship is theoretically meaningful because sustainable resources form the financial foundation on which long-term planning, strategic purchasing, investment, and service continuity depend. Existing evidence suggests that health financing should be evaluated through a comprehensive set of indicators covering revenue collection, pooling, financial protection, purchasing, and resource allocation [14]. Research on financing health-system elements similarly demonstrates that sustainable system performance requires balanced financing across multiple components rather than concentration on isolated services or programs [15]. Thus, the present finding extends previous work by showing empirically that financing innovation can serve as a mechanism through which the sustainability of financial resources is strengthened.

The significant effect of sustainable resources on the optimal financing portfolio further indicates that the availability of durable and predictable financial resources contributes to improved portfolio configuration. Although the path coefficient was smaller than that observed for innovative financing methods, the relationship remained statistically significant, suggesting that the quality and sustainability of the underlying resource base matter for financing decisions. A health system with unstable revenues, weak pooling arrangements, or excessive exposure to short-term fiscal fluctuations is less capable of constructing a financing portfolio that is strategically balanced. This finding corresponds with assessments of Iranian health-system performance showing that structural weaknesses in financing and resource allocation can affect broader system outcomes [3, 4]. It also reinforces the argument that financial sustainability should be understood as an institutional capability rather than merely as the existence of sufficient funding at a particular point in time. In this regard, sustainable resources create the conditions necessary for managers to diversify financing instruments, undertake long-term investment, and respond more effectively to uncertainty.

The findings concerning AI are also important. Although the moderating effect of AI did not reach the conventional 5% level of statistical significance, its positive coefficient and marginal *p* value indicate that AI may strengthen the relationship between innovative financing methods and the optimal financing portfolio under suitable organizational and technological conditions. This interpretation is consistent with the expanding literature on AI in health financing. AI applications have been increasingly used for expenditure prediction, fraud detection, insurance-related decision-making, financial risk assessment, and resource allocation [21]. More broadly, AI has demonstrated substantial potential to improve decision quality and operational efficiency in healthcare [16, 17]. Its

contribution to sustainable healthcare has also been linked to better predictive capacity, more efficient resource utilization, and improved managerial responsiveness [18]. Consequently, the marginal moderation effect found in this study may reflect the fact that AI does not automatically improve financing outcomes; rather, its effectiveness depends on data quality, institutional readiness, managerial capabilities, integration with decision processes, and governance arrangements.

This interpretation is further supported by the health-governance literature. Effective use of AI requires appropriate regulatory frameworks, transparent decision rules, reliable databases, institutional coordination, and sufficient human expertise [22]. Studies of AI in financial and accounting contexts have similarly shown that AI can enhance analytical capability while simultaneously introducing ethical, governance, and accountability challenges [23]. Applications of AI in tax auditing demonstrate its potential to identify complex patterns and support more efficient financial oversight [24], while AI-based models of financial recovery prediction illustrate its usefulness in anticipating financial conditions and supporting forward-looking decisions [25]. These studies help explain why AI may strengthen financing performance without necessarily producing a large independent structural effect. AI functions primarily as an enabling capability: it improves the quality, timeliness, and sophistication of decisions surrounding financing mechanisms rather than replacing those mechanisms. Therefore, the marginal result observed in the present model may indicate that the technological infrastructure required to translate AI capabilities into measurable financing advantages is not yet fully developed.

The positive role of AI is also consistent with studies linking intelligent technologies to sustainable financial development. AI can improve the processing of financial information, scenario analysis, forecasting, and monitoring, all of which are relevant to long-term sustainability [26]. It may also facilitate the development of sustainability-oriented financial reporting and provide stronger informational foundations for sustainable financing decisions [27]. At a wider organizational level, however, AI-driven sustainable development requires the coordination of organizational, technical, and process-level capabilities [20]. The present findings fit this perspective because they suggest that AI alone is insufficient; it becomes more valuable when embedded in a coherent financing framework and supported by complementary organizational systems.

The moderating role of sustainable supply chain performance provides another important contribution. The positive coefficient suggests that better supply chain performance can strengthen the capacity of innovative financing methods to improve the optimal financing portfolio, although the relationship was statistically significant only at the 10% level. This result is conceptually plausible because health-system financing ultimately operates through an operational structure that converts financial inputs into medicines, medical equipment, technologies, services, and other healthcare resources. Even when financial resources are adequate, inefficient procurement, inventory problems, fragmented logistics, and weak coordination can reduce the value generated by those resources. Sustainable supply chain performance can therefore increase the effectiveness of financing by reducing avoidable costs, improving resource availability, and enhancing operational continuity. This interpretation is consistent with broader evidence linking sustainability performance to financial policy and organizational resource allocation [28]. It is also consistent with the notion that financial sustainability and operational sustainability are interdependent rather than separable managerial domains.

The relevance of supply chain performance becomes especially clear under conditions of uncertainty and disruption. Public-health emergencies can simultaneously increase demand, disrupt supply networks, increase procurement costs, and create unexpected financing requirements. Coordinated financing and implementation were identified as essential to sustaining health-system innovation during the COVID-19 crisis [8]. Big-data-based

approaches have also been proposed as tools for improving public financial and policy responses during health emergencies [29]. From this perspective, a sustainable healthcare supply chain provides a mechanism through which financial resources can be converted into timely operational capacity. The relatively weak moderation coefficient observed in the present study may suggest that this effect is conditional on the maturity of supply chain governance, information systems, procurement processes, and interorganizational coordination. Nonetheless, its positive direction supports the inclusion of supply chain performance as a relevant component of sustainable financing models.

The model's predictive and explanatory indicators provide additional support for the overall conceptual framework. The reported R^2 values indicated that the predictor constructs explained 45.4% of the variance in sustainable supply chain performance and 22.4% of the variance in the optimal financing portfolio. The first value indicates a meaningful level of explanatory power, whereas the second suggests that financing portfolio optimization is influenced by additional factors beyond those incorporated in the present model. This is consistent with the multidimensional nature of healthcare financing, which depends on macroeconomic conditions, governance, insurance design, demographic change, epidemiological structure, regulatory policy, and political priorities. Predictive studies have shown that healthcare expenditure can benefit from machine-learning approaches precisely because of the complexity and nonlinearity of its determinants [10, 11]. More recent financial modeling approaches similarly demonstrate the growing role of adaptive computational methods in environments characterized by uncertainty and changing market conditions [12]. The positive Q^2 values reported in this study further indicate that the model possesses predictive relevance and is capable of explaining meaningful portions of variation in the endogenous constructs.

Overall, the findings support an integrated interpretation of sustainable health-system financing. Innovative financing methods appear to play a central role because they directly improve the financing portfolio and strongly strengthen sustainable resources. Sustainable resources, in turn, provide a foundation for portfolio optimization, while AI and sustainable supply chain performance can enhance the context in which financing mechanisms operate. This integrated pattern is compatible with sustainable development perspectives emphasizing long-term alignment among financial, technological, organizational, and operational systems [20, 30]. It also corresponds with the emerging view that health-system sustainability requires not only more funding but better-informed, better-diversified, and more efficiently deployed financing. The findings therefore suggest that policies aimed at financing reform should avoid treating innovative finance, digital transformation, and supply chain management as separate initiatives. Greater benefits are likely to arise when these components are designed as interconnected elements of a unified sustainability strategy.

Several limitations should be considered when interpreting the findings. First, the study employed a cross-sectional descriptive-survey design, and therefore the estimated structural relationships should not be interpreted as definitive evidence of temporal or causal effects. Second, the study relied on expert perceptions collected through a questionnaire, which may introduce self-report bias, common-method variance, and differences in respondents' interpretations of complex concepts such as sustainable resources and optimal financing portfolios. Third, the sample was drawn from experts familiar with health-system financing in the Iranian context, which may limit the direct generalizability of the findings to health systems characterized by different governance, insurance, fiscal, and institutional arrangements. Fourth, some measurement-model indicators, particularly AVE values for selected constructs, were below conventional thresholds, requiring cautious interpretation of convergent validity. Fifth, the moderation effects of AI and sustainable supply chain performance were relatively small and did not meet the

conventional 5% significance threshold, indicating that these findings should be interpreted as preliminary rather than definitive. Finally, the model did not incorporate all potentially relevant determinants of sustainable health financing, including macroeconomic instability, insurance structure, political risk, regulatory quality, population aging, and epidemiological change.

Future studies should evaluate the proposed model using longitudinal designs to determine whether changes in innovative financing methods, digital capabilities, and supply chain performance predict subsequent improvements in financial sustainability over time. Replication in different countries and health-system structures would help establish the external validity of the model and reveal whether the estimated relationships vary according to institutional, economic, or regulatory context. Future research could also incorporate objective financial indicators, administrative data, procurement performance measures, and health expenditure databases alongside expert assessments to reduce reliance on perceptual measures. The moderating roles of AI and sustainable supply chain performance should be examined using more detailed multidimensional constructs, including digital maturity, data quality, AI governance, forecasting capability, procurement resilience, inventory efficiency, and supplier diversification. Researchers could also test additional mediating mechanisms such as financial risk management, organizational resilience, strategic purchasing, and resource-allocation efficiency. Finally, machine-learning, dynamic SEM, system-dynamics modeling, and longitudinal PLS approaches may provide richer insights into nonlinear, time-dependent, and scenario-specific relationships within sustainable health financing systems.

Health policymakers and healthcare managers should develop financing strategies based on diversified portfolios rather than excessive reliance on a single public or insurance-based funding source. Innovative financing mechanisms should be evaluated systematically in terms of cost, stability, risk, equity, scalability, and contribution to long-term financial resilience. Managers should also strengthen the sustainability of underlying resources by improving revenue predictability, pooling arrangements, strategic purchasing, and financial-risk monitoring. Investment in AI should focus on practical applications such as expenditure forecasting, fraud detection, demand prediction, financial scenario analysis, and decision support, while ensuring adequate data governance, transparency, workforce capability, and accountability. At the operational level, supply chain sustainability should be integrated into financing decisions through improved procurement planning, inventory visibility, supplier diversification, and coordination between financial and logistics units. Finally, health-system financing reforms should be implemented as integrated managerial programs in which financing innovation, technological capability, resource sustainability, and supply chain performance are coordinated rather than managed as isolated policy domains.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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