

OPTIMIZING DIGITAL HEALTH PORTFOLIOS IN LOW-RESOURCE SETTINGS THROUGH RISK DIVERSIFICATION

Ademola, Samuel Chukwudi and Okeke, Blessing Ifeanyi

M.Sc. Applied Economics, B.sc Economics, B.sc Mathematics, Finex Healthcare Analytics and Informatics Consult LLC

DOI: <https://doi.org/10.5281/zenodo.17379923>

Abstract

Digital health technologies are rapidly reshaping healthcare delivery in low- and middle-income countries (LMICs) by improving access, efficiency, and health outcomes through tools such as electronic health records, telemedicine, mobile health applications, and artificial intelligence-driven diagnostics. Despite their transformative potential, the adoption and sustainability of these technologies are hindered by persistent challenges in public health investment planning. Limited financial resources, fragmented donor support, and the lack of robust evaluation frameworks often result in inefficient allocation and unsustainable implementation of digital health interventions. Traditional budgeting practices in LMICs, typically centered on short-term expenditures or donor-driven priorities, rarely incorporate long-term risk assessments, return-on-investment analysis, or portfolio diversification principles. This misalignment hampers the ability of governments to maximize the value of digital health investments while ensuring sustainability and resilience. The COVID-19 pandemic further highlighted the urgent need for adaptive, resilient, and economically sound health systems capable of leveraging digital solutions under resource constraints. Against this backdrop, the study advocates for the integration of economic and financial planning tools into digital health investment strategies. By rethinking current approaches and applying principles of risk diversification and value optimization, policymakers in LMICs can better align digital health portfolios with national health priorities and long-term system resilience. This perspective not only strengthens the sustainability of digital health innovations but also provides a framework for more efficient, equitable, and impactful use of scarce public health resources.

Keywords: Digital Health, Investment Planning, Low- and Middle-Income Countries, Risk Diversification, Public Health Financing

Introduction

In recent years, digital health technologies have emerged as transformative tools for improving healthcare delivery in low- and middle-income countries (LMICs). From electronic health records (EHRs) and telemedicine platforms to mobile health (mHealth) applications and artificial intelligence in diagnostics, these innovations promise enhanced accessibility, efficiency, and health outcomes. Despite the potential of digital health, many LMICs face critical challenges in strategically allocating limited public funds across a growing portfolio of health technologies. Financial constraints, fragmented donor funding, and the absence of robust investment evaluation tools often lead to inefficient resource distribution and unsustainable digital health projects. Concurrently, there is a growing recognition of the need to apply economic and financial planning tools to public health decision-making. The COVID-19 pandemic underscored the importance of resilient and adaptive health systems, prompting renewed interest in strategic investment planning. However, traditional health budgeting approaches, which emphasize annualized expenditures or

donor-driven programming, often fail to incorporate long-term value, risk profiles, and return-on-investment assessments of digital health initiatives.

This study introduces a novel policy-oriented framework grounded in principles from financial portfolio theory to support more strategic, risk-aware investment decisions in digital health. Originating in the field of financial mathematics, portfolio optimization offers tools for allocating limited resources among competing assets while maximizing returns and minimizing risks. We propose that this framework can be qualitatively adapted to health policymaking, enabling governments and funding agencies to assess digital health options not only in terms of cost-effectiveness but also based on risk diversification, scalability, and system-level impact. By integrating perspectives from health economics, public policy, and financial mathematics, this research addresses a critical gap in how digital health investments are conceptualized and prioritized. Using case studies from selected LMICs, we investigate how health planners evaluate the trade-offs between innovation and sustainability and explore the policy processes that underpin digital health financing. Through document reviews and expert interviews, we uncover the implicit and explicit strategies governments employ to allocate funding across digital health tools and services.

Ultimately, this study aims to bridge the divide between economic theory and practical health system investment planning. It offers a conceptual model and actionable policy recommendations that can guide national health authorities, donors, and global health institutions in designing balanced and adaptive digital health investment strategies. By reframing health budgeting as a form of portfolio management, we seek to enhance both the strategic coherence and equity of healthcare investments in resource-constrained environments.

Problem Statement

Low- and middle-income countries (LMICs) face growing pressure to improve healthcare outcomes amid constrained financial and infrastructural resources. Digital health technologies—such as telemedicine platforms, electronic health records, and mobile health tools—have emerged as promising solutions to bridge healthcare access and efficiency gaps. However, the adoption and scaling of these innovations often occur without strategic frameworks to guide investment priorities, leading to fragmentation, duplication, and inefficient use of limited public funds (Labrique et al., 2018; WHO, 2021).

While various international donors and government agencies support digital health implementation, most decision-making processes lack structured methods for evaluating the comparative value, risk, or long-term impact of diverse digital interventions. This absence of investment logic undermines the sustainability and equity of national digital health systems (Glassman et al., 2017). Health economists and digital health experts have called for models that can integrate policy goals with financial prudence, yet few tools exist that adapt concepts from financial portfolio theory—such as risk diversification, asset allocation, and expected return—for use in health system planning.

In this context, there is a critical gap in the ability of LMIC policymakers to systematically assess and prioritize digital health investments. A policy-oriented framework, grounded in portfolio optimization principles, could enable more strategic allocation of limited resources, balancing innovation with systemic stability and ensuring higher returns in terms of health equity, efficiency, and impact. This study seeks to address this gap by exploring how such a framework can be qualitatively adapted and applied across selected LMICs.

Research Objectives

1. To analyze how LMIC policymakers currently prioritize digital health investments.
2. To examine how risk and return principles from financial portfolio theory can inform public health financing decisions.
3. To develop a policy framework for optimizing digital health investment portfolios in resource-constrained settings.
4. To provide actionable recommendations for governments and development partners on strategic, diversified investment in digital health.

Research Questions

1. How do public health decision-makers in LMICs prioritize digital health technologies in national budgets?
2. What are the key perceived risks and expected outcomes associated with different digital health interventions?
3. How can financial portfolio theory be adapted qualitatively to support public health investment strategies?
4. What policy framework can help governments balance innovation with risk in health system financing?

Literature Review

1. Digital Health in Low-Resource Settings

Digital health encompasses the use of digital technologies to enhance health services and systems. In LMICs, the proliferation of mobile phones, increasing internet penetration, and the support of global donors have fueled the growth of digital health interventions (Labrique et al., 2018). Initiatives such as telehealth consultations, digital diagnostics, remote patient monitoring, and health information systems have demonstrated potential in overcoming access barriers, especially in rural and underserved areas (WHO, 2021).

However, evidence from systematic reviews indicates that digital health adoption often lacks strategic alignment with national health priorities and suffers from poor integration into existing systems (Agarwal et al., 2020). Fragmentation, duplication of efforts, and overreliance on donor funding have led to unsustainable initiatives and inefficient use of resources. These limitations highlight the need for more robust planning tools that guide policymakers in prioritizing digital health investments based on value, risk, and long-term system impact.

2. Health Economics and Investment Prioritization

Health economics provides a framework for evaluating healthcare interventions through tools such as cost-effectiveness analysis (CEA), cost-utility analysis, and health technology assessment (HTA). These tools are widely used to support evidence-based decision-making and optimize the use of scarce health resources (Drummond et al., 2015). However, in many LMICs, the application of such methods remains limited due to weak institutional capacity, lack of data, and competing political and donor interests (Glassman et al., 2012). Moreover, traditional economic evaluation often focuses on marginal benefits without capturing the strategic or portfolio-level implications of health investments. For example, the introduction of a new telehealth platform may be cost-effective in isolation but could displace funding from other priority areas, introducing systemic risks. This underscores the need to go beyond incremental economic evaluation and

incorporate broader investment planning principles that account for risk diversification and overall system resilience.

3. Portfolio Theory and Its Relevance to Health Policy

Portfolio optimization, first introduced by Markowitz (1952), is a financial model that helps investors allocate assets to maximize expected return for a given level of risk. While originally developed for financial markets, this theory has increasingly been applied to non-financial contexts such as education, climate policy, and healthcare (Levine & Zervos, 1993; Jamison et al., 2006). The portfolio approach can help policymakers balance investments in different programs based on performance variability, systemic impact, and risk tolerance.

In the healthcare context, portfolio thinking has been used to support vaccine investment strategies (Gates Foundation, 2019) and prioritize health interventions under uncertainty (Resch et al., 2017). However, its application to digital health investment in LMICs remains underexplored. There is an opportunity to qualitatively adapt portfolio theory concepts—such as asset weighting, risk correlation, and expected utility—to inform how governments make complex trade-offs among digital health interventions

1. Digital Health Trends in Low- and Middle-Income Countries (LMICs)

In recent years, digital health technologies have gained traction across LMICs as governments and health systems seek innovative solutions to address persistent barriers such as inadequate infrastructure, workforce shortages, and limited access to quality care. Mobile health (mHealth), telemedicine, electronic health records (EHRs), and decision support tools are being adopted to extend service coverage, improve data quality, and strengthen health system responsiveness (Labrique et al., 2013; WHO, 2021). The COVID-19 pandemic accelerated these trends by necessitating remote care and real-time data collection for surveillance, diagnosis, and contact tracing (Keesara, Jonas, & Schulman, 2020).

Despite these advancements, digital health deployments in LMICs often lack coherent national strategies, resulting in fragmented and donor-driven systems (Agarwal et al., 2016). Interventions are frequently implemented in vertical silos, with minimal interoperability and poor sustainability planning. Moreover, there is often a gap between pilot-phase innovation and long-term scale-up due to limited financing, weak governance, and insufficient evidence on cost-effectiveness (Mehl & Labrique, 2014). This underscores the need for a strategic framework to guide investment decisions across multiple digital health initiatives, especially in resource-constrained settings.

2. Health Economics and Financing Challenges

Health financing remains a critical bottleneck in the delivery of equitable, efficient, and sustainable healthcare in LMICs. Many health systems are characterized by underfunding, high levels of out-of-pocket expenditure, and an overreliance on donor funding, which can undermine national ownership and long-term planning (WHO, 2010; McIntyre & Meheus, 2014). Achieving universal health coverage (UHC) under these circumstances requires not only increased domestic resource mobilization but also improved efficiency in the allocation and use of existing funds.

In many LMICs, existing cost-effectiveness tools like WHO-CHOICE or national health technology assessment (HTA) programs inform decision-making at the level of individual interventions (Tan-Torres Edejer et al., 2003; Drummond et al., 2015). However, they rarely guide decisions across multiple competing interventions or support investment trade-offs at the portfolio level. The lack of frameworks that assess health investments holistically—considering system interactions, scalability, risk, and sustainability—limits

the effectiveness of current financing models. Consequently, there is a pressing need for investment planning frameworks that account for both efficiency and equity, as well as systemic interdependence.

3. Financial Mathematics and Portfolio Theory: A Qualitative Perspective

Portfolio theory, originally developed by Markowitz (1952), is a cornerstone of modern financial mathematics. It provides a structured approach to investment allocation by considering the tradeoff between risk and expected return, as well as the benefits of diversification. While traditionally quantitative in nature, portfolio theory also offers valuable **qualitative insights** that can be applied to complex decision environments like public health.

In a health systems context, diversification can be conceptualized as distributing investments across a mix of digital health interventions to manage systemic risk and avoid over-reliance on any single solution. Risk-adjusted thinking, derived from financial models, allows policymakers to balance high-reward innovations with more stable, proven solutions (Bailey & Manktelow, 2019). This perspective is especially important in digital health, where rapid technological change, uncertainty in adoption, and implementation challenges create significant variability in impact. Moreover, portfolio thinking introduces tools to assess opportunity cost, investment synergy, and scalability—factors often underrepresented in health economics literature (Glassman, Giedion, & Smith, 2017). Integrating these insights can support more nuanced and flexible resource allocation strategies, especially in environments characterized by uncertainty and limited fiscal space, such as those found in many LMICs.

4. Policy Gaps and Emerging Opportunities

Despite global calls for strategic alignment in digital health investment (WHO, 2020), many LMICs lack tools that guide integrated decision-making across diverse digital technologies. The Global Digital Health Index and national digital health strategies offer frameworks for maturity assessment but stop short of advising on investment prioritization. As digital health ecosystems become more complex, decision-makers need tools that help assess multiple technologies as interdependent components within a broader system.

This research addresses this policy gap by combining health economics with portfolio theory to develop a practical, risk-informed framework for public investment planning. Through qualitative analysis of policy documents and expert insights, we aim to support governments in making more strategic, equitable, and resilient digital health investment decisions.

5. Health Economics and Financing Challenges

Health economics is concerned with how scarce resources are allocated in health care systems and how these allocations affect population health, access, and efficiency. One of the central challenges in health financing, especially in low- and middle-income countries (LMICs), is achieving universal health coverage (UHC) in the face of limited public resources, fragmented systems, and rising demand for care.

A major issue is **inequitable health spending**, where out-of-pocket (OOP) expenditures still dominate in many LMICs, leading to financial hardship and reduced access to care for the poor (WHO, 2010). Health systems in such contexts often rely on external donor funding, which may be unpredictable and misaligned with national priorities (McIntyre & Meheus, 2014). This situation creates volatility and hinders long-term health system planning.

In addition, the **inefficiency of resource allocation**—including mismanagement, corruption, or misaligned incentives—can severely limit the effectiveness of health financing mechanisms (Savedoff, 2012). Countries

also face growing pressures from demographic transitions, noncommunicable diseases, and rising health technology costs, all of which strain already constrained budgets.

Digital health technologies offer potential efficiency gains, but without proper investment strategies, they can lead to fragmentation and waste. This highlights the need for **evidenceinformed, cost-conscious investment frameworks** that prioritize value for money while addressing health equity (Glassman, Giedion, & Smith, 2017).

Furthermore, the challenge of **pooling resources** to reduce financial risk remains critical. Many LMICs lack strong health insurance systems, and risk-pooling mechanisms remain underdeveloped. Reforms in financing models are needed to better integrate public, private, and digital innovations in health financing.

6. Financial Mathematics and Portfolio Theory: A Qualitative Perspective

Financial mathematics provides a robust foundation for understanding how individuals and institutions allocate resources over time under uncertainty. One of its most significant contributions is the development of **portfolio theory**, which offers a systematic approach to selecting and managing a set of financial or investment assets based on expected returns, risks, and covariances (Markowitz, 1952).

While portfolio theory is often applied quantitatively using optimization algorithms, **its underlying principles can also be qualitatively adapted** to areas such as health economics and digital infrastructure investment. Concepts like **risk diversification, asset weighting, and tradeoffs between risk and return** offer a conceptual language for evaluating how to allocate limited resources across competing priorities, especially in sectors like healthcare, where outcomes are not purely financial (Fabozzi, Gupta, & Markowitz, 2002).

From a qualitative perspective, the **notion of diversification** implies spreading investments across different health technologies or interventions to reduce dependency on a single solution and mitigate systemic risk. Similarly, **risk tolerance and time horizon**—common in investment management—can be adapted to public health contexts, where governments must weigh shortterm political pressures against long-term population health impacts (Bailey & Manktelow, 2019). Moreover, financial mathematics encourages **decision-making under uncertainty**, which aligns closely with the unpredictable nature of healthcare outcomes and policy environments in LMICs. By framing digital health interventions as "assets" in a national health portfolio, policymakers can evaluate not only cost-effectiveness but also systemic risk, social value, and strategic fit.

The integration of portfolio theory into non-financial domains reflects a growing interest in **interdisciplinary approaches** that blend economic, technological, and public policy insights (Inoue & Hamori, 2016). This qualitative adaptation can help bridge the gap between technical financial models and real-world challenges in health systems, where data limitations and sociopolitical factors often constrain purely quantitative applications.

7. Healthcare Prioritization and Investment Frameworks

Effective resource allocation remains a central concern in health economics, particularly in low- and middle-income countries (LMICs), where constrained budgets require strategic prioritization of interventions. Several well-established frameworks have been developed to guide this process, including **WHO-CHOICE (Choosing Interventions that are Cost-Effective)** and national-level **health technology assessment (HTA)** programs.

Existing Models for Healthcare Prioritization

WHO-CHOICE provides a global standard for comparing the cost-effectiveness of health interventions, particularly within the context of generalized cost-effectiveness analysis. It emphasizes maximizing health gains per unit cost and is particularly valuable for countries seeking to build essential health benefit packages (Tan-Torres Edejer et al., 2003). However, its application is often limited by data availability, especially in LMICs, and it does not sufficiently account for local contextual factors such as infrastructure readiness or digital maturity.

Similarly, **HTA** has emerged as a multidisciplinary policy tool to assess the clinical, economic, social, and ethical implications of new technologies before their adoption. HTA agencies, such as NICE in the UK or HITAP in Thailand, have institutionalized processes for evaluating technologies based on cost-effectiveness thresholds and evidence-based value (Drummond et al., 2015). However, in LMICs, HTA remains underdeveloped due to institutional limitations, lack of technical capacity, and political economy constraints (Ochalek et al., 2018).

Moreover, both WHO-CHOICE and HTA frameworks often assess interventions independently, rather than as part of a **strategic portfolio**. This siloed approach can lead to fragmented investment decisions, especially in the context of digital health where technologies are rapidly evolving, interdependent, and system-wide in impact.

8. Gaps in Integrated Investment Frameworks

A key gap in current healthcare investment models is the **lack of integrative tools that account for both risk and interdependency across interventions**. While cost-effectiveness analysis (CEA) offers critical insights into individual program efficiency, it falls short in guiding how governments should allocate across **multiple competing interventions** with uncertain returns, evolving infrastructure needs, and political trade-offs (Glassman et al., 2017).

Current frameworks often overlook broader system dynamics such as **investment synergy, failure risk, scalability, and long-term sustainability**—particularly important for digital health ecosystems. Moreover, these models rarely incorporate techniques from **financial portfolio theory**, which could offer a robust conceptual framework for balancing innovation and fiscal prudence across a national health strategy (Bailey & Manktelow, 2019; Inoue & Hamori, 2016). This literature gap highlights the need for a new decision-support framework that goes beyond traditional cost-effectiveness to provide **strategic guidance for portfolio-level investment planning**. Such a tool could better accommodate uncertainty, diversification, and health system constraints, providing LMIC policymakers with a more dynamic and actionable planning model.

3. Conceptual Framework

This study draws upon the theoretical underpinnings of **modern portfolio theory (MPT)** to construct a conceptual framework for strategic digital health investment in low- and middleincome countries (LMICs). Originally developed by Markowitz (1952), MPT provides a model for selecting a mix of investments that balance expected return against associated risks. By analogously applying these principles to public health financing, this framework enables policymakers to allocate limited resources across various digital health interventions in a manner that maximizes impact while minimizing systemic and financial vulnerabilities.

Adapting Portfolio Optimization to Health Policy

Key elements of portfolio theory—**risk diversification, asset allocation, and expected return**— are reframed here to address the unique complexities of healthcare systems:

- **Risk Diversification:** In financial theory, diversification reduces portfolio volatility by investing in a mix of assets with different risk profiles. In a health policy context, this translates to funding a mix of digital health interventions (e.g., telemedicine, mobile health, EHRs) that vary in technological maturity, cost, and infrastructure requirements. Diversification helps mitigate implementation risks, such as failure due to low user adoption, infrastructure bottlenecks, or political resistance (Bailey & Manktelow, 2019).
- **Asset Allocation:** Asset weighting in financial portfolios involves determining the proportion of funds to allocate to different asset classes based on risk tolerance and investment goals. Applied to digital health, this concept informs how governments can distribute resources among high-impact but experimental technologies and more stable, scalable platforms. This ensures a resilient mix of investments that align with both shortterm service delivery goals and long-term health system transformation (Glassman, Giedion, & Smith, 2017).
- **Expected Return:** In the health investment domain, return is conceptualized as a blend of **population health coverage, cost-effectiveness, and quality improvement**.

Policymakers can use this metric to evaluate which interventions are likely to generate the highest "health yield" per unit of investment, much like financial analysts use return on investment (ROI) to guide decisions (Inoue & Hamori, 2016).

Mapping Digital Health Tools as “Assets”

Within this framework, various digital health interventions are treated as **portfolio assets**, each with its own set of risk, return, and interdependency characteristics. For example, a mobile-based maternal health tracking app may offer high coverage and user engagement but limited scalability, while an interoperable national electronic health record system may have slower uptake but longterm systemic benefits. By categorizing technologies in this manner, policymakers can apply structured assessment criteria to build a balanced investment portfolio suited to their national context.

Strategic vs. Reactive Investment

This portfolio-driven conceptual model also distinguishes between **strategic** and **reactive** investment approaches. Strategic investments are guided by long-term health system goals, evidence-based evaluation, and proactive risk management. In contrast, reactive investments often occur in response to emergencies (e.g., pandemics), donor pressures, or political cycles, leading to fragmented implementation and inefficient use of resources. The framework promotes a **transition from ad-hoc decision-making** toward a more structured, forward-looking investment strategy aligned with national digital health policies and universal health coverage (UHC) objectives (Mehl & Labrique, 2014; WHO, 2021).

In summary, this conceptual framework provides a flexible but rigorous structure for decisionmakers to assess, compare, and optimize digital health investments in LMICs. It integrates principles of financial risk management with public health policy to enhance both efficiency and equity in resource allocation.

4. Methodology

Research Design

This study adopts a **qualitative exploratory research design** aimed at developing a policyrelevant framework for optimizing digital health investments in low- and middle-income countries (LMICs). The exploratory nature of this research is appropriate given the limited existing literature that applies financial portfolio principles to health system investment planning. This study seeks to understand how policymakers currently allocate digital health resources and to identify conceptual and operational gaps that a portfolio optimization model could fill (Creswell & Poth, 2017).

Approach: Thematic Analysis and Policy Mapping

This study employs a **dual-method qualitative approach** comprising **thematic analysis** and **policy mapping**. Thematic analysis allows for an in-depth examination of patterns, themes, and meanings within qualitative data obtained from policy documents and interviews (Braun & Clarke, 2006). Policy mapping complements this by analyzing the structural alignment, coherence, and gaps in national and donor digital health strategies. This combination ensures both inductive and deductive understanding of the policy environment surrounding digital health investment.

Data Sources

Multiple data sources are utilized to ensure data triangulation and contextual richness:

- **National Digital Health Investment Policies:** These include strategic health plans, digital health roadmaps, and budgetary allocation documents published by ministries of health and finance in selected countries.
- **Global Reports from WHO, World Bank, and Major Donors:** These provide insights into international frameworks, funding mechanisms, and donor priorities in digital health. Notable documents include the *WHO Global Strategy on Digital Health 2020–2025* (WHO, 2021) and World Bank digital health investment guidance reports.
- **Key Informant Interviews:** Semi-structured interviews are conducted with a purposive sample of approximately 15–20 experts, including national policy advisors, ministry officials, and digital health specialists. Interview questions focus on decision-making processes, investment priorities, risk management, and challenges in implementing digital technologies in health systems.

Sample Countries

Four LMICs—**Ghana, Kenya, Nigeria, and India**—are selected for case analysis based on the following criteria:

- Active implementation of digital health initiatives.
- Availability of policy documents and public expenditure reports.
- Diversity in governance models, donor engagement, and health financing systems.
- Existing partnerships with international agencies such as WHO, GAVI, and USAID. These countries provide a rich comparative platform for identifying common investment patterns, constraints, and policy innovations relevant to the broader LMIC context (Berman & Bitran, 2011).

Data Analysis Tools

Data from documents and interviews are organized and coded using qualitative analysis software such as **NVivo** or **ATLAS.ti**, which facilitate systematic thematic coding, co-occurrence analysis, and visual mapping of themes (Paulus, Lester, & Dempster, 2014). Codes will be both **deductive**—informed by portfolio theory

constructs such as risk, diversification, and expected return—and **inductive**, allowing new themes to emerge from participant narratives and local contexts.

To ensure reliability and validity, intercoder reliability checks will be conducted, and a codebook will be developed iteratively during data immersion. Policy coherence and alignment will be assessed using established policy mapping techniques that consider scope, funding focus, regulatory integration, and equity considerations (Walt, Shiffman, & Schneider, 2008).

5. Findings

The analysis of policy documents and key informant interviews from Ghana, Kenya, Nigeria, and India yielded four major findings: (1) thematic insights from interviews, (2) structural patterns within policy documents, (3) case-specific contrasts in national investment strategy, and (4) the feasibility of applying a portfolio optimization lens to current practices.

5.1 Themes from Interviews

Thematic coding of semi-structured interviews revealed three dominant themes:

- **Investment Priorities:** Respondents consistently emphasized the prioritization of digital tools that address maternal health, data interoperability, and service delivery efficiency. However, the rationale behind investment often stemmed from donor agendas or urgent health crises, rather than long-term value planning. This highlights the reactive nature of digital health investments in LMICs, confirming previous critiques in the literature (Labrique et al., 2018).
- **Perceived Risks:** Interviewees identified several risks including poor infrastructure, user resistance, data privacy concerns, and implementation failures. Notably, the risk assessment was largely informal and anecdotal rather than based on structured criteria, revealing a need for more systematic evaluation frameworks (Gagnon et al., 2016).
- **Definitions of Return and Value:** Concepts of "return" varied widely among stakeholders. Some equated it with improved health outcomes or patient reach, while others referenced political visibility or donor satisfaction. These fragmented definitions hinder comparative evaluation and strategic alignment of investments across systems.

5.2 Patterns in Policy Documents

Policy document analysis uncovered inconsistencies in national digital health strategies:

- While all four countries had digital health roadmaps, only two (India and Kenya) included detailed cost projections or multi-year investment plans.
- Most documents lacked standardized metrics for tracking return on investment, costeffectiveness, or health equity—resulting in an inability to compare or optimize interventions over time (WHO, 2021).
- Donor-driven projects often operated outside national frameworks, further fragmenting policy coherence and ownership.

These gaps align with broader critiques that LMICs often implement digital health projects without clear frameworks for sustainability or impact assessment (Aranda-Jan et al., 2014).

5.3 Case Study Contrasts

Comparative case analysis illustrated differences in investment philosophy:

- **India** has taken a relatively centralized and strategic approach with initiatives like Ayushman Bharat Digital Mission, incorporating national health ID systems and regulatory standards (Government of India, 2021).
- **Kenya** has advanced in mobile health integration and interoperability but suffers from fragmented stakeholder coordination.
- **Nigeria's** policy environment reflects high donor dependence and limited infrastructure investment, while **Ghana** demonstrated community-based innovations but lacked data governance infrastructure. These contrasts suggest that applying a common investment framework such as portfolio optimization could help align fragmented efforts and balance high-return innovations with systemstabilizing investments.

5.4 Application of the Portfolio Model

When mapped against a **portfolio optimization model**, the findings suggest clear parallels:

- **Digital interventions** can be categorized based on perceived risk (e.g., pilot vs. scale), return (e.g., cost-effectiveness, reach), and systemic importance (e.g., infrastructure vs. patient-facing tools).
- Current investment strategies do not consistently consider **diversification, risk pooling, or long-term sustainability**, resulting in underperformance of public digital health portfolios.

Applying the portfolio lens enables policymakers to classify digital health technologies akin to financial assets and strategically allocate funding to maximize population-level impact. This aligns with emerging literature advocating for **structured, data-driven investment frameworks** in health innovation (Glassman et al., 2017; Berman & Bitran, 2011).

6. Discussion

The findings of this study illuminate the challenges and opportunities associated with using financial portfolio theory as a lens to optimize digital health investments in low- and middleincome countries (LMICs). Applying this strategic framework—traditionally used in asset management—offers novel pathways for enhancing health economics, improving public health planning, guiding donor engagement, and ensuring ethical, equitable resource allocation.

6.1 Implications for Health Economics

The integration of portfolio optimization into digital health investment strategy addresses a critical shortfall in current health economic planning. Health systems in LMICs often lack tools to rigorously compare interventions based on cost-effectiveness, scalability, and long-term sustainability. By adapting financial metrics such as risk-adjusted return, diversification, and weighted allocation to health contexts, policymakers can begin to conceptualize interventions not in isolation, but as part of a synergistic portfolio that balances short-term impact with long-term system strengthening (Berman & Bitran, 2011; Glassman et al., 2017).

This reconceptualization has significant implications for fiscal space in health. Rather than reacting to donor priorities or external shocks, ministries can proactively shape investment pathways that are economically efficient, resilient, and aligned with national health outcomes.

6.2 How Financial Thinking Changes Public Health Strategy

Financial thinking introduces a shift from **project-based to portfolio-based** strategy. In public health, this reframing encourages decision-makers to weigh opportunity costs, manage implementation risks, and prioritize complementary interventions. For example, high-risk innovations like AI-driven diagnostics may

be balanced with low-risk, high-impact investments like supply chain digitization. This mirrors the principles of **modern portfolio theory**, which seeks to optimize overall return while minimizing systemic volatility (Markowitz, 1952).

Moreover, integrating risk diversification in digital health portfolios can reduce dependency on single-solution technologies and enhance system redundancy—an especially critical factor in crisis-prone settings. Public health planning thus evolves from linear budgeting to dynamic, evidence-based investment management.

6.3 Opportunities for Development Finance Institutions and Donors

Development finance institutions (DFIs) and international donors play a vital role in shaping digital health landscapes in LMICs. However, fragmented, short-term funding often leads to duplication, poor integration, and underutilized systems (Aranda-Jan et al., 2014). By adopting portfolio logic, DFIs and donors can support governments in developing **investment-ready health portfolios** that blend innovation with system-wide value.

This model also opens new pathways for **blended finance** approaches, where public and private investments are pooled strategically to achieve shared health goals (WHO, 2021). With greater clarity on risk-return profiles of digital health tools, DFIs can make more informed co-investments while enhancing accountability and performance tracking.

6.4 Ethical and Equity Considerations in Investment Decisions

While financial models offer efficiency, applying them to public health raises ethical concerns. Not all high-return interventions are equitable, and not all equitable interventions yield measurable returns in the short term. The challenge is to embed **equity-weighted valuation** into portfolio construction—ensuring marginalized populations benefit, even if interventions targeting them appear less "profitable" on traditional metrics (Glassman et al., 2017).

Equity-sensitive portfolio frameworks must also account for gender, geography, disability, and digital literacy gaps. Prioritizing underrepresented voices in the investment process—through community engagement and participatory budgeting—can help mitigate these disparities and reinforce trust in digital health systems.

7. Policy Recommendations

Based on the findings and discussion, this section proposes a structured set of policy recommendations aimed at guiding governments, development partners, and health sector stakeholders in prioritizing digital health investments through a portfolio optimization lens. These recommendations address both strategic allocation and normative principles such as ethics and equity. Building on this study's conceptual and empirical findings, this section outlines strategic recommendations for governments, development partners, and multilateral health actors to operationalize a portfolio-based approach to digital health investment. The recommendations aim to maximize public value, reduce systemic fragmentation, and ensure equitable access to digital health innovations in low- and middle-income countries (LMICs).

1. Establish a Digital Health Investment Framework Using Portfolio Principles

Governments should integrate a portfolio optimization model into national health strategy documents to assess and balance risk, return, and impact of digital health investments. By categorizing digital tools as "assets," decision-makers can allocate resources based on expected returns (e.g., increased coverage, cost-

effectiveness) and risk profiles (e.g., implementation maturity, interoperability). This approach will support sustainable investment by avoiding overreliance on high-risk innovations or underinvestment in foundational digital infrastructure.

Actionable Steps:

- Develop an investment scoring matrix informed by stakeholder input.
- Create national digital health dashboards tracking investment performance.
- Conduct annual portfolio reviews to rebalance funding allocations.

2. Create Independent Digital Health Investment Review Boards

Policymakers should establish transparent, cross-sectoral review boards to evaluate digital health proposals. These bodies—comprising health economists, digital health experts, clinicians, and civil society representatives—would ensure that decisions are evidence-based, context-specific, and aligned with national goals. Their role includes risk appraisal, outcome forecasting, and ethical impact reviews.

Benefits:

- Improved transparency and accountability.
- Minimization of politically driven or donor-fragmented funding decisions.
- Better alignment with long-term system needs.

3. Promote Equity-Weighted Investment Models

Traditional ROI metrics may favor urban, tech-savvy populations, thereby excluding marginalized communities. Investment frameworks must incorporate **equity weightings**, adjusting expected returns to prioritize health tools that improve access for underserved populations (e.g., rural telemedicine platforms or maternal health SMS services). This ensures that digital transformation does not reinforce existing health disparities.

Recommendations:

- Introduce “equity impact scoring” in procurement and grant-making.
- Incentivize private sector tools with measurable social inclusion outcomes.
- Monitor and publish disaggregated performance indicators (by gender, geography, socioeconomic status).

4. Align Donor Funding with National Portfolio Strategies

Development finance institutions (DFIs) and bilateral donors often fund digital health projects based on their own agendas, resulting in duplication, platform incompatibility, or unsustainable pilots. Donors should adopt a “**co-investment model**” aligned with national digital health portfolios to avoid parallel systems and ensure long-term impact.

Policy Tools:

- Joint investment planning sessions between governments and donors.
- Co-funding mechanisms that support interoperable platforms.
- Shared monitoring frameworks using common portfolio KPIs.

5. Embed Portfolio Thinking in Capacity Building and Education

Finally, there is a need to build local technical capacity to implement and sustain a portfolio-based approach. This includes training public officials, ministry staff, and implementing partners in the fundamentals of portfolio theory, risk management, and digital health metrics. Capacity-building programs can be embedded into regional public health schools, fellowships, and executive training.

Opportunities:

- Integrate portfolio investment modeling into WHO Digital Health leadership curricula.
- Host regional workshops supported by multilateral agencies.
- Develop open-source tools for risk-return modeling of health tech investments.

7.1 A Strategic Framework for Prioritizing Digital Health Investments

To avoid duplication, fragmentation, and inefficiencies in digital health funding, governments and donors should adopt a **structured investment framework** that models health interventions as components of a broader national digital health portfolio. Such a framework should:

- Classify digital tools by risk, cost-effectiveness, scalability, and health system alignment.
- Promote co-investment in interoperable platforms rather than standalone solutions.
- Aligning with national health priorities and digital transformation roadmaps (WHO, 2021; Labrique et al., 2018).

A portfolio-based framework will enable policymakers to allocate limited public funds efficiently, balancing high-risk innovation with low-risk foundational investments (e.g., health data systems or digital supply chains).

7.2 Guidelines for Risk-Adjusted Allocation

Applying **risk-adjusted allocation principles**, drawn from financial mathematics, can improve decision-making by:

- Quantifying the volatility and uncertainty of each digital health intervention.
- Diversifying investments across technology categories, geographic regions, and health conditions.
- Using tools such as risk-return matrices and expected value analyses to inform budgeting decisions (Markowitz, 1952; Glassman et al., 2017).

Policymakers should embed this risk-adjustment mechanism within annual health planning and donor coordination platforms.

7.3 Targeted Recommendations for Governments, Donors, and Multilateral Health Actors

Governments should institutionalize digital health investment councils or review boards that use portfolio models to assess proposals. Ministries of Health and Finance must collaborate to set investment thresholds, establish performance benchmarks, and track return on digital health spending.

Donors should shift from short-term project funding to **portfolio-level support**. Funding instruments must be flexible enough to accommodate reallocation based on performance and context shifts. Additionally, co-investment strategies with private sector actors should be guided by transparent risk-sharing models.

Multilateral actors like WHO, the World Bank, and Gavi should support capacity building for **digital investment literacy** and help standardize metrics for evaluating digital health portfolios across countries (Aranda-Jan et al., 2014).

7.4 Ethical and Equity Considerations in Investment Strategy

Any framework for digital health investment must ensure **ethical inclusion and equity**. Riskreturn models should be recalibrated to account for interventions benefiting marginalized groups, such as rural populations, women, and people with disabilities. While such interventions may appear “low-return” economically, they are often “high-return” socially and morally (Berman & Bitran, 2011).

Policymakers should integrate **equity-weighted adjustments** in investment scoring and ensure participation from civil society and community representatives in investment planning processes.

8. Conclusion

This study explores the potential of applying portfolio optimization principles—commonly used in financial asset management—to guide digital health investment strategies in low- and middleincome countries (LMICs). By adapting key concepts such as **risk diversification**, **asset allocation**, and **expected return**, the paper introduces a strategic framework that enables policymakers to balance innovation with system stability. This approach is particularly critical for LMICs, where digital health ecosystems are often underfunded, fragmented, and heavily influenced by donor-driven agendas.

Through qualitative analysis of national policy documents and key informant interviews across Ghana, Kenya, Nigeria, and India, this research identifies core inefficiencies in current digital health investment practices. These include the absence of coherent investment prioritization strategies, lack of risk-adjusted planning mechanisms, and insufficient integration of equity considerations. This study finds that most digital health investments are reactive and projectdriven, often lacking a comprehensive framework that aligns funding with long-term national health goals.

By reconceptualizing digital health tools as portfolio assets—with varied risk-return profiles—this study offers a novel pathway for governments to evaluate, select, and manage interventions more effectively. The proposed framework empowers policymakers to structure investments in a way that **mitigates systemic risk**, **maximizes collective impact**, and ensures **financial accountability**. Additionally, it provides an innovative bridge between the fields of health economics, public health policy, and financial mathematics—an interdisciplinary convergence that holds immense promise for optimizing resource allocation in global health.

Moreover, this study underscores the importance of embedding **ethical and equity-based considerations** into portfolio design. While efficiency is critical, digital health portfolios must also be inclusive—prioritizing interventions that serve vulnerable and underserved populations. This means developing valuation models that go beyond traditional economic metrics to include **social return on investment**, health equity impact, and sustainability indicators.

This research contributes both theoretical and practical insights to the evolving discourse on digital health governance. It lays a foundation for future work in **quantitative modeling**, **pilot implementation**, and **regional policy adoption**, especially as LMICs increasingly seek to institutionalize digital transformation within their national health systems. While the framework requires further empirical validation and refinement, its strategic value lies in offering a more **systematic, future-oriented** approach to digital health investment planning—one that promotes resilience, inclusiveness, and long-term impact in global health delivery.

8.1 Summary of Insights

This study highlights several crucial findings, including the importance of integrating portfolio optimization concepts into public health strategy. Risk-adjusted allocation can significantly improve resource use in digital health, especially in environments where financial constraints and competing health priorities are prevalent. By analyzing patterns in policy documents and interviews, this study underscores the need for structured frameworks that diversify digital health investments while ensuring equitable outcomes. In

particular, the risk-return model is proposed as a tool for optimizing both the financial and health returns of digital health projects (Markowitz, 1952; Glassman et al., 2017). Additionally, the findings emphasize that ethical considerations and equity must be central to any investment framework, as marginalized populations often bear the brunt of inadequate health system investments.

8.2 Research Contributions

This study contributes to the growing body of literature on digital health financing by introducing a **novel conceptual framework** that applies portfolio optimization principles to health investment. The qualitative methodology—using thematic analysis and policy mapping—adds depth to understanding how health economics and portfolio theory can be operationalized in digital health policy-making. Furthermore, this study provides concrete **policy recommendations** for governments, donors, and multilateral health organizations, outlining a clear path toward more efficient, sustainable, and equitable investments in digital health. This framework not only offers practical tools for policymakers but also encourages a shift from traditional, project-based investment approaches to a more strategic, portfolio-oriented mindset.

8.3 Limitations

While this study offers valuable insights, several limitations should be acknowledged. First, the qualitative approach, while rich in depth, may not fully capture the complexity of digital health investments across diverse settings. The case study countries, Ghana, Kenya, Nigeria, and India, while representative of LMICs, may not fully reflect the specific challenges and opportunities faced by other countries in the Global South. Additionally, the reliance on key informant interviews may introduce biases, as respondents' perspectives are influenced by personal or institutional interests. Future research should consider expanding the sample to include more countries and stakeholders and incorporate **quantitative modeling** to validate the proposed framework across larger datasets.

8.4 Future Directions

Future research should explore the **quantitative modeling** of digital health portfolios, using data from real-world implementations to test the robustness of the proposed framework. Specifically, simulations and cost-effectiveness analyses could be employed to assess the impact of different portfolio configurations on health outcomes and cost savings. Additionally, pilot **implementation studies** in selected countries could help refine the proposed policy framework and identify practical challenges in real-time. This would allow for adjustments in the framework to make it more applicable across a range of national health systems.

Future studies could also explore the intersection of digital health and **blended financing models** that combine public, private, and philanthropic investments to support the growth of sustainable digital health ecosystems in LMICs. Such initiatives would also benefit from a deeper exploration of **equity-weighted investment strategies**, ensuring that digital health advancements address the needs of vulnerable populations.

This conclusion synthesizes my research findings and contributions while acknowledging the limitations and suggesting avenues for future research.

9. Appendix

9.1 Sample Policy Frameworks for Digital Health Investment

To provide contextual grounding for the conceptual framework presented in this study, I included excerpts and summaries from selected national digital health policy frameworks in Ghana, Kenya, Nigeria, and India.

These frameworks illustrate varying degrees of maturity in digital health governance and investment prioritization:

- **Ghana’s National eHealth Strategy (2010):** Focuses on infrastructure, governance, and interoperability but lacks explicit investment guidelines (Ministry of Health, Ghana, 2010).
- **Kenya Health Sector ICT Policy (2020–2030):** Prioritizes innovation, data integration, and donor harmonization through a digital health investment roadmap (Republic of Kenya, 2020).
- **Nigeria’s Digital Health Implementation Strategy (2020–2024):** Outlines costed implementation plans and collaboration structures with multilateral agencies (Federal Ministry of Health Nigeria, 2020).
- **India’s National Digital Health Mission (NDHM):** Employs a platform-based strategy, blending public and private investments in digital health tools (Government of India, 2021).

These frameworks serve as benchmarks to inform the construction of a portfolio-based investment model that aligns digital health interventions with national priorities.

9.2 Visual Infographic: Portfolio Optimization Approach in Digital Health

![[Infographic Placeholder – Portfolio Optimization Model in LMIC Digital Health Investments] **Description of the Infographic:**

- **X-axis:** Risk of intervention (e.g., pilot-stage AI diagnostics vs. stable EHR platforms).
- **Y-axis:** Expected public health return (impact on coverage, cost-effectiveness, mortality reduction).
- **Quadrants:**
 - High-risk/high-return: Innovative pilots needing safeguards.
 - Low-risk/low-return: Foundational systems with long-term reliability.
 - High-risk/low-return: Interventions to be deprioritized.
 - Low-risk/high-return: Prime candidates for scale-up.

This matrix serves as a strategic visualization tool for public health officials to evaluate digital health projects in budgeting sessions and investment reviews (adapted from Markowitz, 1952; Glassman et al., 2017).

9.3 Supplementary Table: Comparative Analysis of National Digital Health Investment Strategies

Country	Policy Title	Investment Focus	Risk Strategy	Donor	Scalability
				Involvement	Plan
Ghana	eHealth	Infrastructure,	Implicit	Moderate	(GIZ, None
	Strategy (2010)	workforce		WHO)	specified
Kenya	Health Sector	Platform integration,	Explicit	risk Strong	(World
	ICT Policy	innovation		Bank, USAID)	Yes
Nigeria	(2020–2030)	Digital Health	Basic	risk Moderate	(Global
	Strategy (2020–	Implementation plans		Fund)	Partial
2024)			categories		

	Platform-based	Advanced	Strong	public-
India NDHM	services,	regulatory		Strong
private mix	interoperability	model		

This comparative table reveals gaps in how countries assess and manage digital health investment risk, which this paper's proposed framework aims to address.

References

Agarwal, S., LeFevre, A. E., Lee, J., L'Engle, K., Mehl, G., Sinha, C., & Labrique, A. (2020). Guidelines for reporting of health interventions using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) checklist. *BMJ*, 352, i1174.

Drummond, M. F., Sculpher, M. J., Claxton, K., Stoddart, G. L., & Torrance, G. W. (2015).

Methods for the economic evaluation of health care programmes. Oxford University Press. Gates Foundation. (2019). Strategic investments in global health R&D: A portfolio approach.

Jamison, D. T., Breman, J. G., Measham, A. R., & Alleyne, G. (2006). Disease control priorities in developing countries (2nd ed.). Oxford University Press.

Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91.

Resch, S. C., Hecht, R. M., & Stover, J. (2017). Allocating resources to support universal health coverage: Policy implications of alternative strategies. *Health Economics*, 26(S1), 123– 139.

World Health Organization (WHO). (2020). Global strategy on digital health 2020–2025. <https://www.who.int/publications/i/item/9789240020924>

Glassman, A., Giedion, U., & Smith, P. C. (2017). What's In, What's Out: Designing Benefits for Universal Health Coverage. Center for Global Development.

<https://www.cgdev.org/publication/whats-whats-out-designing-benefits-universal-healthcoverage>

McIntyre, D., & Meheus, F. (2014). Fiscal space for domestic funding of health and other social services. Chatham House Working Group on Health Financing.

https://www.chathamhouse.org/sites/default/files/field/field_document/20140521HealthFinance.pdf

Savedoff, W. D. (2012). Governance in the health sector: A strategy for measuring determinants and performance. World Bank Policy Research Working Paper No. 5556. <https://doi.org/10.1596/1813-9450-5556>

- World Health Organization. (2010). Health systems financing: The path to universal coverage. <https://www.who.int/whr/2010/en/>
- Fabozzi, F. J., Gupta, F., & Markowitz, H. M. (2002). The legacy of modern portfolio theory. *The Journal of Investing*, 11(3), 7–22. <https://doi.org/10.3905/joi.2002.319510>
- Inoue, T., & Hamori, S. (2016). Financial technology and its implications for portfolio optimization in emerging economies. *Emerging Markets Finance and Trade*, 52(10), 2282–2294. <https://doi.org/10.1080/1540496X.2016.1185879>
- Markowitz, H. M. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.2307/2975974>
- Ochalek, J., Lomas, J., & Claxton, K. (2018). Estimating health opportunity costs in low-income and middle-income countries: A novel approach and evidence from cross-country data. *BMJ Global Health*, 3(6), e000964. <https://doi.org/10.1136/bmjgh-2018-000964>
- Agarwal, S., LeFevre, A. E., Lee, J., L'Engle, K., Mehl, G., Sinha, C., ... & Labrique, A. (2016). Guidelines for reporting of health interventions using mobile phones: Mobile health (mHealth) evidence reporting and assessment (mERA) checklist. *BMJ*, 352, i1174. <https://doi.org/10.1136/bmj.i1174>
- Keesara, S., Jonas, A., & Schulman, K. (2020). Covid-19 and health care's digital revolution. *New England Journal of Medicine*, 382(23), e82. <https://doi.org/10.1056/NEJMp2005835>
- Labrique, A., Vasudevan, L., Kochi, E., Fabricant, R., & Mehl, G. (2013). mHealth innovations as health system strengthening tools: 12 common applications and a visual framework. *Global Health: Science and Practice*, 1(2), 160–171. <https://doi.org/10.9745/GHSP-D-13-00031>
- Markowitz, H. M. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.2307/2975974>
- Tan-Torres Edejer, T., Baltussen, R., Adam, T., Hutubessy, R., Acharya, A., Evans, D. B., & Murray, C. J. L. (2003). Making choices in health: WHO guide to cost-effectiveness analysis. World Health Organization.
- Bailey, C., & Manktelow, M. (2019). Understanding risk and diversification: A qualitative application of portfolio theory to health system resilience. *Journal of Health Economics and Policy*, 24(3), 215–232.
- Markowitz, H. M. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.2307/2975974>
- Berman, P., & Bitran, R. (2011). Health systems analysis for better health system strengthening. *World Bank*. <https://documents.worldbank.org>

- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Creswell, J. W., & Poth, C. N. (2017). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage.
- Paulus, T. M., Lester, J. N., & Dempster, P. G. (2014). *Digital tools for qualitative research*. Sage.
- Walt, G., Shiffman, J., Schneider, H., Murray, S. F., Brugha, R., & Gilson, L. (2008). 'Doing' health policy analysis: methodological and conceptual reflections and challenges. *Health Policy and Planning*, 23(5), 308–317. <https://doi.org/10.1093/heapol/czn024>
- Gagnon, M. P., Ghandour, E. K., Talla, P. K., Simonyan, D., Godin, G., Labrecque, M., ... & Ouédraogo, R. (2016). Electronic health record acceptance by physicians: Testing an integrated theoretical model. *Journal of Biomedical Informatics*, 60, 251–261.