**UNIVERSITY OF FINANCE AND ECONOMICS**



**TUMENDELGER LKHAGVASUREN**

# Improving Strategic Asset Allocation for a Sovereign Wealth Fund in a Resource-Dependent Developing Economy:

## Empirical Evidence from the Future Heritage Fund of Mongolia

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**041301**

**Business Administration**

**Doctoral Dissertation**

**Supervisor**

Bolorsuvd Batbold, Ph.D/Professor

Ulaanbaatar, 2026

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Ulaanbaatar, 2026

## STATEMENT

The research presented in this dissertation is my own original work. All sources drawn from the work of other authors have been properly acknowledged and cited. I take full responsibility for any matters relating to the theories, research materials, images, and data used in this study.

I understand that this research project shall be the property of the University of Finance and Economics (UFE), and I consent to its unrestricted use by the UFE Library for academic and research purposes.

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| | |
|---|---|
| GDP | Gross domestic product |
| GPFG | Government Pension Fund Global |
| GIC | Government Investment Corporation |
| SWF | Sovereign Wealth Funds |
| SOE | State Owned Enterprise |
| SAA | Strategic Asset Allocation |
| IPS | Investment Policy Statement |
| IFSWF | International Forum of Sovereign Wealth Fund |
| PIF | Public Investment Fund |
| PIH | Permanent Income Hypothesis |

## LIST OF CONFERENCE PRESENTATIONS

- **"On the Construction of Feasible Portfolios within a Convex Mean–Variance Framework."** presented at the *19th International Conference on Algorithmic Aspects in Information and Management (AAIM 2025)*, Ulaanbaatar, Mongolia, 23 – 25 June 2025.
- **"Improving Sovereign Wealth Fund Asset Allocation in Resource-Dependent Developing Economies:** Empirical Evidence from the Future Heritage Fund of Mongolia**"** presented at the Research Seminar in *Institue of Mathematics and Digital Technolgy, Mongolian Academy of Science,* 24 March 2026.

## ABSTRACT

Resource-dependent developing economies are frequently exposed to macroeconomic instability arising from commodity-price volatility, procyclical fiscal revenues, external vulnerability, and the intergenerational challenge of managing exhaustible natural-resource wealth. In such contexts, sovereign wealth funds are often established to preserve public wealth, support long-term savings, and strengthen macroeconomic resilience. However, an important research gap remains in the sovereign wealth fund literature: the problem of determining an appropriate long-term strategic asset allocation for sovereign wealth funds has not been sufficiently developed, particularly for resource-dependent developing economies operating under uncertainty. Although macroeconomic conditions may justify the creation and operation of a sovereign wealth fund, the literature still provides limited operational guidance on how appropriate strategic asset allocation should be determined under such conditions.

This dissertation addresses that problem by examining how the strategic asset allocation of the Future Heritage Fund of Mongolia can be improved within its current investment mandate. The study adopts Al Sayed's five-step sovereign wealth fund design model as its overarching conceptual framework and develops its structural-design stage through a more explicit asset-allocation methodology.

The dissertation first identifies the macroeconomic conditions and sovereign objectives relevant to the Fund, with particular emphasis on long-term savings, macroeconomic resilience, and intergenerational wealth preservation in a resource-dependent developing economy. It then examines the Fund's mandate environment and evaluates the strategic asset-allocation problem within this setting. At the quantitative stage, the dissertation compares the current government-mandated portfolio with benchmark, convex, and sphere-packing portfolios to identify a more appropriate and robust long-term strategic asset allocation under conditions of uncertainty. It further evaluates the opportunity cost associated with maintaining a highly conservative and weakly diversified portfolio instead of adopting a more robust and diversified allocation.

The findings show that the current portfolio of the Future Heritage Fund of Mongolia is highly conservative and weakly diversified relative to its long-term savings objective, and that more robust portfolio structures can improve long-term return-risk performance and sovereign wealth accumulation. In this way, the dissertation contributes to the sovereign wealth fund literature by addressing the strategic asset-allocation problem directly, applying convex and sphere-packing approaches in a sovereign fund setting, and providing policy-relevant evidence on the long-term opportunity cost of conservative public fund management. The study therefore offers a practical framework for improving sovereign wealth fund strategic asset allocation in resource-dependent developing economies.



**Keywords:** sovereign wealth fund, resource-dependent developing economy, strategic asset allocation, convex and sphere-packing portfolio optimization, opportunity cost.

# ХУРААНГУЙ

Байгалийн баялгаас хамааралтай хөгжиж буй эдийн засагтай орнууд нь түүхий эдийн үнийн хэлбэлзэл, төсвийн орлогын мөчлөг дагасан савлагаа, гадаад секторын эмзэг байдал, валютын ханшийн дарамт, мөн шавхагдах баялгийг одоо болон ирээдүй үеийн хооронд шударга хуваарилах сорилттой тулгардаг. Ийм нөхцөлд баялгийн сан нь зөвхөн илүүдэл орлогыг хадгалах хэрэгсэл бус, харин байгалийн баялгийн орлогыг урт хугацааны санхүүгийн хөрөнгө болгон хувиргах, улсын санхүүгийн тогтвортой байдлыг хамгаалах, ирээдүй үеийн хуримтлалыг бүрдүүлэх бодлогын чухал механизм болдог.

Гэсэн хэдий ч баялгийн сангийн талаарх олон улсын судалгаанд санг яагаад байгуулах, ямар макро эдийн засгийн зорилгоор ашиглах талаар өргөн судлагдсан боловч урт хугацааны стратегийн хөрөнгийн хуваарилалтыг тодорхойгүй нөхцөл, сул төрөлжилт, хязгаарлагдмал хөрөнгө оруулалтын мандаттай хөгжиж буй эдийн засгийн хувьд хэрхэн оновчтой тодорхойлох асуудал хангалттай судлагдаагүй байна. Ал Сайдын баялгийн сангийн институтийн дизайны загвар нь сангийн макро эдийн засгийн нөхцөл, зорилго, мандат, бүтэц, нөлөөллийн үнэлгээг үе шаттай авч үздэг боловч стратегийн хөрөнгийн хуваарилалтыг тоон оновчлолын түвшинд гүнзгийрүүлэх шаардлага хэвээр байна.

Энэхүү диссертацийн үндсэн зорилго нь Монгол Улсын Ирээдүйн өв сангийн урт хугацааны стратегийн хөрөнгийн хуваарилалтыг одоогийн хөрөнгө оруулалтын мандат болон төрийн сангийн удирдлагын орчны хүрээнд хэрхэн сайжруулах асуудлыг судлахад оршино. Судалгааны гол асуулт нь: Монгол Улсын Ирээдүйн өв сангийн одоогийн мандат, тодорхойгүй байдал, төрөлжилтийн хязгаарлалт, төрийн удирдлагын нөхцөлд илүү зохистой бөгөөд робуст урт хугацааны стратегийн хөрөнгийн хуваарилалтыг хэрхэн тодорхойлох вэ? гэсэн асуудал юм.

Судалгаанд Ал Сайдын баялгийн сангийн дизайны таван үе шатат загварыг ерөнхий үзэл баримтлалын хүрээ болгон ашигласан. Үүнд Монгол Улсын макро эдийн засгийн нөхцөл, Ирээдүйн өв сангийн зорилго, одоогийн мандат ба институтийн зохион байгуулалт, стратегийн хөрөнгийн хуваарилалтын математик загвар, мөн өөр өөр багцын урт хугацааны үр нөлөөг харьцуулан үнэлэх асуудлыг хамруулсан.

Арга зүйн хувьд судалгаа нь макро-институтийн шинжилгээ болон математик загварчлал, багцын оновчлолыг хослуулсан. Эхний хэсэгт Монгол Улсын макро эдийн засгийн орчин, сангийн зорилго, сангийн төрлийг Ал Сайдын загварын хүрээнд тодорхойлсон бол дараагийн хэсэгт стратегийн хөрөнгийн хуваарилалтын асуудлыг гүдгэр программчлал болон хучилтын бодлогын онолын үүднээс томьёолж, робуст багцын оновчлол хийсэн. Гүдгэр программчлалын хүрээнд одоогийн жишиг багцаас хамгийн бага хазайлттай, өгөөж болон эрсдэлийн шаардлагыг хангах боломжит багцыг тодорхойлсон бол хучилтын бодлогын арга нь тодорхойгүй нөхцөлд илүү тогтвортой, дотоод байрлалтай багцыг сонгох боломжийг бүрдүүлсэн.

Тоон шинжилгээнд Засгийн газраас баталсан одоогийн мандаттай багцыг жишиг болгон авч, түүнийг гүдгэр программчлалын багц болон хучилтын бодлогын аргаар тодорхойлсон робуст багцтай харьцуулсан. Харьцуулалтыг өгөөж, эрсдэл, төрөлжилт, багцын тогтвортой байдал, урт хугацааны хуримтлалын боломж зэрэг үзүүлэлтээр хийж,

одоогийн хэт консерватив, төрөлжилт сул багц хадгалагдвал Ирээдүйн өв сангийн урт хугацааны хуримтлалд үүсэх алдагдсан боломжийн өртгийг тооцоолсон.

Судалгааны үр дүнгээс үзэхэд Монгол Улсын Ирээдүйн өв сангийн одоогийн багц нь урт хугацааны хуримтлалын зорилготой харьцуулахад хэт консерватив, төрөлжилт сул, өгөөжийн боломжийг бүрэн ашиглаж чадаагүй байна. Одоогийн бүтэц нь богино хугацааны аюулгүй байдлыг хангах давуу талтай боловч урт хугацаанд сангийн хөрөнгийн өсөлт, үе хоорондын баялгийн хуримтлал, бодит хөрөнгө оруулалтын орлого олох боломжийг хязгаарлаж байна. Харин гүдгэр программчлал болон хучилтын бодлогын аргаар тодорхойлсон робуст багцууд нь одоогийн мандатын хүрээнд илүү зохистой эрсдэл-өгөөжийн тэнцвэрийг бий болгож, багцын төрөлжилтийг сайжруулах боломжтойг харуулсан.

Энэхүү диссертацийн гол хувь нэмэр нь гурван түвшинд илэрнэ. Нэгдүгээрт, байгалийн баялгаас хамааралтай хөгжиж буй эдийн засгийн нөхцөлд баялгийн сангийн хэрэгцээ, зорилго, мандат, стратегийн хөрөнгийн хуваарилалтыг холбосон макро-институтийн оношилгооны хүрээг санал болгосон. Хоёрдугаарт, Ал Сайдын институтийн дизайны загварын бүтцийн дизайны үе шатыг стратегийн хөрөнгийн хуваарилалтын тоон аргачлалаар гүнзгийрүүлсэн. Гуравдугаарт, гүдгэр программчлал болон хучилтын бодлогын математик загварыг Монгол Улсын Ирээдүйн өв сангийн хөрөнгө удирдлагад хэрэглэж, хэт консерватив төрийн сангийн удирдлагаас үүсэх урт хугацааны алдагдсан боломжийн өртгийг тооцоолсон.

Иймээс энэхүү судалгаа нь Монгол Улсын Ирээдүйн өв сангийн хөрөнгө удирдлагыг сайжруулах практик ач холбогдолтой төдийгүй баялгийн сангийн стратегийн хөрөнгийн хуваарилалтын онол, арга зүйд хувь нэмэр оруулж байна. Судалгааны үр дүн нь байгалийн баялгаас хамааралтай, хөгжиж буй, институтийн чадавх харьцангуй сул, хөрөнгө оруулалтын мандат нь хязгаарлагдмал бусад улс орнуудад баялгийн сангийн урт хугацааны хөрөнгө удирдлагыг сайжруулах жишиг аргачлал болж болох юм.

**Түлхүүр үгс:** Баялгийн сан, Ирээдүйн өв сан, байгалийн баялгаас хамааралтай хөгжиж буй эдийн засаг, стратегийн хөрөнгийн хуваарилалт, робуст багцын оновчлол, алдагдсан боломжийн өртөг.

# Introduction

## Background

Sovereign wealth funds (SWFs) have become increasingly important state-owned institutional investors in the management of national wealth, macroeconomic stabilization, intergenerational savings, and long-term strategic investment (Clark & Monk, 2017; Clark, Dixon, & Monk, 2013; Dixon & Monk, 2011; Cummine, 2016). Although early SWFs were often established to manage surplus fiscal revenues or excess foreign exchange reserves, their contemporary role has broadened to include sovereign balance-sheet management, fiscal stabilization, diversification of national wealth, and the transformation of temporary revenue windfalls into long-term public financial assets (Lu et al., 2009; Cummine, 2016; Dixon, Tufts, & Capapé, 2022). By 2021, global sovereign wealth fund assets under management exceeded USD 10.5 trillion, underscoring both their financial scale and their policy significance in the global economy (SWFI, 2022).

The importance of SWFs is particularly pronounced in resource-dependent developing economies, where governments frequently face revenue volatility, export concentration, procyclical fiscal pressures, and recurrent exposure to external shocks (Davis et al., 2001; IMF, 2014; Gelb et al., 2014; Venables, 2016; Van der Ploeg, 2017). In such settings, sovereign wealth funds are commonly justified as institutional mechanisms for stabilizing public expenditure, preserving exhaustible resource wealth, reducing macroeconomic vulnerability, and supporting long-term intergenerational savings (Raymond, 2010; Arezki et al., 2012; Clark et al., 2013; World Bank, 2013). However, the mere establishment of a sovereign wealth fund does not in itself guarantee effective performance. The capacity of a fund to achieve its intended objectives depends on whether its macroeconomic rationale, institutional design, governance arrangements, and investment strategy are mutually coherent and operationally implementable (IMF, 2007; World Bank, 2013; Wirth & Ramírez-Cendrero, 2016; Al-Hassan et al., 2018).

This issue is especially important because sovereign wealth funds are not ordinary institutional investors. Unlike private funds, pension funds, or conventional reserve portfolios, SWFs operate under public mandates, fiscal rules, legal withdrawal arrangements, and sovereign policy priorities, all of which shape their investment horizon, liquidity needs, risk tolerance, and strategic asset-allocation choices (Lu et al., 2009; Chhaochharia & Laeven, 2008; Cummine, 2016; Al-Hassan et al., 2018). For this reason, SWF asset allocation cannot be treated as a purely technical financial exercise detached from public policy. Rather, it must be understood as the operational expression of sovereign objectives within a specific macroeconomic and institutional setting (Clark & Monk, 2010b; Clark et al., 2013; Bachher, Dixon, & Monk, 2016). This point is particularly relevant in developing economies, where institutional fragility, limited technical capacity, evolving mandates, and policy uncertainty complicate the translation of broad sovereign objectives into durable long-term portfolio rules (Gelb et al., 2014; Venables, 2016; Arezki et al., 2012).

Comparative experience further demonstrates that sovereign wealth fund design is inherently context specific. Norway's Government Pension Fund Global is frequently presented as a benchmark for long-horizon savings, rule-based governance, and globally diversified investment under strong institutional conditions, while Singapore's Temasek reflects a more development-oriented and state-strategic model shaped by different macroeconomic objectives

and institutional capacities (Clark et al., 2013; Thomas & Chen, 2018; Dixon et al., 2022). These differences indicate that sovereign wealth fund design cannot be transferred mechanically from one national setting to another. Instead, fund objectives, mandate structures, governance arrangements, accumulation and withdrawal rules, and investment strategies must be aligned with the home country's macroeconomic structure, fiscal framework, and institutional capacity (IMF, 2007; World Bank, 2013; Wirth & Ramírez-Cendrero, 2016; Al-Hassan et al., 2018).

For developing and resource-dependent economies, this challenge becomes especially acute at the stage of long-term strategic asset allocation. Existing literature provides substantial analysis of the macroeconomic rationale for SWFs, their typologies, and their governance principles, but it offers more limited operational guidance on how macroeconomic objectives and institutional constraints should be translated into implementable long-term asset-allocation decisions (Clark & Monk, 2017; Cummine, 2016; Al-Hassan et al., 2018; Dixon et al., 2022). This limitation is important because traditional mean–variance portfolio theory relies on reasonably stable estimates of expected returns, covariance structures, and investor risk preferences (Markowitz, 1952). In newly established sovereign wealth funds operating under macroeconomic volatility, structural breaks, limited historical data, and evolving mandates, these assumptions are often weak (Chopra & Ziemba, 1993; Schmidt, 2016). Under such conditions, conventional optimization methods may prove too fragile for sovereign long-horizon portfolio design.

Robust portfolio optimization offers a possible response to these weaknesses. A substantial literature has developed worst-case optimization, robust convex methods, distributionally robust approaches, and Bayesian or hybrid methods to address estimation uncertainty in portfolio construction (Ben-Tal & Nemirovski, 1998; Goldfarb & Iyengar, 2003; Garlappi, Uppal, & Wang, 2007; Fabozzi, Huang, & Zhou, 2010). However, these approaches remain only weakly integrated into the broader sovereign wealth fund literature, especially in developing economies where macroeconomic uncertainty, institutional instability, and limited technical capacity make robust asset allocation particularly valuable (Clark & Monk, 2017; Al-Hassan et al., 2018; Venables, 2016). The central gap, therefore, is not the absence of portfolio theory itself, but the absence of an operational bridge linking sovereign objectives, institutional design, and long-term strategic asset allocation within a sovereign wealth fund framework.

This dissertation addresses that gap by adopting Al Sayed's five-step sovereign wealth fund design model as its overarching conceptual foundation and by deepening its structural-design stage through portfolio optimization (Al Sayed, 2023). In this approach, macroeconomic conditions are used to identify the appropriate sovereign objectives of the fund; institutional design defines the mandate, governance structure, and admissible operating constraints; and portfolio optimization provides the mechanism through which these macroeconomic and institutional elements are translated into implementable long-term asset-allocation decisions. This logic is consistent with the view that sovereign portfolio structure must be derived from fund purpose, public constraints, and long-term national objectives rather than from purely private investment logic (Clark et al., 2013; Bachher et al., 2016; Cummine, 2016).

The empirical case of the dissertation is the Future Heritage Fund of Mongolia. Mongolia provides a relevant case because it is a resource-dependent developing economy characterized by commodity dependence, fiscal volatility, exposure to external shocks, and the long-term challenge of transforming exhaustible mineral revenues into sustainable financial wealth (World Bank, 2013; IMF, 2014; Gelb et al., 2014). Within this context, the dissertation focuses specifically on improving the Fund's long-term strategic asset allocation within its current investment mandate. By comparing the existing government-mandated portfolio with alternative benchmark, convex, and sphere-packing allocations, the study evaluates whether a more robust and diversified portfolio structure can improve long-term performance under uncertainty and reduce the opportunity cost of excessively conservative asset allocation (Markowitz, 1952; Ben-Tal & Nemirovski, 1998; Goldfarb & Iyengar, 2003).

In this sense, the dissertation is not a general study of all aspects of sovereign wealth fund design and operation. Rather, it is a focused contribution to one specific and underdeveloped area of the broader SWF literature: the problem of long-term strategic asset allocation in a sovereign wealth fund operating under public constraints in a resource-dependent developing economy (Clark & Monk, 2017; Cummine, 2016; Al-Hassan et al., 2018).

**Problem Statement**

The central research problem addressed in this dissertation is how to determine an improved and robust long-term strategic asset allocation for a sovereign wealth fund, with reference to the Future Heritage Fund of Mongolia. This problem is especially important because sovereign wealth funds differ fundamentally from private investment funds. Unlike private funds, which are managed primarily according to commercial portfolio logic, sovereign wealth funds operate within public-management structures shaped by sovereign mandates, legal restrictions, governance arrangements, fiscal policy considerations, and political oversight. As a result, their asset management may be less flexible, less diversified, and less efficient than that of private institutional investors, creating a risk of underperformance relative to their long-term savings purpose. The dissertation's analysis of the Future Heritage Fund of Mongolia supports this concern by showing that the Fund operates within a transitional institutional arrangement and that its mandate, governance structure, and broader public-management environment impose specific constraints on investment strategy, with continuing emphasis on safety, liquidity, and administrative control.

This problem is also well grounded in the broader sovereign wealth fund literature. Bodie and Brière note that only a limited number of studies examine sovereign wealth fund asset allocation directly, and that actual sovereign wealth fund allocations often differ significantly from theoretical ones. They further argue that sovereign financial management is complicated by the difficulty of coordinating investment strategy with fiscal policy, monetary policy, and public debt management, especially where aggregate data and risk-sensitive balance-sheet information are limited. In practice, this means that strategic asset allocation in sovereign wealth funds is not simply a return-maximization problem. Rather, it is a sovereign asset–liability and public-policy problem in which the portfolio must reflect broader macroeconomic risks, fiscal variability, and long-term intergenerational obligations.

The sovereign wealth fund literature also shows that strategic asset allocation is a core determinant of fund effectiveness. The investment strategy literature emphasizes that the choice of investment strategy is not merely a financial decision, but one of the principal mechanisms through which the institutional design and policy purpose of a sovereign wealth fund are operationalized. It further shows that major sovereign wealth funds generally rely on diversification, risk management, and portfolio resilience as central components of long-term strategic asset allocation, while newly established funds in developing economies face acute difficulty in formulating such portfolios because expected returns, risk preferences, and historical data are incomplete or weakly specified. The same logic is present in Al-Sayed's framework, where structural design explicitly includes strategic asset allocation parameters, liquidity and risk-management policies, capital deposit and withdrawal rules, and the distribution of authority across supervisory, management, and oversight bodies.

For the Future Heritage Fund of Mongolia, this problem has direct empirical relevance. The dissertation shows that the Fund is primarily a long-term savings vehicle designed to ensure the equal distribution of natural-resource revenue between present and future generations, yet its current institutional structure remains transitional and conservative, with strategic authority, investment responsibility, and operational management only partially separated. The empirical findings further indicate that a more robust and internally stable portfolio structure can improve long-term accumulation outcomes relative to the current government-mandated portfolio, and that gradual diversification within a still conservative mandate can generate higher projected investment income and a stronger net asset value path over time without departing from the Fund's underlying savings objective. This suggests that the issue is not merely whether the Fund exists or whether its legal structure is adequate, but whether its current strategic asset allocation is sufficiently aligned with its long-term objective.

Accordingly, the research problem of this dissertation is not simply the design of a sovereign wealth fund in general, nor the translation of macroeconomic objectives into portfolio constraints. Rather, it is the more specific problem of determining a more appropriate and robust long-term strategic asset allocation under public-management constraints. In resource-dependent developing economies such as Mongolia, sovereign wealth funds may remain excessively conservative, weakly diversified, and prone to underperformance because asset management is shaped by public-sector institutional arrangements rather than by purely private portfolio logic. The central challenge, therefore, is how to improve the long-term strategic asset allocation of the Future Heritage Fund of Mongolia within its current investment mandate and institutional environment, while addressing the risk of underperformance and foregone sovereign wealth accumulation associated with conservative and weakly diversified public fund management.

**Thesis Question**

To address the problem of improving the long-term strategic asset allocation of the Future Heritage Fund of Mongolia, this dissertation examines the following research questions:

1. How can a more appropriate and robust long-term strategic asset allocation be determined for the Future Heritage Fund of Mongolia within its current investment mandate?

2. How can the Fund's strategic asset allocation be improved under conditions of uncertainty, limited diversification, and public-management constraints?

3. What long-term opportunity cost may result from maintaining the current conservative portfolio instead of adopting a more robust and diversified asset-allocation framework?

**Thesis Aim**

The aim of this dissertation is to improve the long-term strategic asset allocation of the Future Heritage Fund of Mongolia within its current investment mandate. The study addresses a central challenge faced by sovereign wealth funds in resource-dependent developing economies: although macroeconomic conditions may justify the creation and operation of a fund, the literature provides limited guidance on how an appropriate long-term asset-allocation strategy should be designed under conditions of uncertainty. This problem is especially important when highly conservative and weakly diversified portfolio structures may generate significant long-term opportunity costs in sovereign wealth accumulation.

To achieve this aim, the dissertation proceeds in two connected stages. First, it identifies the macroeconomic objectives relevant to the Future Heritage Fund of Mongolia, with particular attention to long-term savings, macroeconomic resilience, and intergenerational wealth preservation. Second, it develops and applies an operational portfolio framework through which a more appropriate and robust long-term strategic asset allocation can be derived under uncertainty, rather than relying solely on conventional mean–variance assumptions.

The Future Heritage Fund of Mongolia serves as the empirical application of the study, providing a concrete and policy-relevant case through which the framework is implemented and evaluated. In addition to deriving an improved asset-allocation structure consistent with the Fund's sovereign objectives, the dissertation also examines the opportunity cost that may arise when a highly conservative and weakly diversified portfolio is maintained instead of adopting a more robust and diversified strategic allocation.

Through this approach, the dissertation seeks to contribute to the sovereign wealth fund literature by addressing the strategic asset-allocation problem of sovereign wealth funds in resource-dependent developing economies, by providing an operational method for improving long-term portfolio design under uncertainty, and by demonstrating how the absence of robust and diversified investment may impose a measurable long-term cost on sovereign wealth accumulation.

**Thesis Objectives**

To achieve the overall aim of the dissertation, the study pursues the following specific objectives:

1. To identify the macroeconomic objectives of the Future Heritage Fund of Mongolia that should guide its long-term strategic asset allocation.

2. To examine whether the Fund's current strategic asset allocation is consistent with these objectives within its current investment mandate.

3. To develop and apply a portfolio framework for determining a more appropriate and robust long-term strategic asset allocation for the Fund under uncertainty.

4. To evaluate the long-term opportunity cost of not adopting a more robust and diversified strategic asset-allocation approach.

**Thesis Hypothesis**

*H1 Portfolio Optimization Hypothesis.*

- A robust optimization-based strategic asset allocation for the Future Heritage Fund of Mongolia improves portfolio efficiency relative to the current government mandated portfolio and standard benchmark allocations, as measured by return-risk performance, diversification, and downside-risk indicators.

*H2 Opportunity Cost Hypothesis.*

- The current government-mandated portfolio imposes an economically meaningful long-term opportunity cost relative to the robust strategic asset allocation, even after accounting for conservative risk limits, mandate restrictions, and adverse market conditions.

**Thesis Rationale**

This dissertation is motivated by the need to address the strategic asset-allocation problem of sovereign wealth funds (SWFs), particularly in resource-dependent developing economies. Although SWFs are widely recognized as instruments for fiscal stabilization, intergenerational savings, reserve diversification, and long-term public wealth management, the literature still provides limited guidance on how an appropriate long-term asset-allocation strategy should be determined for such funds (Davis et al., 2001; Al-Hassan et al., 2013; Frankel, 2012; Al-Hassan et al., 2018). This limitation is especially important because SWFs are not ordinary institutional investors. Unlike private funds, their portfolio choices must reflect sovereign mandates, public-policy objectives, macroeconomic vulnerability, and institutional constraints, all of which shape the feasible structure of long-term investment decisions (Clark & Monk, 2015; Cummine, 2016; Wirth & Ramírez-Cendrero, 2016).

The rationale for this dissertation arises from an important weakness in existing SWF literature. One major strand of research explains why sovereign wealth funds are established, emphasizing commodity-price volatility, fiscal procyclicality, external vulnerability, and intergenerational equity as the principal macroeconomic justifications for sovereign savings mechanisms (Davis et al., 2001; Frankel, 2012; van den Bremer, van der Ploeg, & Wills, 2016). A second strand focuses on institutional design, governance quality, transparency, and accountability, drawing on the Santiago Principles and the experience of established funds in advanced and emerging economies (IWG, 2008; Truman, 2010; Clark & Monk, 2015). However, these two strands have largely evolved in parallel. As a result, the literature still offers only limited operational guidance on the asset-allocation problem itself; namely, how a sovereign wealth fund should determine a long-term portfolio that is consistent with its macroeconomic purpose, mandate, and institutional environment.

This issue is directly related to Al Sayed's (2023) contribution. His five-step framework provides an important macro-institutional architecture for sovereign wealth fund design by linking economic conditions, policy objectives, mandate selection, structural design, and evaluation. Step 4 identifies the structural-design stage as the point at which capital allocation, governance strategy, portfolio management, and withdrawal policy should be specified (Al Sayed, 2023). Yet this stage remains largely conceptual. The framework indicates where the asset-allocation problem belongs, but it does not fully operationalize how that problem should be solved. This dissertation is therefore motivated not by the need to replace Al Sayed's model, but by the need to develop its structural-design stage more explicitly through a long-term strategic asset-allocation methodology.

The asset-allocation problem is especially acute in resource-dependent developing economies. In such settings, sovereign wealth funds often face volatile revenue inflows, short data histories, structural breaks, evolving mandates, shallow domestic financial systems, and uncertainty in long-term risk-return conditions (Gelb et al., 2014; IMF, 2014; Venables, 2016). Under these circumstances, macroeconomic objectives may be broadly clear in policy terms, such as long-term savings, preservation of resource wealth, and macroeconomic resilience, but much less clear in portfolio-design terms. At the same time, classical mean-variance optimization requires stable expected returns, reliable covariance estimates, and clearly specified investor risk preferences, assumptions that are frequently difficult to justify in developing-country sovereign wealth funds (Markowitz, 1952; Michaud, 1989; Best & Grauer, 1991; Chopra & Ziemba, 1993; DeMiguel, Garlappi, & Uppal, 2009; Schmidt, 2016). Consequently, policymakers may lack a sound analytical basis for determining a strategic asset allocation that is both financially effective and institutionally feasible.

This problem is not merely technical. It also has direct implications for fund performance. Where strategic asset allocation remains excessively conservative, weakly diversified, or poorly aligned with the long-term purpose of the fund, sovereign wealth funds may underperform relative to their savings objectives and generate lower long-term accumulation than would otherwise be possible. This concern is particularly relevant for public funds because their asset management may be shaped by administrative caution, mandate restrictions, and broader public-sector controls to a greater extent than in private investment funds. In this sense, the strategic asset-allocation problem of SWFs is not only a matter of portfolio efficiency, but also one of long-term public wealth preservation.

Although robust optimization provides important tools for dealing with parameter uncertainty, these approaches have only rarely been embedded in a sovereign wealth fund setting in which portfolio design begins from sovereign objectives and public-management conditions rather than from generic investor preferences (Ben-Tal & Nemirovski, 1998; Goldfarb & Iyengar, 2003; Garlappi et al., 2007). Literature therefore still lacks a sufficiently developed sovereign-specific framework for determining long-term strategic asset allocation under uncertainty. The central problem is not the absence of portfolio theory in general, but the absence of a method for applying it to sovereign wealth funds in a way that is consistent with their mandates, macroeconomic roles, and institutional constraints.

The rationale for this dissertation therefore rests on three related considerations. First, resource-dependent developing economies require SWF asset-allocation frameworks that are derived from sovereign purpose and public-policy function rather than borrowed mechanically from generic institutional-investor models (Davis et al., 2001; Frankel, 2012; van den Bremer et al., 2016). Second, Al Sayed's (2023) framework already locates capital allocation and portfolio management at the structural-design stage, but this stage remains under-operationalized and therefore invites further development. Third, uncertainty in long-term financial parameters requires an asset-allocation framework that can produce feasible and resilient portfolio structures without relying entirely on the strong informational assumptions of classical mean-variance optimization (Michaud, 1989; Chopra & Ziemba, 1993; Schmidt, 2016).

Accordingly, this dissertation addresses the strategic asset-allocation problem of sovereign wealth funds by focusing on the Future Heritage Fund of Mongolia. It examines how a more appropriate and robust long-term strategic asset allocation can be determined within the Fund's current investment mandate, and how the failure to adopt a more robust and diversified portfolio may generate a measurable long-term opportunity cost in sovereign wealth accumulation. By doing so, the dissertation seeks to contribute to the sovereign wealth fund literature not simply by restating macroeconomic rationale or governance principles, but by addressing the core question of how a sovereign fund should allocate its assets over the long run under conditions of uncertainty.

**Thesis Contribution**

This dissertation makes one methodological contribution and one policy contribution.

*Methodological Contribution*

The dissertation contributes to the literature by applying convex optimization and sphere-packing portfolio methods to the strategic asset-allocation problem of a sovereign wealth fund. While existing sovereign wealth fund research has examined macroeconomic justification, governance, and institutional design extensively, it has given more limited attention to the problem of determining long-term asset allocation under uncertainty. This dissertation addresses that gap by showing that convex optimization and sphere-packing approaches can be used to construct feasible, robust, and internally stable long-term portfolio allocations for sovereign wealth funds, particularly in resource-dependent developing economies.

*Policy Contribution*

The dissertation also makes a policy contribution through its empirical application to the Future Heritage Fund of Mongolia. By comparing the current government-mandated portfolio with alternative benchmark, convex, and sphere-packing allocations, the study provides a practical basis for improving the Fund's long-term strategic asset allocation within its existing mandate. It further evaluates projected returns, net asset value, and the opportunity cost of maintaining an overly conservative and weakly diversified portfolio. In this way, the dissertation offers policy-relevant evidence for strengthening the long-term financial management of the Future Heritage Fund of Mongolia.

**Thesis Methodology**

This dissertation adopts a sequential methodological approach to the analysis of sovereign wealth fund asset allocation in a resource-dependent developing economy. The methodology follows the broad logic of Al Sayed's five-step sovereign wealth fund design framework but places its main analytical emphasis on the operational development of the structural-design stage. In this dissertation, macroeconomic analysis and institutional interpretation are treated primarily as inputs into the asset-allocation problem, while portfolio analysis is treated as the central methodological mechanism through which a more appropriate and robust long-term strategic asset allocation is derived for the Future Heritage Fund of Mongolia.

The first methodological component is macroeconomic diagnosis. This stage evaluates the structural conditions relevant to sovereign wealth fund operation in a resource-dependent developing economy, including resource dependence, revenue volatility, fiscal procyclicality, external vulnerability, and intergenerational savings requirements. The purpose of this stage is not to determine portfolio weights directly, but to identify the sovereign objectives that should guide the long-term role of the fund. In the case of Mongolia, the analysis indicates that persistent mineral dependence, repeated fiscal cyclicality, and exposure to external shocks justify a savings-oriented sovereign wealth fund with conservative operational features and limited stabilization characteristics. These findings establish the macroeconomic context within which the strategic asset-allocation problem must be addressed.

The second methodological component is institutional interpretation. In this dissertation, institutional analysis is used in a narrower and more operational sense than in earlier versions of the study. It is not treated as an independent empirical pillar requiring separate validation. Rather, it is used to clarify the investment mandate, governance setting, and policy environment within which the Future Heritage Fund of Mongolia operates. The dissertation interprets the Fund as a long-term savings vehicle with a conservative mandate, Ministry-of-Finance-led strategic direction, and Bank-of-Mongolia-led operational execution. These institutional features are important because they shape the feasible scope of asset allocation and imply an emphasis on admissibility, prudence, and resilience rather than aggressive return maximization. Methodologically, institutional analysis therefore functions as a constraint-identification step that helps define the portfolio environment.

The third and central methodological component is portfolio analysis. This is the main methodological focus of the dissertation. At this stage, the sovereign objectives identified in macroeconomic analysis and the constraints implied by the institutional setting are brought into the asset-allocation problem. The dissertation proceeds from the view that the strategic asset allocation of a sovereign wealth fund should not be treated as a generic investor problem, but as a portfolio problem shaped by sovereign purpose, mandate restrictions, and public-management conditions. For this reason, the study does not rely on purely abstract optimization exercise. Instead, it develops a portfolio framework for identifying a more appropriate and robust long-term strategic asset allocation for the Future Heritage Fund of Mongolia within its current investment mandate.

Quantitative implementation is designed for a setting in which conventional assumptions are weak. The dissertation maintains that classical mean-variance optimization becomes difficult

to apply defensibly when expected returns, covariance structures, and effective risk preferences cannot be specified with sufficient reliability. This problem is especially relevant for newly established or evolving sovereign wealth funds in developing economies. The methodology therefore does not begin with the assumption of fully stable and well-defined risk-return parameters. Instead, it examines the strategic asset-allocation problem by comparing the current government-mandated portfolio with alternative benchmark, convex, and sphere-packing portfolios to identify a more appropriate allocation under uncertainty. In this way, the quantitative stage is used not merely to solve an optimization problem, but to evaluate whether the current portfolio can be improved in a manner consistent with the Fund's sovereign purpose.

The empirical application of this methodology is the Future Heritage Fund of Mongolia. Mongolia is used not simply as an illustrative case, but as the setting through which the asset-allocation framework is applied and interpreted. The dissertation shows that, in Mongolia's context, asset management cannot be understood as a purely technical financial exercise because it is shaped by macroeconomic necessity, legal design, and governance capacity. The empirical analysis therefore compares the current highly conservative portfolio with alternative asset-allocation structures and evaluates their relative return-risk characteristics, projected long-term accumulation, and associated opportunity costs. Methodologically, this means that the case study is used to assess the practical coherence and policy relevance of the proposed asset-allocation approach rather than to estimate a universal model detached from country context.

Accordingly, the methodology of this dissertation may be summarized as a sequential process. Macroeconomic diagnosis identifies the sovereign purpose of the fund; institutional interpretation clarifies the mandate and admissible investment environment; and portfolio analysis addresses the core research problem by examining how the strategic asset allocation of the Future Heritage Fund of Mongolia can be improved within its current investment mandate. In this respect, the dissertation does not attempt to build a fully general theory of sovereign wealth fund design. Rather, it uses the macroeconomic and institutional framework as the basis for addressing the specific and central problem of long-term strategic asset allocation in the Future Heritage Fund of Mongolia.

**Thesis Limitations**

Several limitations of this dissertation should be acknowledged.

Because the sovereign wealth fund literature is broad and multidisciplinary, this dissertation deliberately focuses on one specific dimension: the portfolio-optimization problem of long-term strategic asset allocation in the Future Heritage Fund of Mongolia.

First, the sovereign wealth fund literature covers a wide range of issues, including macroeconomic stabilization, intergenerational savings, governance, legal design, political economy, public financial management, and development policy. This dissertation does not attempt to examine all these dimensions in equal depth. Its primary focus is the strategic asset-allocation problem of the Future Heritage Fund of Mongolia, particularly the application of portfolio-optimization methods to improve long-term asset allocation under uncertainty. Accordingly, the study should be understood as a focused contribution to one specific area of

the wider sovereign wealth fund literature rather than as a complete theory of sovereign wealth fund design and operation.

Second, macroeconomic and institutional factors are incorporated mainly as contextual and constraint-defining elements for the portfolio problem. The dissertation does not seek to provide an exhaustive treatment of sovereign wealth fund governance, legal accountability, or administrative organization. Instead, these dimensions are examined only to the extent that they shape the Fund's investment mandate, operating constraints, and feasible asset-allocation environment.

Third, the dissertation gives limited attention to internal managerial processes and day-to-day operational decision-making. It does not examine internal administrative procedures, informal decision-making practices, or organizational behavior within the institutions involved in managing the Fund. These factors may influence investment outcomes in practice, but they fall outside the central scope of the thesis.

Fourth, political-economy considerations are treated only in a limited way. Although political pressures, competing fiscal priorities, and changing policy preferences are recognized as part of the environment in which sovereign wealth funds operate, they are not modeled explicitly as endogenous determinants of portfolio choice. The thesis therefore abstracts from the full complexity of political decision-making to preserve analytical focus on the asset-allocation problem.

Fifth, quantitative analysis is subject to data limitations. The empirical application relies on publicly available financial-market data and on the investable asset universe specified in the study, rather than on confidential internal portfolio data of the Future Heritage Fund of Mongolia. Likewise, the interpretation of the Fund's mandate and institutional setting is based on publicly available legal, regulatory, and policy materials. The dissertation therefore develops an operational framework for asset allocation under observable sovereign conditions, but it does not claim to reproduce the full internal decision environment of the Fund.

Sixth, the empirical application is based on a stylized asset universe and a single-country case setting. While this is appropriate for evaluating the strategic asset-allocation problem and for comparing the current government-mandated portfolio with benchmark, convex, and sphere-packing alternatives, it limits the immediate generalizability of the numerical allocation results. The broader contribution of the dissertation lies not in any single portfolio outcome, but in the analytical framework it develops for evaluating and improving long-term sovereign asset allocation under uncertainty.

Seventh, the dissertation does not attempt to estimate the full macroeconomic or developmental impact of the Future Heritage Fund of Mongolia in a causal sense. The analysis is centered on portfolio design and strategic asset allocation rather than on ex post economy-wide outcomes such as growth, diversification, employment, or fiscal-stabilization effects. These are important questions, but they require a different research design, broader data, and a longer evaluation horizon.

Eighth, the sphere-packing optimization approach has methodological limitations that should be recognized. Its effectiveness depends on the existence of a sufficiently well-defined and non-empty feasible portfolio region. If return thresholds, variance limits, or other constraints are specified too restrictively, the admissible region may become very narrow or empty, preventing the method from identifying a meaningful robust allocation. In addition, the sphere-packing procedure emphasizes geometric feasibility and internal stability rather than guaranteeing a globally superior portfolio in all return–risk dimensions. The method should therefore be interpreted as a robustness-oriented portfolio design tool that complements, rather than fully replaces, conventional portfolio evaluation techniques.

Finally, the estimated opportunity cost of maintaining a highly conservative and weakly diversified portfolio is based on projected outcomes under the assumptions of the study. It should therefore be interpreted as an analytical estimate of foregone long-term accumulation rather than as a precise forecast of realized future values.

Despite these limitations, the dissertation makes a focused and policy-relevant contribution by addressing one underdeveloped area of the sovereign wealth fund literature: the problem of long-term strategic asset allocation. Its main value lies in showing how the portfolio of the Future Heritage Fund of Mongolia can be evaluated and improved within its current investment mandate, and how overly conservative and weakly diversified asset allocation may impose a measurable long-term cost on sovereign wealth accumulation. The limitations identified above also point to directions for future research, including deeper institutional investigation, richer political-economy analysis, broader cross-country comparison, and the application of the framework using proprietary sovereign portfolio data.

# Chapter 1: Literature Review on SWF Design

## 1.1 Introduction

The preceding chapter established the macroeconomic rationale for sovereign wealth funds (SWFs), particularly in resource-dependent developing economies where revenue volatility, fiscal cyclicality, external vulnerability, and intergenerational savings requirements create a strong case for long-term sovereign wealth accumulation. Building on that foundation, this chapter reviews the evolution of SWFs, their typologies, governance frameworks, investment strategies, and the practical challenges that shape their design and implementation. The purpose of this review is to clarify the conceptual foundations necessary for analyzing the Future Heritage Fund of Mongolia and, more specifically, for examining how macroeconomic objectives can be translated into long-term strategic asset-allocation decisions.

Over the past several decades, SWFs have expanded significantly in number, scale, and strategic purpose. Their growth reflects increasing recognition by governments that temporary, volatile, or exhaustible public revenues often derived from natural-resource rents, fiscal surpluses, or accumulated foreign exchange reserves must be transformed into long-term financial assets capable of supporting fiscal resilience, macroeconomic stability, and intergenerational wealth preservation. This evolution has taken place across diverse economic settings, including hydrocarbon-exporting states, mineral-rich economies, and non-commodity countries seeking to improve the strategic management of public wealth.

The literature identifies several core pillars of effective SWF design, including clearly defined fund types and mandates, credible governance and accountability arrangements, coherent investment strategies, and alignment between sovereign objectives and portfolio decisions. At the same time, it highlights persistent challenges, especially in developing economies, including mandate ambiguity, political interference, limited institutional capacity, and weak analytical foundations for long-term asset allocation under uncertain or unstable risk-return conditions. These unresolved issues are central to the present dissertation.

Accordingly, this chapter synthesizes the relevant literature on sovereign wealth fund evolution, governance, and investment design to identify the key theoretical and practical gap addressed by this study. The central argument is that, although the literature explains why sovereign wealth funds are established and how they should be broadly designed, it provides more limited operational guidance on how macroeconomic objectives should be converted into explicit portfolio constraints and long-term asset-allocation rules. It is this gap that motivates the dissertation's focus on operationalizing the structural-design stage of sovereign wealth fund development in the case of the Future Heritage Fund of Mongolia.

## 1.2 Changing Economic Conditions and the Evolution of Sovereign Wealth Funds

The evolution of sovereign wealth funds (SWFs) has been closely shaped by shifts in global economic conditions, changing fiscal-management strategies, and the growing need for long-term financial resilience. Over the past several decades, SWFs have evolved from a niche policy instrument used by a small number of resource-rich countries into a globally significant class of institutional investors with diverse mandates and operating models. This transformation reflects not only the macroeconomic realities faced by individual countries, but also the broader

restructuring of the international financial system and governments' increasing emphasis on prudent sovereign wealth management.

The earliest SWFs emerged in response to the accumulation of surplus revenues from natural resources, particularly oil and gas. Mid-twentieth-century examples such as the Kuwait Investment Authority and Kiribati's Revenue Equalization Reserve Fund illustrate the original rationale for these funds: stabilizing fiscal outcomes and preserving finite resource wealth for future generations. These early funds were designed to address relatively narrow policy objectives, such as smoothing short-term revenue fluctuations or supporting intergenerational savings, and they operated within comparatively simple institutional frameworks. However, as global oil shocks, exchange-rate volatility, and fiscal pressures intensified from the 1970s onward, governments increasingly recognized the need for more sophisticated institutional mechanisms capable of managing windfall revenues and supporting long-term macroeconomic stability.

By the 1990s, structural changes in the global economy further accelerated both the creation and diversification of SWFs. A growing number of Asian and emerging economies, including Singapore, China, and South Korea, began channeling accumulated foreign exchange reserves into sovereign investment vehicles to enhance returns, strengthen external balance sheets, and support national development strategies. The rise of non-commodity-based SWFs broadened the conceptual boundaries of sovereign wealth by demonstrating that such funds need not be confined to natural-resource exporters; rather, they can emerge wherever sustained fiscal surpluses or reserve accumulation create opportunities for strategic public investment.

The global financial crisis of 2008 marked a major turning point in the evolution of SWFs. As major economies faced severe liquidity shortages and financial instability, many SWFs acted as countercyclical stabilizers by injecting capital into distressed financial institutions, supporting domestic markets, and reinforcing sovereign balance sheets. Their behavior during the crisis strengthened international recognition of SWFs as long-horizon investors capable of absorbing shocks and mitigating systemic risk. This reputation was further reinforced by their relative resilience during subsequent episodes of global financial turbulence and commodity-price volatility.

In the years following the crisis, SWFs expanded further in scale, mandate, and investment sophistication. Many funds diversified into private equity, infrastructure, and global real assets, while others adopted more explicit development-oriented roles aimed at promoting economic diversification, industrial upgrading, or technological innovation. At the same time, greater awareness of sustainability and climate-related risks encouraged the increasing integration of environmental, social, and governance considerations into SWF investment policies, reflecting broader shifts in global investment norms and the rising importance of long-term environmental and social objectives.

Despite this global evolution, substantial disparities persist between SWFs operating in advanced economies and those operating in developing economies. Well-established funds typically benefit from mature governance frameworks, strong analytical capacity, and clearly defined long-term mandates. By contrast, newly created SWFs in developing economies often operate in environments characterized by fiscal volatility, limited technical expertise, political

constraints, and underdeveloped domestic capital markets. These structural conditions weaken their ability to articulate coherent mandates, implement effective governance arrangements, and adopt quantitatively rigorous portfolio strategies.

These differences point directly to the central research problem addressed in this dissertation: how developing economies can design sovereign wealth funds whose macroeconomic roles, institutional structures, and portfolio strategies are coherently aligned with national economic realities, particularly in contexts where risk-return parameters are uncertain and classical optimization models cannot be applied with confidence.

The evolution of SWFs therefore highlights two themes that are central to this study. First, sovereign wealth fund design must remain responsive to changing macroeconomic conditions and long-term development priorities. Second, the sophistication and stability of portfolio management depend critically on institutional capacity and on the availability of reliable financial data. These insights provide the foundation for the following sections of the literature review, which examine SWF typologies, governance frameworks, and the portfolio-optimization challenges faced by developing economies.

### 1.2.1 Growth in the Number of Countries with Sovereign Wealth Funds

The global landscape of sovereign wealth funds (SWFs) has expanded significantly over the past seven decades, reflecting both structural changes in the world economy and the growing recognition of SWFs as strategic instruments for long-term public wealth management. In the early 1950s, only a small number of countries most notably Kuwait in 1953 and Mexico shortly thereafter had established sovereign investment vehicles. Since then, the number of countries operating SWFs has increased markedly. By 2021, approximately 70 countries had created sovereign funds, collectively managed nearly 100 active entities and undertaken more than 450 international investment operations (IE University, 2022). This expansion illustrates the widespread adoption of SWFs as tools for fiscal stabilization, intergenerational savings, development finance, and long-term economic management.

A notable recent trend is the rising interest among African economies in establishing SWFs. According to the African Development Bank (2021), at least 24 African countries have either created or initiated plans to establish sovereign funds, although levels of institutional maturity vary considerably. Hydrocarbon exporting nations such as Nigeria, Libya, Angola, and Algeria capitalize their funds primarily through oil and gas revenues, while countries including Botswana and Zimbabwe have begun developing funds aimed at managing mineral revenues, promoting economic diversification, or accumulating fiscal surpluses. This shift underscores a broader continental recognition that SWFs can function both as buffers against commodity price volatility and as instruments for long-term national development.

Parallel to the geographic expansion of SWFs is the emergence of countries operating multiple sovereign investment vehicles. In several cases, governments have established separate funds to pursue distinct objectives such as stabilization, long-term savings, domestic development, and strategic investment. The United States, for example, administers 23 sovereign or sub-sovereign investment funds, most of which are state level permanent funds; China manages six major national level SWFs; Australia operates five; and the United Arab Emirates oversees multiple emirate level funds, including the Abu Dhabi Investment Authority, Mubadala, and

ADQ (Global SWF, 2022). Such multi fund structures reflect the increasing specialization of sovereign investment strategies and the diversification of national policy priorities.

Table 1-1 summarizes the countries with the largest number of SWFs globally. While the distribution varies widely across countries, the overall trend demonstrates that SWFs have evolved from niche policy instruments employed primarily by rich resource states into mainstream institutional mechanisms adopted by a broad range of advanced, emerging, and developing economies.

**Table 1-1:** Top 10 Countries with the highest Number of Sovereign Wealth Funds

| Rank | Country / Jurisdiction | Number of SWFs | SWF AuM (USD bn) | Number of PPFs | PPF AuM (USD bn) | Total Funds (SWFs + PPFs) | Total AuM (USD bn) |
|---|---|---|---|---|---|---|---|
| 1 | USA | 23 | 319 | 94 | 10,844 | 117 | 11,163 |
| 2 | China | 6 | 3,081 | 3 | 173 | 9 | 3,254 |
| 3 | Australia | 5 | 356 | 15 | 900 | 20 | 1,256 |
| 4 | Canada | 4 | 17 | 16 | 1,698 | 20 | 1,715 |
| 5 | UAE – Abu Dhabi | 4 | 1,266 | 2 | 33 | 6 | 1,299 |
| 6 | Kazakhstan | 4 | 137 | 1 | 31 | 5 | 168 |
| 7 | Ghana | 4 | 2 | 1 | 2 | 5 | 4 |
| 8 | Malaysia | 3 | 115 | 4 | 285 | 7 | 400 |
| 9 | UAE – Dubai | 3 | 379 | 0 | 0 | 3 | 379 |
| 10 | Nigeria | 3 | 4 | 1 | 32 | 4 | 36 |
| 11 | Others | 31 | 17 | 33 | 98 | 64 | 115 |

*Source: Global SWF, 2023*

The continued expansion of SWFs across diverse regions highlights a global recognition of the importance of long-term fiscal stabilization, intergenerational wealth preservation, and strategic investment capacity. For developing economies, this proliferation offers a wide range of institutional models, governance arrangements, and policy experiences that may be adapted to local macroeconomic and institutional conditions. This trend underscores the relevance of the present dissertation, which seeks to develop a macro–institutional and robust portfolio optimization framework suited to newly established sovereign wealth funds in resource dependent developing economies such as Mongolia.

### 1.2.2 Growth in Non-Commodity-Based Sovereign Wealth Funds

Although the earliest sovereign wealth funds (SWFs) were largely established to manage fiscal surpluses derived from natural resources, most notably oil, gas, and minerals, the global development of SWFs has increasingly expanded beyond commodity-based funding sources. As Fry, McKibbin, and O'Brien (2011) observe, while first wave SWFs of the 1950s and 1960s were predominantly created to save and invest commodity windfalls, subsequent decades have witnessed the emergence of funds financed through non-resource channels, including foreign exchange reserves, fiscal surpluses, and proceeds from state owned enterprises. This evolution reflects broader structural changes in the global economy, the deepening of international capital markets, and the growing incorporation of sovereign investment vehicles into national development and wealth management strategies.

Singapore and China exemplify this transition. Both economies accumulated sovereign wealth not through natural resource extraction but through sustained export-led growth, balance of payments surplus, and disciplined fiscal and industrial policies. Singapore's Temasek Holdings and GIC, as well as China's China Investment Corporation (CIC), demonstrate that sovereign wealth can emerge from macroeconomic strength, national savings strategies, and deliberate state-led investment policies. These examples challenge the conventional view of SWFs as instruments exclusive to resource exporters and highlight their increasing relevance across a wider range of economic contexts.

Recent trends indicate not only the proliferation of non-commodity-based SWFs but also significant shifts in their investment orientation. According to IE University (2022), technology accounted for approximately 42 percent of all SWF transactions in 2021, surpassing traditional sectors such as infrastructure and real estate. Lu (2021) similarly notes that many commodity-based SWFs having accumulated substantial reserves are increasingly diversifying toward high-growth sectors, particularly technology and innovation. Norway's Government Pension Fund Global (GPFG), originally established to manage petroleum revenues, exemplifies this transition by 2021, it had become one of the largest shareholders in Apple Inc., with an estimated equity position of approximately USD 27 billion.

Norway's fund remains the largest SWF globally, with assets exceeding USD 1.3 trillion, followed closely by China's sovereign funds, which collectively manage more than USD 1.2 trillion (SWFI, 2022). In 2021, GPFG delivered an annual return of 14.5 percent equivalent to approximately USD 176 billion reflecting its extensive global equity exposure and long-term investment horizon (Taraldsen & Ummelas, 2022). Klesty (2022) reports that the fund holds equity stakes in more than 9,100 companies worldwide, amounting to ownership of roughly 1.4 percent of all listed global equities, and invests across four major asset classes: equities, fixed income, real estate, and renewable energy infrastructure (Norges Bank Investment Management).

Singapore's Temasek and GIC exhibit similar diversification patterns, with significant allocations to technology, financial services, and global private markets (Temasek Foundation, 2021). Other major SWFs, such as the Qatar Investment Authority (QIA), have likewise expanded into strategic global assets, holding substantial positions in multinational firms including Barclays, Porsche, and Credit Suisse (Doherty, 2013). Collectively, these examples highlight the growing emphasis of both commodity and non-commodity-based SWFs on high growth sectors, global equity markets, and long-term strategic investments.

The continued expansion of non-commodity funded SWFs reflects deeper structural changes in the global economy and reinforces the principle that sovereign wealth can be accumulated through diverse financial channels beyond natural resource extraction. This trend holds relevance for developing economies such as Mongolia, where resource dependence coexists with aspirations to build long-term savings and diversify external assets. Understanding the rise and strategic behavior of non-commodity-based SWFs therefore provides essential context for designing future-oriented sovereign investment frameworks especially in environments where risk and return parameters remain uncertain, as is typical for newly established funds.

### 1.2.3 Growth in Sovereign Wealth Fund Governance Models and Principles

As sovereign wealth funds (SWFs) have expanded in number, scale, and global financial influence, their governance models and regulatory frameworks have undergone significant transformation. Early SWFs often operated with limited transparency, loosely defined mandates, and minimal public disclosure. However, growing geopolitical sensitivities, deeper global financial integration, and concerns over the strategic motivations of state-owned cross border investments spurred intense international scrutiny. These developments accelerated global demand for formal governance structures that ensure accountability, legitimacy, and adherence to international best practices.

As sovereign wealth funds (SWFs) have expanded in number, scale, and global financial influence, their governance models and regulatory frameworks have undergone significant transformation. Early SWFs often operated with limited transparency, loosely defined mandates, and minimal public disclosure. However, growing geopolitical sensitivities, deeper global financial integration, and concerns regarding the strategic motivations of state-owned cross border investments generated intensified international scrutiny. These developments accelerated global demand for formal governance structures capable of ensuring accountability, legitimacy, and adherence to internationally accepted standards.

Alhashel (2015) notes that the global shift toward stronger SWF governance was driven largely by host country concerns related to national security, industrial policy, and the possibility that sovereign investments could pursue political rather than commercial objectives. As SWFs assumed increasingly prominent roles in international capital markets, recipient countries particularly advanced economies called for greater clarity, transparency, and explicit assurances that investment decisions were grounded in financial and risk adjusted return considerations.

In response to these pressures, several influential governance frameworks emerged, the most significant of which are the Santiago Principles, formally known as the Generally Accepted Principles and Practices (GAPP). Endorsed in 2008 by the International Working Group of Sovereign Wealth Funds, the Santiago Principles comprise 24 voluntary guidelines intended to promote transparency, sound governance, and prudent investment practices among SWFs.

The principles emphasize:

- Clear legal and institutional foundations,
- Transparent and accountable governance structures,
- Operational independence from political authorities,
- Disclosure of investment objectives and risk management frameworks, and
- Long-term, commercially oriented portfolio management practices.

The adoption of the Santiago Principles marked a pivotal shift in the evolution of SWF governance. The framework enhanced host country confidence in sovereign investment flows while encouraging SWFs to institutionalize practices that strengthen legitimacy, credibility, and organizational independence. Subsequent assessments conducted by the International Forum of Sovereign Wealth Funds (IFSWF) indicate rising levels of compliance, with an increasing number of funds publishing annual reports, governance charters, and asset allocation guidelines.

Parallel to these global initiatives, many SWFs have strengthened their internal governance arrangements by establishing independent boards, layered oversight structures, dedicated risk management units, investment committees, and formal performance evaluation systems. These reforms reflect a growing recognition that effective long-term asset management depends not only on financial expertise but also on institutional integrity, internal controls, and clearly defined decision-making hierarchies.

For developing economies, the evolution of SWF governance principles underscores a critical insight, robust institutional architecture is a prerequisite rather than a secondary consideration for successful fund operation. Weak governance can undermine even the most theoretically sound macroeconomic or investment strategies, whereas strong governance provides the structural foundation necessary for implementing quantitative models, including robust portfolio optimization frameworks designed to operate under uncertain risk–return conditions.

For newly established funds such as the Future Heritage Fund of Mongolia, these governance developments carry important implications. They highlight the necessity of embedding transparency, mandate clarity, accountability mechanisms, and institutional independence from the earliest stages of fund creation, thereby ensuring that quantitative portfolio decisions are supported by a credible, resilient, and policy consistent institutional framework.

### 1.2.4 Investment Strategy and Design

Investment strategy is a central component of sovereign wealth fund (SWF) design because it determines how sovereign wealth is allocated across assets to serve the macroeconomic purpose of the fund. In the SWF context, investment strategy is not merely a financial choice; it is the mechanism through which sovereign objectives such as stabilization, long-term savings, diversification, and wealth preservation are translated into portfolio structure (Gelb et al., 2014; Hamilton & Hepburn, 2014). As your literature already notes, strategic portfolios must remain aligned with macroeconomic objectives, institutionally coherent, globally diversified, and resilient to uncertainty, especially in developing-economy settings where investment strategy must be both theoretically coherent and practically feasible.

International experience shows that SWF investment strategies vary substantially according to the macroeconomic role of the fund, its source of financing, and its institutional mandate. Long-term wealth-preservation strategies, exemplified by Norway's Government Pension Fund Global, emphasize broad international diversification across equities, fixed income, real estate, and renewable energy infrastructure to support intergenerational equity and long-horizon accumulation. Wealth-creation strategies, such as those pursued by Singapore's Temasek and GIC, accept greater risk in search of higher long-term returns through exposure to private equity, technology, alternative assets, and emerging markets. Strategic partnership and development-oriented strategies, observed in funds such as the Qatar Investment Authority, Australia's Future Fund, and several Canadian provincial funds, combine long-horizon investing with broader national aims such as sectoral diversification, strategic international positioning, and development support. Commodity-based diversification strategies, such as those associated with Saudi Arabia's Public Investment Fund and Oman's emerging sovereign funds, channel hydrocarbon revenues into diversified global portfolios to reduce exposure to resource-price volatility and support broader economic diversification. These international

patterns show that the investment strategy of an SWF must be derived from the role the fund is expected to perform rather than from a single generic portfolio template.

At the same time, the sovereign wealth fund literature makes clear that the central issue is not simply the existence of different investment styles, but the difficulty of determining an appropriate strategic asset allocation for sovereign funds. Bodie and Brière explicitly frame SWF asset management as an optimal asset-allocation problem and argue that real-life SWF asset allocations often differ strongly from theoretical allocations. They also emphasize that sovereign financial management is hampered by the lack of aggregate data and by the difficulty of coordinating sovereign wealth management with fiscal policy, monetary policy, and public debt management. In the same paper, they note that sovereign wealth funds tend to invest with low diversification and poor medium-term performance, while research on optimal sovereign wealth management remains comparatively scarce. This is especially important for SWFs because, unlike private institutional investors, they operate under public mandates, sovereign liabilities, and macroeconomic policy responsibilities that make portfolio construction fundamentally different from standard private-fund asset allocation.

This asset-allocation problem is particularly acute in newly established or evolving sovereign wealth funds in developing economies. As your literature already argues, such funds must often formulate long-term strategic asset allocations in environments where risk preferences, expected returns, and historical data are incomplete, unreliable, or entirely undefined. Under these conditions, conventional mean-variance optimization becomes difficult to apply with confidence because the required parameters cannot be estimated reliably. Your own theoretical discussion makes the same point: classical portfolio theory assumes stable expected returns, reliable covariance matrices, long financial histories, and clearly defined risk preferences, assumptions that often break down for early-stage sovereign funds such as the Future Heritage Fund of Mongolia.

The broader SWF design literature reinforces this point. Al-Sayed argues that policymakers still lack adequate roadmaps and models for developing sovereign wealth funds in line with their specific macroeconomic conditions and objectives and treats structural design as the stage where capital allocation, strategy, operational model, and mandate must be aligned with the country's economic realities. Your own literature review similarly identifies a gap in prescriptive and execution-based studies: although governance principles, fiscal rules, and investment strategy are discussed, existing research still does not provide a sufficiently unified framework showing how macroeconomic conditions, institutional constraints, and asset-management methodology should be connected in developing economies.

For the purposes of this dissertation, therefore, investment strategy is important not merely because SWFs invest in different asset classes, but because they face a distinct strategic asset-allocation problem. In resource-dependent developing economies, sovereign wealth funds must preserve public wealth, reduce exposure to volatile resource cycles, and support long-term resilience while operating under public-management constraints, conservative mandates, and uncertain financial conditions. Under such circumstances, the core problem is not simply how to choose an investment strategy in general, but how to determine an admissible and robust long-term strategic asset allocation for a sovereign fund whose objectives are sovereign and

public rather than purely commercial. This is the sense in which the present dissertation moves beyond general discussion of SWF investment strategy and concentrates on the specific problem of long-term asset allocation in the Future Heritage Fund of Mongolia.

### 1.2.5 Wealth Creation Versus Wealth Preservation

A fundamental consideration in the design of a sovereign wealth fund (SWF) is whether its strategic orientation prioritizes wealth creation or wealth preservation. These two orientations reflect distinct macroeconomic priorities, institutional conditions, and risk–return expectations, and they play a decisive role in shaping the fund's mandate, governance architecture, and portfolio design. Understanding this distinction is particularly important for developing economies, where the economic rationale for establishing an SWF must be translated into an investment strategy that is both conceptually coherent and operationally feasible.

Wealth creation strategies seek to expand the value of national assets by pursuing higher expected returns while accepting greater exposure to investment risk. Investors adopting this approach typically tolerate significant short to medium term fluctuations in asset values in exchange for long-term capital appreciation (Jennings, 2021). Within the SWF context, wealth creation aligns closely with mandates that emphasize economic diversification, structural transformation, and development finance objectives commonly pursued by countries aiming to reduce dependence on volatile commodity revenues and accelerate long-term growth (Al-Hassan et al., 2018). Such strategies often involve substantial allocations to equities, private markets, infrastructure, and technology sectors, reflecting the pursuit of higher growth opportunities, frequently through international investments (Lu et al., 2009).

In contrast, wealth preservation strategies focus on maintaining the real value of public wealth over time, ensuring that the proceeds of exhaustible resources are converted into a stable and enduring financial legacy for future generations. This strategic orientation is central to intergenerational savings funds, where the objective is not rapid accumulation but the protection of national wealth from market volatility, fiscal shocks, and long-term economic uncertainty (van den Bremer, van der Ploeg & Wills, 2016). Wealth preservation funds therefore tend to adopt more conservative portfolios, emphasizing broad global diversification and lower risk asset classes, including investment grade fixed income and stable equity exposures. Sovereign pension reserve funds follow similar principles, prioritizing long horizon solvency, liquidity, and financial sustainability (Dreassi, Miani & Paltrinieri, 2017).

These orientations have direct implications for portfolio construction:

- Wealth creation mandates favor higher risk, return seeking allocations often concentrated in equities, private equity, venture capital, infrastructure, and emerging markets.

- Wealth preservation mandates emphasize conservative and diversified portfolios focused on capital protection, liquidity provision, and volatility reduction, typically grounded in fixed-income instruments and broad market equity exposure.

For developing economies, the distinction between these two strategic orientations is particularly salient. Countries experiencing high macroeconomic volatility, shallow financial

markets, or weak institutional capacity often require wealth preservation mechanisms to stabilize fiscal outcomes and accumulate credible financial buffers. Conversely, economies pursuing structural transformation or diversification may adopt wealth creation strategies to catalyze investment, promote domestic development, and capture global growth opportunities. The appropriate strategic orientation therefore depends on a careful assessment of macroeconomic vulnerabilities, institutional maturity, and national development priorities.

Critically, the wealth creation wealth preservation dichotomy intersects with the central portfolio optimization challenge addressed in this dissertation. Newly established SWFs in developing economies frequently lack reliable return histories, well defined risk preferences, or stable covariance structures, making it difficult to design investment strategies consistent with either orientation using classical mean–variance techniques. Under such conditions, robust optimization approaches capable of operating under deep parameter uncertainty provide a more suitable analytical basis for identifying stable long-term portfolios that remain aligned with the fund's strategic purpose.

### 1.3 Challenges of Designing of SWFs in Macroeconomic and Development Contexts

Although sovereign wealth funds (SWFs) offer clear macroeconomic benefits such as stabilizing fiscal revenues, supporting intergenerational savings, and providing buffers against external shocks, their successful design and implementation present multiple challenges, particularly in developing economies. These challenges arise from constraints in decision-making, institutional capacity, political dynamics, and the integration of SWFs into broader macroeconomic development strategies. Understanding these issues is essential for constructing a conceptual model that aligns SWF design with national macroeconomic objectives.

#### 1.3.1 Challenges Affecting Sovereign Wealth Fund Development

Although sovereign wealth funds (SWFs) are designed to stabilize economies, support fiscal sustainability, and provide long-term savings for future generations, their effective establishment and operation remain constrained by several structural and institutional challenges. These challenges are particularly acute in resource dependent developing economies, where institutional capacity, policy coherence, and data reliability are often limited. Understanding these constraints is essential for developing a conceptual model that aligns SWF design with macroeconomic realities, institutional environments, and long-term investment requirements.

A central challenge lies in the initial decision-making process surrounding whether a country should establish an SWF and what form the fund should take. As Das, Mazarei, and Van der Hoorn (2009) note, policymakers must assess whether the country possesses adequate resource revenues or foreign exchange buffers to sustain a fund without compromising essential fiscal needs. In many developing economies, limited technical capacity, unclear mandates, and insufficient strategic planning hinder this early-stage decision making. Moreover, as Global SWF (2021) highlights, developing countries often struggle to articulate the purpose, mission, and operational parameters of a fund, resulting in weak alignment between the SWF's design and the country's macroeconomic conditions.

A second challenge concerns political influence and governance quality, which can significantly affect how SWFs are capitalized, managed, and utilized. Political actors may exert pressure over investment choices, capital injections, or withdrawals, especially when SWFs invest in large foreign or domestic entities with geopolitical or strategic implications (Hildebrand, 2008). In environments with fragile governance structures, this political interference may undermine long-term savings objectives, increase the risk of misallocation, and weaken public trust. While governance frameworks such as the Santiago Principles promote transparency and accountability, their implementation varies widely across countries.

Third, countries often experience challenges related to the integration of SWFs into broader macroeconomic frameworks. As Le Borgne and Medas (2007) argue, an SWF is most effective when embedded within a coherent fiscal framework one that clearly defines the rules for savings, withdrawals, and investment. Yet many countries fail to establish this integration, leading to inconsistencies in fund mandates, unclear withdrawal rules, and misalignment between SWF operations and fiscal or monetary policy. This misalignment reduces the SWF's ability to stabilize revenues or support long-term development objectives.

Finally, developing economies face challenges related to technical and analytical capacity, particularly in portfolio construction. Traditional portfolio optimization models rely on stable expected returns, reliable covariance matrices, and well-defined risk return targets. However, new SWFs in developing economies rarely possess long historical data or stable financial markets from which to derive these parameters. This lack of reliable data renders classical models ill-posed and constrains a country's ability to design robust long-term portfolios a challenge this dissertation directly addresses through its robust optimization framework.

Together, these challenges underscore the need for a structured, theory-based model capable of guiding countries in designing SWFs that are both economically justified and institutionally feasible. They form the analytical foundation for the conceptual framework developed in the subsequent sections of this dissertation.

### 1.3.2 Challenges in Decision-Making When Developing Sovereign Wealth Funds

One of the earliest obstacles to policymakers' faces is determining whether a sovereign wealth fund is the appropriate instrument for achieving their macroeconomic goals. Das, Mazarei, and Van der Hoorn (2009) emphasize that governments must first assess whether the country possesses sufficient and stable international reserves, whether it can manage balance of payments pressures, and whether a fund can meaningfully contribute to long-term development. These decisions are especially difficult for developing economies where fiscal pressures are acute and technical expertise is limited.

Global SWF (2021) notes that governments in countries such as Papua New Guinea often struggle to define a clear mandate or long-term mission for their funds due to limited financial expertise and capacity. Inadequate clarity in purpose increases the likelihood of political interference and misalignment between fund design and economic realities. While some authors argue that developing economies could model their SWFs after successful examples such as Norway (Wills, Senbet and Simbanegavi, 2016), such replication is rarely feasible due to differences in economic structure, revenue sources, institutional capacity, and policy priorities.

### 1.3.3 Political and Economic Influence in Managing Sovereign Wealth Funds

Political dynamics present a second major challenge to effective SWF design and governance. Decisions on capital allocation, withdrawals, and strategic investments may be influenced by political agendas, especially when SWFs invest in foreign companies or domestic projects with strategic implications (Hildebrand, 2008). This political influence complicates the fund's ability to operate with long-term discipline and increases the risk that investment choices are driven by short-term political considerations rather than macroeconomic objectives.

In the Gulf region, SWFs hold symbolic and political significance in addition to economic importance. As Hanieh (2018) argues, they form part of broader transformations in the political economy, reflecting shifts in global power and financial capitalism. Their growing influence also reflects regional efforts to demonstrate modernity and economic leadership (Clark and Monk, 2012). However, these symbolic roles may expose funds to political pressures that affect governance and strategy.

Dixon and Monk (2016) further observe that both financial and political obstacles can impede SWF development, particularly in countries where governance systems are still evolving. To build legitimacy and reduce risk mismanagement, SWFs require strong institutional frameworks characterized by independence, transparency, and accountability attributes that are not always present in developing economies.

Economic conditions also shape SWF performance. Strong GDP growth, export performance, and investment inflows enhance the financial base of an SWF (Divya and Devi, 2014), whereas inflation or economic stagnation reduce contributions to the fund (Batayneh, Al Salamat and Momani, 2021). These macroeconomic constraints further complicate fund design by influencing both revenue inflows and long-term sustainability.

### 1.3.4 Integration of Sovereign Wealth Funds in Macroeconomic Development

A third, and arguably the most critical, challenge concerns the effective integration of sovereign wealth funds (SWFs) into national macroeconomic development strategies. Le Borgne and Medas (2007) emphasize that SWFs yield their greatest benefits when embedded within a coherent fiscal framework and explicitly linked to national budgets, long-term savings plans, and broader economic development objectives. Yet, in many countries, SWFs are established without a comprehensive assessment of macroeconomic constraints or fiscal realities, resulting in institutional misalignment and weakened policy effectiveness.

Insufficient integration manifests in several ways:

- Misalignment between the SWF mandate and the country's economic structure, such as establishing a stabilization fund in economies where revenue volatility is limited or creating a development fund without complementary industrial policies.
- Inconsistent savings and withdrawal rules, which undermine the intertemporal purpose of the fund and reduce its ability to smooth fiscal cycles or accumulate long-term assets.
- Poor coordination with fiscal and monetary policies, limiting the fund's capacity to support macroeconomic stability or avoid unintended economic distortions.
- Unclear or unimplementable investment strategies, particularly in developing economies where data limitations prevent the application of classical portfolio optimization frameworks.

These challenges reveal a broader conceptual gap: while the literature frequently discusses the macroeconomic roles, governance principles, and operational models of SWFs, it offers limited guidance on how fund design should be analytically aligned with national macroeconomic objectives especially in resource dependent developing economies. The absence of such alignment often leads to suboptimal fund performance, inconsistencies between fiscal policy and investment mandates, and weakening of the SWF's contribution to long-term development.

This gap underscores the rationale for the integrated macro–institutional and robust optimization framework developed in this dissertation, which seeks to operationalize the linkages between macroeconomic structure, institutional design, and long-horizon portfolio strategy.

### 1.3.5 Challenges in Strategic Asset Allocation for Sovereign Wealth Fund

Strategic asset allocation constitutes one of the most difficult and least operationalized dimensions of sovereign wealth fund (SWF) design. While the broader literature explains why sovereign wealth funds are established and how their mandates and governance structures should be defined, it provides more limited guidance on how an appropriate long-term portfolio should be determined, especially in developing economies. This challenge is important because strategic asset allocation is not a secondary technical detail; it is the mechanism through which sovereign objectives are translated into long-term investment structure.

A first challenge arises from the fact that SWFs differ fundamentally from private investment funds. Sovereign wealth funds must pursue public objectives such as stabilization, intergenerational savings, reserve diversification, and long-term fiscal resilience, while operating under sovereign mandates, legal constraints, governance structures, and broader macroeconomic policy responsibilities. As Bodie and Brière argue, sovereign wealth management is not simply an asset-only portfolio problem, but part of a broader sovereign balance-sheet and asset–liability management problem involving fiscal surplus variability, foreign and domestic liabilities, and coordination with fiscal policy, monetary policy, and public debt management. They further note that real-world SWF allocations often diverge sharply from theoretical ones, and that research on optimal sovereign wealth management remains relatively scarce.

A second challenge is the persistent gap between macroeconomic purpose and operational portfolio design. Existing SWF literature has developed rich analysis of macroeconomic rationale, including resource dependence, revenue volatility, fiscal cyclicality, and intergenerational wealth preservation, as well as institutional design issues such as governance quality, transparency, and mandate clarity. However, these strands have often evolved in parallel rather than being brought together at the point of long-term strategic asset allocation. Your own literature review already identifies this as a major weakness in existing models: they provide valuable insights into governance and fiscal integration, but insufficient guidance on portfolio design under uncertainty and limited institutional capacity. Al-Sayed's framework is particularly relevant here. It explicitly identifies structural design as the stage where capital allocation, governance strategy, portfolio management, and withdrawal policy should be specified, yet leaves that stage largely conceptual rather than fully operationalized.

A third challenge concerns parameter uncertainty. Newly established or evolving SWFs in developing economies must often formulate long-term strategic asset allocations in environments where expected returns, covariance structures, and effective risk preferences are incomplete, unstable, or weakly specified. Your own literature review correctly notes that this makes conventional mean–variance optimization difficult to apply in a defensible way, because the required parameters cannot be estimated with confidence. More broadly, the portfolio literature shows that even small estimation errors can produce unstable allocations with concentrated asset weights and poor out-of-sample performance, which is especially problematic for sovereign funds with long horizons and public responsibilities.

A fourth challenge is low diversification and weak medium-term performance in actual sovereign portfolios. Bodie and Brière note that empirical studies of SWF investment behavior frequently find concentration in large foreign firms, low diversification, and poor medium-term performance. This is particularly important for the present dissertation because it suggests that the strategic asset-allocation problem is not abstract. Poorly structured or excessively conservative sovereign portfolios may fail to support the long-term accumulation objective of savings-oriented funds. In developing economies, where public-management environments often encourage caution, administrative simplicity, and limited diversification, this can create a persistent gap between the legal purpose of the fund and its actual long-term investment performance.

A fifth challenge is the role of governance and operating model in shaping the feasible portfolio. The literature indicates that clearer separation between mandate-setting, strategic oversight, and operational execution is associated with stronger portfolio discipline and more coherent diversification. Al-Sayed's comparative analysis shows, for example, that changes in operating model can materially affect a fund's ability to control capital, diversify its portfolio, and align asset allocation with macroeconomic objectives. Likewise, your own analysis of the Future Heritage Fund of Mongolia argues that the current institutional arrangement remains conservative and transitional, implying that investment policy must emphasize admissibility, resilience, and gradual diversification rather than abrupt risk expansion. In this sense, strategic asset allocation in an SWF cannot be separated from the public-management environment within which it is implemented.

Taken together, these challenges show that strategic asset allocation is a central research problem for sovereign wealth funds. The difficulty lies not only in choosing between asset classes, but in determining an admissible long-term portfolio for a public fund operating under sovereign objectives, macroeconomic volatility, institutional constraints, and uncertain parameters. This problem is especially acute in resource-dependent developing economies, where savings-oriented funds must preserve wealth across generations while remaining conservative enough to satisfy legal, governance, and operational requirements. It is precisely this strategic asset-allocation problem that motivates the quantitative framework developed later in this dissertation.

### 1.3.6 Existing Knowledge Gaps in Sovereign Wealth Fund Development

Despite the growing body of literature on sovereign wealth funds (SWFs), several important knowledge gaps remain concerning their design, institutional configuration, and integration into

macroeconomic and financial policymaking. These gaps are particularly relevant for developing economies, where institutional capacity is limited, financial data are unstable, and long-term investment strategies must be formulated under uncertainty. Identifying these gaps is essential for constructing the conceptual framework advanced in this dissertation.

A central gap relates to the integration of SWFs into a country's macroeconomic development strategy. While scholars such as Das, Mazarei, and Van der Hoorn (2009) and Wills, Senbet, and Simbanegavi (2016) emphasize the need for clear roadmaps to guide the establishment of funds, the literature provides limited practical guidance on how SWFs should be aligned with macroeconomic conditions, fiscal frameworks, and long-term savings needs. Existing studies highlight important considerations such as determining whether a country has sufficient reserves to capitalize a fund, assessing the agreement between the central bank and the government, and clarifying fiscal objectives such as stabilization or savings but they stop short of offering a structured model for linking these macroeconomic variables to specific SWF designs. Notably absent is guidance on how portfolio allocation decisions should reflect a country's macroeconomic vulnerabilities or intertemporal objectives.

A second major gap involves the lack of technical expertise and analytical capacity in developing economies regarding the establishment and management of SWFs. Several studies point to challenges in determining whether an SWF is preferable to alternative institutional arrangements, in identifying where assets should be invested, and in deciding which macroeconomic objectives should be prioritized (Das, Mazarei, and Van der Hoorn, 2009; Martínek, 2021). In many cases, the absence of reliable financial data, insufficient modelling capacity, and limited experience with long-term institutional investing hinder the development of sound asset allocation frameworks. This lack of technical expertise also impairs the ability of policymakers to design funds that are analytically consistent with macroeconomic realities. Furthermore, the literature provides few tools that policymakers can use to systematically evaluate whether a proposed fund is appropriate for a given economic environment or how it should be governed and capitalized.

A third and critical gap concerns the absence of robust models and well-developed theory on the institutional design of SWFs, particularly frameworks that link macroeconomic conditions to governance structures, mandates, and portfolio strategies. The existing literature discusses governance principles (Al-Hassan et al., 2018), the economic rationale for establishing SWFs (Eldredge, 2019), optimal asset allocation from a theoretical perspective (Bodie and Brière, 2013), and issues of regulation (Barbary and Bortolotti, 2011). However, there is a notable lack of integrated models that explain how macroeconomic indicators, institutional constraints, and investment objectives should collectively shape the design of an SWF. Even fewer studies address the unique challenge faced by newly established SWFs in developing economies namely, that risk and return parameters are undefined or unreliable, making classical portfolio optimization models inapplicable.

These gaps highlight the need for a comprehensive framework that connects macroeconomic rationale, institutional design, and robust portfolio optimization in a unified manner. Addressing this need, the present dissertation develops an integrated macro–institutional and

robust optimization model that is specifically suited to the realities of developing economies with weak institutional capacity and high parameter uncertainty.

## 1.4 Theory

This dissertation is grounded in an integrated theoretical framework linking public wealth management, institutional design, portfolio choice, and robust optimization. These theories jointly explain why sovereign wealth funds (SWFs) are established, how their long-term objectives should be protected, and how strategic asset allocation can be designed under uncertainty.

The first theoretical foundation concerns the management of natural-resource revenues as public wealth. The Permanent Income Hypothesis explains why exhaustible resource revenues should be converted into long-term financial assets for future generations, while Dutch disease theory highlights the macroeconomic risks of excessive domestic absorption of commodity revenues. Tax smoothing theory further supports the use of SWFs to reduce fiscal procyclicality and stabilize public expenditure in resource-dependent economies (Friedman, 1957; Barro, 1979; Corden & Neary, 1982; Davis et al., 2001; Frankel, 2012).

The second foundation is institutional and agency theory. SWFs require clear mandates, accountability, and sufficient operational independence to protect long-term public wealth from short-term political or administrative pressures. These governance conditions are important for strategic asset allocation because weak institutions may result in overly conservative, unstable, or politically influenced investment decisions (Debroux, 2010; De Jonge, 2015; Nowacki, Monk & Decoster, 2020).

The third foundation is modern portfolio theory, which provides the basic rationale for diversification and long-term strategic asset allocation. However, classical mean–variance models depend on stable return estimates, covariance structures, and risk preferences, assumptions that are often weak for newly established SWFs in developing economies (Markowitz, 1952; Luenberger, 1998; Fabozzi et al., 2007).

For this reason, the dissertation also draws on robust optimization theory, which supports portfolio design under parameter uncertainty. Convex and sphere-packing approaches are used to identify feasible and internally stable allocations that are less dependent on precise risk–return estimates. Thus, the theoretical logic of the dissertation proceeds from public wealth preservation to institutional protection, to strategic portfolio design, and finally to robust optimization under uncertainty. This integrated framework guides the analysis of the Future Heritage Fund of Mongolia.

### 1.4.1 Public Wealth, Resource Dependence, and the Rationale for Sovereign Savings

Natural-resource revenues constitute a form of public wealth that must be managed across time rather than treated solely as current fiscal income. In resource-dependent economies, large commodity export receipts generate foreign-exchange inflows and fiscal revenues, but they also expose the economy to volatility, external shocks, and the risk of overdependence on exhaustible resources. Sovereign wealth funds emerge as institutional mechanisms for converting these temporary and unstable revenue streams into long-term financial assets.

Three related theories explain this rationale. First, Dutch disease theory shows that large resource inflows can appreciate the real exchange rate, weaken non-resource tradable sectors, and intensify economic concentration. By investing part of resource revenues abroad, sovereign wealth funds can help reduce domestic absorption pressures and support macroeconomic balance (Corden & Neary, 1982; Davis et al., 2001; van der Ploeg & Venables, 2013). Second, the Permanent Income Hypothesis argues that exhaustible natural-resource revenues should be transformed into income-generating financial assets so that their benefits are shared across present and future generations (Friedman, 1957; Barnett & Ossowski, 2003). Third, tax smoothing theory supports saving part of volatile commodity revenues during boom periods to reduce fiscal procyclicality and preserve expenditure stability over time (Barro, 1979; Talvi & Végh, 2005; Frankel, 2012).

Taken together, these theories provide the public wealth foundation for the Future Heritage Fund of Mongolia. Mongolia's mineral dependence, exposure to commodity cycles, and intergenerational savings objective justify the use of a sovereign wealth fund to transform exhaustible resource revenues into diversified long-term financial assets. This rationale establishes why sovereign savings are necessary; the subsequent theoretical sections explain how institutional design and strategic asset allocation determine whether that savings objective can be effectively achieved.

### 1.4.2 Institutional and Agency Foundations of Sovereign Wealth Fund Asset Allocation

Macroeconomic justification alone does not ensure that a sovereign wealth fund achieves its long-term purpose. Because SWFs manage public wealth on behalf of citizens, their effectiveness depends critically on the institutional arrangements that protect the fund's mandate, govern decision-making authority, and align investment practice with long-term national objectives.

Institutional theory explains that sovereign wealth funds are shaped by the legal, political, and regulatory environments in which they operate. Their mandates, governance structures, reporting systems, and operational practices reflect both domestic institutional conditions and international standards of good governance (Debroux, 2010; De Jonge, 2015). For developing economies, this is especially important because weak institutions may produce mandate ambiguity, political interference, inconsistent funding rules, and unstable investment strategies. By contrast, clear legal foundations, transparency, accountability, and operational independence strengthen the capacity of an SWF to pursue a coherent long-term asset-allocation policy (Nowacki, Monk & Decoster, 2020; Martínek, 2021).

Agency theory complements this perspective by examining the separation between ownership and control in sovereign wealth management. Citizens are the ultimate owners of national resource wealth, while governments, governing boards, and asset managers act as agents responsible for preserving and investing that wealth. This structure creates potential conflicts of interest, information asymmetry, and short-term political incentives that may undermine intergenerational savings objectives (Jensen & Meckling, 1976; Panda & Leepsa, 2017). In the SWF context, such agency problems may appear through politically motivated withdrawals, excessive administrative caution, or investment decisions that are not fully aligned with the fund's long-term mandate.

These institutional and agency considerations are directly relevant to strategic asset allocation. A fund with weak governance or limited operational independence may be unable to maintain a disciplined long-term portfolio, even when its macroeconomic purpose is clearly defined. Conversely, a well-designed governance framework enables investment strategy to reflect the fund's true horizon, risk tolerance, and savings objective. Clear mandates, independent oversight, transparent reporting, audit mechanisms, and professional delegation therefore function not only as governance safeguards, but also as preconditions for credible long-term portfolio design.

Fund independence affects strategic asset allocation by shaping whether investment decisions can remain aligned with the fund's long-term mandate rather than short-term political or administrative pressures. A savings-oriented sovereign wealth fund with weak operational independence may be pushed toward excessively liquid, highly conservative, or frequently revised allocations, even when its intergenerational purpose justifies a longer investment horizon and broader diversification. By contrast, a fund with clearly delegated investment authority and protection from ad hoc intervention is better positioned to maintain a disciplined strategic asset allocation, define stable risk tolerance, and rebalance portfolios consistently over time.

Table 1-2 summarizes the basic principle–agent relationships relevant to sovereign wealth fund governance.

**Table 1-2:** Principal–Agent Relationships in Sovereign Wealth Fund Governance

| Principal | Agent |
|---|---|
| Citizens (ultimate owners of national wealth) | Government and SWF governing bodies |
| Government | SWF management, boards, external asset managers |

*Source: Adapted from Jensen & Meckling (1976)*

Institutional and agency theories therefore provide the governance foundation of this dissertation. They explain why the transition from public resource wealth to long-term financial assets requires not only macroeconomic rationale, but also an institutional structure capable of protecting strategic asset allocation from short-term pressures. This argument is particularly relevant for the Future Heritage Fund of Mongolia, whose long-term savings function depends on a governance framework that supports disciplined, transparent, and professionally implemented asset management.

### 1.4.3 Modern Portfolio Theory and the Strategic Asset-Allocation Problem

Modern Portfolio Theory provides the financial foundation for strategic asset allocation by explaining how diversification can improve the balance between expected return and risk. Markowitz's mean–variance framework identifies efficient portfolios by either minimizing risk for a given expected return or maximizing expected return for a given level of risk (Markowitz, 1952). For sovereign wealth funds, this principle is central because long-term public wealth must be allocated across assets in a way that supports capital preservation, accumulation, and intergenerational objectives.

In the SWF context, strategic asset allocation is not simply a technical investment choice. It is the mechanism through which the fund's macroeconomic purpose and institutional mandate are translated into a long-term portfolio structure. Savings-oriented funds require portfolios consistent with long investment horizons, while stabilization-oriented funds require greater liquidity and lower risk exposure. Accordingly, portfolio design must reflect fund objectives, legal constraints, liquidity needs, and governance capacity rather than relying on a generic private-investor model.

However, classical mean–variance theory depends on assumptions that are often weak in newly established sovereign wealth funds in developing economies. It requires reliable estimates of expected returns, stable covariance structures, and clearly defined risk preferences. In practice, these conditions may not hold where financial histories are limited, macroeconomic conditions are volatile, and institutional mandates are still evolving. Under such circumstances, even small estimation errors can produce unstable and highly concentrated portfolios with weak practical relevance (Chopra & Ziemba, 1993).

Thus, Modern Portfolio Theory establishes the importance of diversification and strategic asset allocation, but it does not fully resolve the portfolio-design problem faced by sovereign wealth funds operating under deep uncertainty. This limitation creates the need for more robust optimization approaches, which are examined in the following subsection.

### 1.4.4 Robust Optimization and Geometric Portfolio Stability under Uncertainty

The limitations of classical mean–variance portfolio theory create the need for more uncertainty-sensitive approaches to strategic asset allocation. Robust optimization theory addresses this problem by designing portfolios that remain feasible and resilient when expected returns, risk estimates, or other model parameters are uncertain. Rather than relying on a single set of point estimates, robust optimization evaluates portfolio decisions across a range of plausible conditions and seeks allocations that are less vulnerable to estimation error (Ben-Tal & Nemirovski, 1998; Goldfarb & Iyengar, 2003).

This perspective is particularly relevant for newly established sovereign wealth funds in developing economies. Such funds often operate with evolving mandates, limited investment histories, and uncertain long-term risk–return parameters. In these circumstances, the central portfolio problem is not only how to identify an efficient allocation, but also how to construct a stable and admissible allocation that remains consistent with the fund's mandate under uncertainty. Robust optimization therefore provides a stronger theoretical basis for sovereign strategic asset allocation than models that depend entirely on precise parameter forecasts.

Within this dissertation, robustness is further interpreted through a geometric stability perspective. Sphere-packing and design-centering approaches examine the internal structure of the feasible portfolio region by identifying allocations that remain sufficiently distant from binding constraint boundaries. The associated robustness radius measures the extent to which portfolio weights or parameters may vary before the allocation becomes infeasible. A portfolio located more centrally within the admissible region is therefore interpreted as more structurally stable than one positioned near its limits.

This geometric interpretation is well suited to sovereign wealth funds because their portfolios must satisfy institutional, legal, and risk-management constraints over long horizons. For the Future Heritage Fund of Mongolia, the sphere-packing approach provides a way to assess not only whether a portfolio is feasible, but also whether it is robustly feasible under uncertainty. It complements traditional portfolio analysis by emphasizing resilience, internal stability, and consistency with a conservative public investment mandate.

Robust optimization and geometric portfolio stability therefore form the final theoretical foundation of this dissertation. They extend modern portfolio theory from the search for efficient allocations toward the construction of uncertainty-resilient strategic asset allocations, providing the conceptual basis for the convex and sphere-packing methods applied later in the empirical analysis.

### 1.4.5 Integrated Theoretical Logic of the Dissertation

The theories reviewed above form a single analytical logic for this dissertation. Public wealth and intertemporal resource-management theories explain why exhaustible mineral revenues should be transformed into long-term financial assets rather than consumed immediately. In the Mongolian context, this provides the rationale for the Future Heritage Fund as a mechanism for intergenerational savings, macroeconomic resilience, and preservation of national wealth.

Institutional and agency theories then explain why this public wealth objective requires a credible governance framework. Clear mandates, accountability, operational independence, and professional delegation are necessary to prevent short-term pressures from distorting long-term asset-management decisions. These theories therefore connect the purpose of the Fund with the institutional conditions required for disciplined strategic asset allocation.

Modern portfolio theory provides the financial basis for diversification and long-term asset allocation, but its classical assumptions are difficult to apply when expected returns, covariance structures, and risk preferences are uncertain. Robust optimization theory, including the sphere-packing approach, addresses this limitation by focusing on feasible, stable, and uncertainty-resilient portfolio structures.

Taken together, the theoretical logic of the dissertation proceeds through four connected steps: resource wealth must be preserved; preservation requires institutional protection; institutional purpose must be translated into strategic asset allocation; and strategic asset allocation under uncertainty requires robust optimization. This integrated framework provides the theoretical foundation for analyzing and improving the long-term asset-management strategy of the Future Heritage Fund of Mongolia.

## 1.5 Knowledge Gaps in Existing Portfolio Optimization

Modern portfolio theory, beginning with Markowitz's mean–variance framework, provides the classical foundation for strategic asset allocation by identifying efficient risk–return combinations (Markowitz, 1952; Luenberger, 1998). However, its practical reliability depends heavily on accurate estimates of expected returns and covariance matrices. A substantial literature shows that estimation error, structural breaks, and regime shifts can produce unstable and highly concentrated portfolios, weakening their usefulness for long-term institutional investors (Michaud, 1989; Chopra & Ziemba, 1993).

This limitation is particularly important for sovereign wealth funds. Unlike unconstrained private investors, SWFs operate under legal mandates, risk limits, allocation rules, liquidity considerations, and public accountability requirements. Their portfolio problem is therefore not only to identify an efficient allocation, but to determine a feasible and stable strategic asset allocation that remains consistent with institutional constraints and long-term sovereign objectives. This issue is especially relevant for newly established funds in developing economies, where return targets, risk tolerances, and reliable financial parameters may be only weakly defined.

Existing robust portfolio optimization literature addresses uncertainty through uncertainty sets, worst-case formulations, distributional robustness, and related methods (Ben-Tal & Nemirovski, 1998; Goldfarb & Iyengar, 2003). These approaches significantly improve on classical mean–variance optimization by reducing sensitivity to parameter error. Yet much of this literature focuses on modifying model inputs, objective functions, or probability assumptions rather than on the geometric structure of the feasible portfolio region itself.

For mandate-driven institutional portfolios, this geometric perspective is important. Portfolios located close to the boundary of the feasible region may satisfy constraints formally, but they can quickly become infeasible after small changes in returns, risks, or allocation weights. In contrast, portfolios located more centrally within the admissible region may offer greater structural stability. Despite this practical relevance, the literature has given more limited attention to methods that explicitly construct interior, robustly feasible allocations under relaxed institutional constraints and parameter uncertainty.

Accordingly, the key gap addressed in this dissertation is the lack of a portfolio framework that combines benchmark-consistent feasibility restoration, tolerance-based admissibility under uncertain return, risk, and budget conditions, and geometric identification of internally stable allocations within the feasible set.

This gap is especially relevant for sovereign wealth funds such as the Future Heritage Fund of Mongolia, where strategic asset allocation must be not only diversified and return-aware, but also feasible, institutionally consistent, and robust under uncertainty. The dissertation responds to this need by applying convex and sphere-packing-based methods to construct long-term portfolio allocations that emphasize feasibility, stability, and robustness rather than relying solely on extremal efficient-frontier solutions.

### 1.6 Chapter summary

This chapter reviewed the literature relevant to the strategic asset-allocation problem of sovereign wealth funds, with particular emphasis on resource-dependent developing economies. The discussion established an integrated theoretical logic for the dissertation. Public wealth and intertemporal resource-management theories explain why exhaustible natural-resource revenues should be transformed into long-term financial assets. Institutional and agency theories show that this objective requires clear mandates, accountability, and governance arrangements capable of protecting long-term investment discipline. Modern portfolio theory provides the basis for diversification and strategic asset allocation, while robust optimization addresses the limitations of conventional portfolio models under parameter uncertainty.

The review further showed that sovereign wealth fund research has developed substantial insights into macroeconomic rationale, governance design, and investment principles, but these strands are often treated separately. Existing studies provide less operational guidance on how macroeconomic objectives and institutional constraints should be translated into a long-term strategic asset-allocation framework, particularly for newly established funds in developing economies.

This gap is directly relevant to Mongolia. The Future Heritage Fund of Mongolia operates in a context of mineral dependence, revenue volatility, evolving institutional arrangements, and the need to preserve resource wealth across generations. In such a setting, the central problem is not only why a sovereign wealth fund is needed, but how long-term portfolio should be designed in a way that is institutionally feasible and robust under uncertainty.

Accordingly, this dissertation focuses on improving the strategic asset allocation of the Future Heritage Fund of Mongolia. The next chapter presents the conceptual framework and methodological structure through which macroeconomic diagnostics, institutional interpretation, and robust portfolio optimization are combined to address this problem.

# Chapter 2: Research Methodology

## 2.1 Introduction

This chapter presents the research methodology and analytical framework adopted in this dissertation. As established in Chapter 1, the central purpose of the study is to examine how the strategic asset allocation of the Future Heritage Fund of Mongolia can be improved within its current investment mandate. The dissertation focuses on the asset-allocation problem of a sovereign wealth fund operating in a resource-dependent developing economy, where public-management conditions, limited diversification, and uncertainty in long-term investment parameters make portfolio design especially difficult.

Unlike earlier draft versions of the thesis, this dissertation does not employ a comparative empirical case-study design based on Kuwait, Singapore, or Qatar. These international cases are used only in the literature review and conceptual discussion to illustrate broader principles of sovereign wealth fund design and investment strategy. The empirical application of the study is limited to Mongolia and, more specifically, to the Future Heritage Fund of Mongolia. This narrower focus allows the dissertation to examine in greater depth the macroeconomic setting, mandate environment, and strategic asset-allocation problem of the Fund.

The chapter is structured to support this single-country application. It first outlines the philosophical position of the research and explains the overall research approach and design. It then presents the conceptual framework that guides the dissertation and clarifies how macroeconomic diagnosis, institutional interpretation, and portfolio analysis are connected within the study. In this dissertation, the framework is not treated as a purely theoretical construct. Rather, it provides the analytical sequence through which the strategic asset-allocation problem of the Future Heritage Fund of Mongolia is examined and operationalized.

Because the research problem concerns macroeconomic conditions, sovereign policy objectives, institutional arrangements, and long-horizon portfolio design, the study relies exclusively on secondary data. These include official Mongolian policy documents, Bank of Mongolia publications, legal and regulatory texts, international institutional reports, macroeconomic datasets, and financial market data. This research design is appropriate because the dissertation examines sovereign wealth fund asset allocation as a macroeconomic, institutional, and portfolio-management problem rather than as a question of individual attitudes or behaviour.

Overall, this chapter establishes the methodological foundation of the dissertation. It explains how the research problem is approached, how the conceptual framework is applied, and how the evidence is organized for the empirical analysis that follows. The next chapter applies this framework to the Future Heritage Fund of Mongolia by examining the macroeconomic and institutional setting of the Fund, evaluating its current strategic asset allocation, and comparing it with alternative portfolio structures to assess how its long-term performance may be improved.

## 2.2 Thesis Philosophy

The research philosophy of this dissertation defines the assumptions about how knowledge is generated, interpreted, and validated throughout the study. Research philosophy is important

because it shapes how the research problem is understood, how evidence is interpreted, and how conclusions are drawn.

This dissertation adopts a mixed philosophical stance, combining interpretivism in the macroeconomic and institutional components with a more objective realist perspective in the quantitative portfolio-analysis component. This approach is appropriate because the dissertation addresses two related but methodologically distinct dimensions of sovereign wealth fund design.

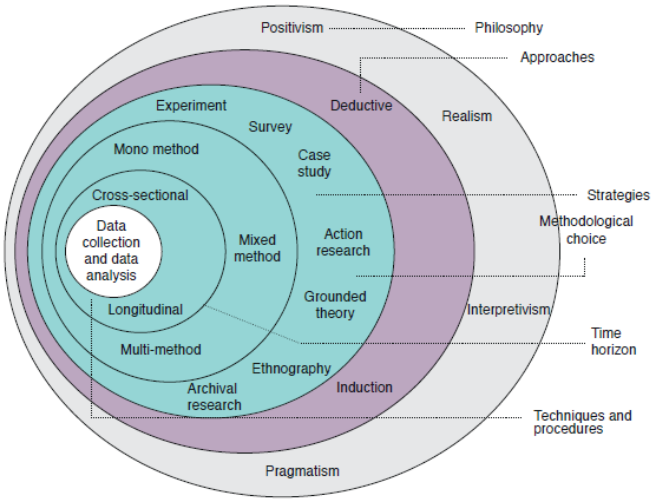
On the one hand, the analysis of macroeconomic conditions, governance arrangements, legal structure, and institutional capacity is interpretive in nature. The design of a sovereign wealth fund is not determined by numerical indicators alone, but also by the political, historical, and institutional context in which the fund operates. For this reason, interpretivism is appropriate for examining how Mongolia's macroeconomic vulnerabilities and institutional constraints shape the mandate and governance structure of the Future Heritage Fund of Mongolia.

On the other hand, the portfolio-analysis component is based on formal quantitative relationships among returns, risk, and portfolio constraints. The application of convex optimization and sphere-packing methods assumes that financial data can be examined through mathematical models. In this part of the study, a realist perspective is appropriate because portfolio feasibility, diversification, and robustness are treated as phenomena that can be analyzed through observable data and formal structure.

From an axiological perspective, the dissertation recognizes that the researcher's judgment influences the selection of indicators, institutional criteria, and modelling assumptions. However, these choices are guided by transparent reasoning, established academic literature, and secondary data sources. This helps maintain analytical rigor while acknowledging that institutional analysis remains context sensitive.

Overall, this combined philosophical position is appropriate for the dissertation because it allows the macroeconomic and institutional dimensions of sovereign wealth fund design to be analyzed in a contextual manner, while supporting the portfolio component through rigorous quantitative methods.

**Figure 2-1:** Research Onion Model




*Source: Saunders, Lewis, and Thornhill (2009)*

## 2.3 Thesis Approach and Design

A research approach defines how evidence is processed, interpreted, and transformed into conclusions. It provides the logical pathway through which a study moves from data to conceptual understanding. In methodological literature, three broad approaches are commonly identified: deductive, inductive, and abductive.

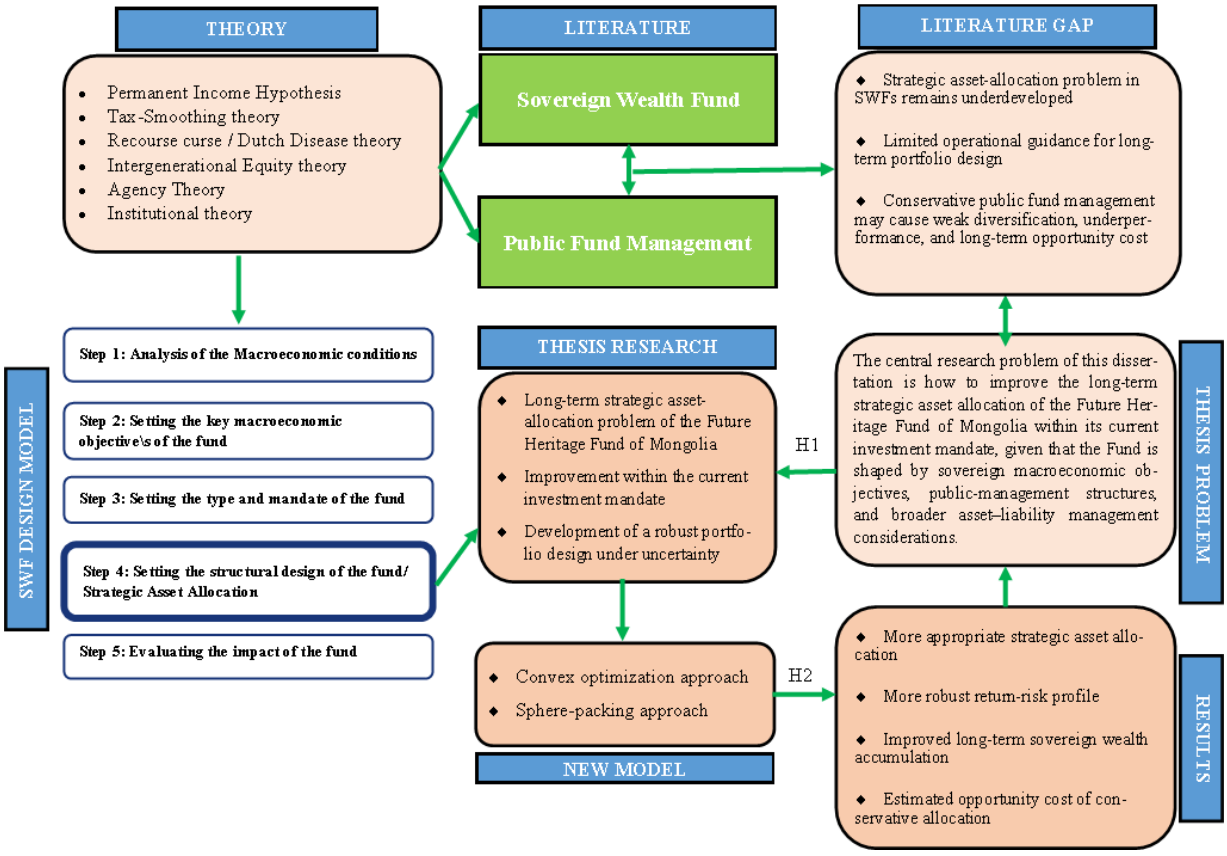
This thesis adopts an inductive approach. This is appropriate because the study develops conceptual and practical insights from documentary evidence, macroeconomic indicators, institutional arrangements, and financial market data rather than testing a pre-formulated general theory of sovereign wealth fund asset allocation. The analysis begins with the macroeconomic and institutional setting of the Future Heritage Fund of Mongolia and proceeds toward the construction of a more appropriate long-term strategic asset-allocation framework under conditions of uncertainty.

Three considerations support this choice. First, the existing literature does not provide a sufficiently developed operational framework for improving the long-term strategic asset allocation of sovereign wealth funds in resource-dependent developing economies. Second, the research relies entirely on secondary sources, including government reports, legal and policy documents, macroeconomic datasets, and financial market data. Third, the framework developed in this thesis must reflect the specific institutional and economic realities of Mongolia rather than rely on assumptions derived from more mature sovereign wealth fund systems.

Alongside this inductive logic, the thesis employs exploratory research design. This is appropriate because the strategic asset-allocation problem of sovereign wealth funds remains underdeveloped in the literature, particularly in contexts where sovereign objectives, public-management constraints, and long-term portfolio design must be considered simultaneously. Existing studies have focused mainly on macroeconomic rationale, governance, and institutional design, while providing more limited operational guidance on long-term asset allocation under uncertainty. An exploratory design therefore allows the study to generate insight from documentary analysis and empirical portfolio evaluation while remaining responsive to Mongolia's specific context.

The overall research design of the dissertation is presented in Figure 2-2. The figure shows the logical progression from the theoretical foundations of sovereign wealth funds and the broader literature on sovereign wealth funds and public fund management to the identification of the central research gap. That gap is defined as the insufficient development of the strategic asset-allocation problem in the sovereign wealth fund literature, particularly under conditions of uncertainty and public-management constraints. The figure further shows how the dissertation builds on Al-Sayed's sovereign wealth fund design model, with particular emphasis on the structural-design stage, to frame the core research problem of the thesis: how to improve the strategic asset allocation of the Future Heritage Fund of Mongolia within its current investment mandate.

**Figure 2-2:** Research Design of the Dissertation




*Source: Ph.D. Candidate (2026)*

After identifying the research gap, the design locates the dissertation's methodological contribution in the application of convex and sphere-packing portfolio approaches. These methods are used to construct and compare alternative long-term portfolio allocations for the Future Heritage Fund of Mongolia. The figure therefore links the theoretical and institutional foundations of the study to its empirical portfolio-analysis stage and to its main expected outputs, including improved strategic asset allocation, a more robust return-risk profile, improved long-term asset-management outcomes, and the estimation of opportunity cost associated with maintaining a highly conservative portfolio.

The overall design of the thesis is therefore best described as a mixed qualitative-quantitative research design. The qualitative component interprets macroeconomic indicators, policy documents, governance structures, and institutional arrangements through documentary and contextual analysis. The quantitative component addresses the central asset-allocation problem of the thesis by comparing the current government-mandated portfolio with alternative benchmark, convex, and sphere-packing portfolios. In this way, the study combines contextual institutional analysis with formal portfolio evaluation.

This integrated design reflects the multidisciplinary nature of sovereign wealth fund research. It allows the thesis to move systematically from macroeconomic diagnosis and institutional interpretation to the practical problem of long-term strategic asset allocation. Accordingly, the dissertation does not treat macroeconomic analysis, public fund management, and portfolio construction as separate fields of inquiry, but as sequential and connected elements contributing

to the central question of how the strategic asset allocation of the Future Heritage Fund of Mongolia can be improved within its current investment mandate.

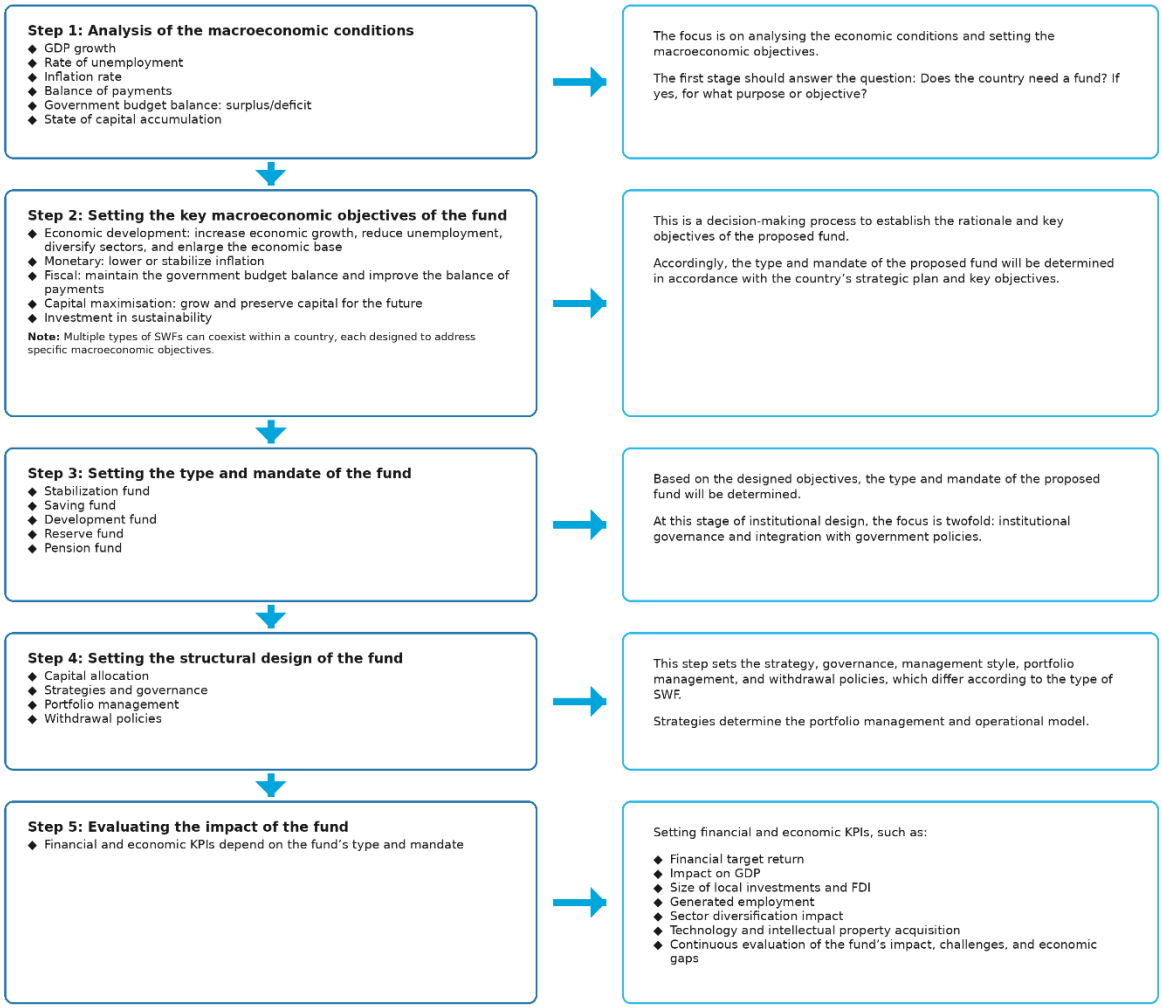
## 2.4 Conceptual Model

This sub-section develops the conceptual model that guides the establishment, governance, and long-term asset management of sovereign wealth funds (SWFs) in resource dependent developing economies. Building directly on the theoretical foundations and knowledge gaps identified in literature review, the model integrates macroeconomic diagnostics, institutional design principles, and robust quantitative portfolio optimization into a single sequential framework. Its purpose is to provide a structured and operational roadmap through which policymakers can determine whether a country should establish an SWF, how the fund should be legally and institutionally configured, and how strategic asset allocation can be constructed when conventional risk–return parameters are undefined.

The conceptual model responds to three major deficiencies in the existing literature: (i) the absence of a coherent mechanism for linking macroeconomic conditions to the decision to create an SWF; (ii) limited guidance on designing institutional mandates, governance structures, and accountability mechanisms suitable for low-capacity environments; and (iii) the near complete lack of quantitative portfolio design frameworks appropriate for newly established SWFs operating under deep uncertainty. To address these gaps, the proposed model expands classical public-sector decision frameworks and aligns them with insights from institutional theory, agency theory, and modern robust optimization.

The model is presented conceptually in Figure 2-3, which illustrates the five-step sequence through which SWF design and evaluation should proceed. Each step corresponds to a specific analytical task: assessing macroeconomic fundamentals; defining fund objectives; establishing governance and mandate structures; specifying operational and investment rules; evaluating financial and developmental performance; and, uniquely introduced in this thesis, applying a robust quantitative optimization layer that integrates convex and geometric (sphere-packing) methods to determine stable long-term asset allocations when risk and return parameters are uncertain.

**Figure 2-3:** Sovereign Wealth Fund Establishment Process




*Source: Al-sayed (2023)*

Together, these five steps form a comprehensive methodological framework capable of aligning national macroeconomic vulnerabilities, institutional capacity constraints, and long-horizon investment requirements into a unified SWF design process. The proposed model ensures that strategic asset allocation decisions are grounded not only in fiscal and macroeconomic logic but also in governance feasibility and quantitative robustness elements that are essential for the successful operation of newly established SWFs such as the Future Heritage Fund of Mongolia. The subsections that follow (2.4.1 – 2.4.5) elaborate each step in detail and demonstrate how they collectively constitute an actionable roadmap for SWF design in developing economies.

### 2.4.1 Step 1: Analysis of the Economic Condition

Step 1 of the conceptual model (Figure 2-3) begins with a systematic assessment of a country's macroeconomic conditions to determine whether the establishment of a sovereign wealth fund (SWF) is economically justified and to clarify the specific purpose such a fund should serve. This diagnostic step forms the analytical foundation of the conceptual framework, as it links macroeconomic vulnerabilities and long-term fiscal needs to the eventual design of institutional structures and strategic asset allocation rules.

The analysis evaluates a range of structural and cyclical indicators including GDP growth trends, sectoral composition, unemployment dynamics, inflation pressures, fiscal balance patterns, exchange-rate volatility, external-balance positions, commodity revenue dependency, and absorptive capacity of domestic capital markets. Collectively, these indicators reveal the degree of exposure to macroeconomic volatility, the sustainability of current revenue streams, and the scale of intertemporal savings required to support future fiscal stability. For resource dependent developing economies, particular emphasis is placed on the volatility of commodity revenues, pro-cyclical fiscal behavior, and the vulnerability of the domestic economy to external shocks.

Within the broader SWF literature, such macroeconomic diagnostics are central to determining both whether a country requires an SWF and what type of SWF is appropriate. Commodity-exporting economies, for example, often justify the creation of stabilization or savings funds to smooth revenue volatility and preserve wealth for future generations, whereas economies with large foreign reserve balances may prioritize reserve investment funds to enhance returns on excess reserves. In all cases, the economic diagnosis clarifies not only the rationale for establishing a fund but also the constraints that should shape its mandate, governance structure, and long-term investment strategy.

For newly established funds such as the Future Heritage Fund of Mongolia the need for a rigorous macroeconomic assessment is especially critical. Mongolia's persistent dependence on mineral exports, exposure to global commodity cycles, fiscal pro-cyclicality, and long-term intergenerational savings requirements directly influence the fund's role and design. Step 1 therefore ensures that the SWF's mandate is not conceptually imposed but rather analytically derived from the country's macroeconomic realities, thereby aligning the fund's purpose with structural economic needs and long-term development objectives.

Through this systematic diagnostic process, Step 1 provides the essential input for all subsequent stages of the conceptual model. It identifies why an SWF is needed, what macroeconomic vulnerabilities it must address, and which policy goals stabilization, savings, development, or hybrid functions should be embedded in its design.

### 2.4.2 Step 2: Establishing the Key Objectives of the Fund

Step 2 of the conceptual model (Figure 2-3) focuses on defining the core objectives of the sovereign wealth fund (SWF) based on the macroeconomic conditions identified in Step 1. Once the economic diagnosis clarifies the country's exposure to revenue volatility, long-term savings requirements, and structural development constraints, policymakers must determine the precise purpose the SWF is intended to serve. This stage is critical because the fund's mandate ultimately shapes its legal structure, governance framework, investment strategy, and operational rules. Within the broader sovereign wealth fund literature, four principal objectives are commonly identified: monetary stabilization, fiscal stabilization, economic development, and intergenerational savings. The relevance of each objective depends on a country's macroeconomic structure, fiscal capacity, institutional environment, and long-term policy priorities.

Monetary stabilization objectives aim to mitigate macroeconomic instability arising from large capital inflows or commodity-driven export revenues. Resource-rich economies often

experience exchange-rate appreciation, inflationary pressures, and volatility in domestic liquidity during commodity booms. Sovereign wealth funds can help reduce these pressures by channeling a portion of export revenues into foreign financial assets, thereby limiting excessive capital inflows into the domestic economy.

Fiscal stabilization objectives address the volatility of government revenues associated with commodity price fluctuations. By accumulating savings during periods of high resource revenues and drawing on those assets during downturns, stabilization funds allow governments to maintain more predictable fiscal policies and reduce procyclical public spending.

Development objectives focus on promoting long-term economic diversification and strengthening domestic productive capacity. In countries where financial markets are shallow or private investment is insufficient, sovereign capital may be deployed to support strategic sectors, infrastructure development, and industrial transformation. Development-oriented sovereign wealth funds therefore seek to expand the economy's productive base and reduce structural dependence on natural resources.

Intergenerational savings objectives respond to the exhaustible nature of natural resource revenues. Because mineral and hydrocarbon resources are finite, governments must decide how to allocate these revenues across generations. Savings-oriented sovereign wealth funds transform temporary resource income into diversified financial assets that can generate sustainable income for future generations.

The central task in Step 2 is therefore to determine which of these objectives or which combination of them best aligns with the country's macroeconomic conditions and long-term national priorities. Some countries establish single-purpose funds focused exclusively on stabilization or savings, while others adopt multi-purpose sovereign wealth funds that integrate several objectives within a unified institutional structure.

For newly established funds in developing economies, such as the Future Heritage Fund of Mongolia, this stage is particularly important. Mongolia faces multiple structural challenges, including high dependence on mineral exports, exposure to global commodity price cycles, limited economic diversification, and the need to accumulate long-term savings from exhaustible natural resources. These conditions imply that the sovereign wealth fund must balance stabilization and savings objectives while also supporting broader economic resilience.

By linking the macroeconomic diagnosis in Step 1 with the institutional mandate of the fund, Step 2 ensures that the purpose of the sovereign wealth fund is derived from objective economic conditions rather than short-term political considerations. This alignment provides the foundation for the subsequent stages of the conceptual framework, including the design of governance structures and the development of robust portfolio optimization strategies.

### 2.4.3 Step 3: Establishing the Type and Mandate of the SWF

Step 3 of the conceptual model (Figure 2-3) translates the macroeconomic conditions identified in Step 1 and the objectives defined in Step 2 into a concrete institutional structure by specifying the appropriate type of sovereign wealth fund (SWF) and defining a clear legal mandate. This stage establishes the institutional architecture that governs how the fund operates, how it

interacts with fiscal and monetary frameworks, and how it pursues its long-term policy objectives. Because the mandate determines governance arrangements, investment rules, accountability mechanisms, and the fund's role within the broader public finance system, this step forms the institutional foundation upon which all subsequent operational and investment decisions depend.

The first component of this step involves the establishment of a legally empowered and operationally autonomous institutional entity. A sovereign wealth fund must be created through legislation or an equivalent legal framework that clearly defines its objectives, sources of capital, deposit and withdrawal rules, reporting requirements, and accountability structure. Effective institutional design requires several core governance principles. These include: (i) a clear separation between political oversight and day-to-day investment management; (ii) transparent and rule-based mechanisms governing deposits into and withdrawals from the fund; (iii) independent auditing and supervisory oversight; and (iv) sufficient operational autonomy to enable professional investment management to be insulated from short-term political pressures. These governance principles are widely recognized in international practice and are reflected in global standards such as the Santiago Principles, which emphasize transparency, mandate clarity, and strong institutional controls as prerequisites for credible sovereign wealth fund management.

The second component of Step 3 concerns ensuring that the type of sovereign wealth fund and its mandate are consistent with the country's fiscal, monetary, and development policies. The determination of whether the fund should function primarily as a stabilization fund, a long-term savings fund, a development fund, or a hybrid structure must follow directly from the macroeconomic diagnosis conducted in Step 1. Countries facing significant commodity revenue volatility may prioritize stabilization functions to smooth fiscal cycles, while economies dependent on exhaustible natural resources may emphasize long-term savings objectives to preserve wealth for future generations. In other cases, governments may adopt development-oriented mandates to support economic diversification and infrastructure investment. Regardless of the specific mandate, the institutional framework of the sovereign wealth fund must complement existing fiscal rules, budgetary frameworks, and monetary policy objectives. Such alignment ensures that the fund operates as an integrated component of the national macroeconomic architecture rather than as an isolated financial institution.

For newly established funds in developing economies, including the Future Heritage Fund of Mongolia, this stage is particularly important. Mongolia's economy is characterized by significant exposure to mineral revenue volatility, procyclical fiscal dynamics, and the long-term challenge of converting finite resource revenues into sustainable financial wealth. These structural conditions suggest the need for a hybrid institutional mandate that combines stabilization and intergenerational savings objectives. Implementing such a mandate requires institutional arrangements capable of balancing short-term liquidity needs with long-term investment horizons while maintaining strong governance safeguards and policy credibility.

Step 3 therefore ensures that the institutional foundation of the sovereign wealth fund is derived from the country's macroeconomic realities and long-term development priorities. By establishing a clear legal mandate and governance structure, this stage provides the institutional

platform required for the subsequent implementation of investment policies and portfolio management strategies, including the robust portfolio optimization framework developed later in this dissertation.

In asset-management terms, institutional independence is necessary to preserve the consistency of strategic asset allocation. The public authorities responsible for ownership and oversight should determine the Fund's purpose, broad risk tolerance, and accountability framework, while professional investment bodies should implement portfolio strategy within those boundaries. This separation reduces the risk that short-term fiscal needs or changing political preferences alter the portfolio in ways that are inconsistent with the Fund's long-term savings objective.

### 2.4.4 Step 4: Establishing the Structural Design of the Fund

Step 4 of the conceptual model (Figure 2-3) focuses on the determination of the long-term strategic asset allocation of the sovereign wealth fund. Whereas Step 3 defines the type, mandate, governance structure, and operational environment of the Fund, Step 4 translates these institutional and macroeconomic conditions into a long-term portfolio structure. In this dissertation, strategic asset allocation is treated as the central operational problem of sovereign wealth fund design, because it is through portfolio structure that sovereign objectives are ultimately implemented in practice.

The need for a dedicated portfolio-design stage arises from the limitations of existing sovereign wealth fund frameworks. Although earlier steps establish the macroeconomic rationale of the Fund, identify its long-term objectives, and clarify its institutional and governance structure, they do not by themselves provide a rigorous method for determining how the Fund should allocate its assets over the long run. This gap is especially important in newly established sovereign wealth funds in developing economies, where expected returns, risk preferences, and covariance structures are often weakly specified or unstable.

The strategic asset-allocation problem is particularly acute in resource-dependent developing economies. In such settings, sovereign wealth funds commonly face short and noisy financial time series, structural macroeconomic volatility, evolving institutional mandates, limited analytical capacity, and relatively shallow domestic financial systems. Under these conditions, classical mean–variance optimization becomes difficult to apply defensibly because it depends heavily on precise parameter estimation and stable statistical relationships among asset returns. In practice, even relatively small estimation errors may produce unstable portfolio allocations, extreme asset weights, and poor out-of-sample performance. Consequently, a more robust and institutionally grounded approach to portfolio design is required.

To address this challenge, Step 4 introduces a quantitative framework that combines robust optimization with a sphere-packing-based geometric approach to portfolio stability. Robust optimization provides a systematic method for managing parameter uncertainty by defining uncertainty sets around unknown model inputs and selecting portfolio allocations that perform satisfactorily across a range of plausible parameter configurations. Rather than relying on a single estimated value of expected returns or covariances, the robust framework identifies portfolios that remain feasible and stable under adverse or uncertain conditions. This approach

reduces the sensitivity of portfolio weights to estimation error and provides a more disciplined decision framework for sovereign wealth funds operating with limited data.

Complementing this approach, the sphere-packing method introduces an additional geometric measure of portfolio stability. This method evaluates the robustness of the feasible portfolio region by identifying the largest Euclidean sphere that can be inscribed within the admissible set of portfolios. The radius of this sphere provides a quantitative measure of resilience, indicating the extent to which portfolio parameters or weights may vary before the allocation violates the underlying constraints. In contrast to conventional robust optimization, which focuses mainly on local stability around estimated parameters, the sphere-packing approach provides a broader geometric interpretation of portfolio resilience and internal stability.

Importantly, Step 4 integrates the insights generated in the earlier stages of the conceptual model. The macroeconomic diagnostics established in Step 1 influence the investment horizon, external orientation, and long-term purpose of the Fund. The sovereign objectives identified in Step 2 determine whether savings, stabilization, development, or hybrid functions dominate the investment logic. The institutional design defined in Step 3 specifies the mandate, governance constraints, liquidity requirements, and legal boundaries within which portfolio choices must be made. Through this integration, the robust optimization framework transforms macroeconomic and institutional conditions into implementable strategic asset-allocation decisions.

The outputs of Step 4 include several key elements. First, the framework generates a more appropriate and robust long-term strategic asset allocation that does not depend entirely on fragile parameter estimates. Second, it produces portfolios that remain feasible under adverse market conditions and parameter uncertainty. Third, it provides a transparent and reproducible allocation methodology consistent with institutional accountability and risk management. Fourth, it supports a long-term risk-budgeting structure compatible with governance constraints typically observed in emerging economy institutions. Finally, the sphere-packing method introduces a measurable robustness indicator that can help assess the internal stability of alternative long-term allocations.

By incorporating Step 4 in this way, the conceptual model moves beyond a descriptive macro–institutional framework and becomes an operational methodology for sovereign wealth fund asset allocation. The robust portfolio-optimization framework serves as the quantitative engine through which macroeconomic objectives and institutional constraints are translated into implementable long-term investment strategies. In doing so, it addresses a critical gap in the existing sovereign wealth fund literature and offers a scientifically grounded approach to long-term portfolio construction for newly established sovereign wealth funds such as the Future Heritage Fund of Mongolia.

### 2.4.5 Step 5: Evaluating the Impact of the Fund

Step 5 of the conceptual model focuses on the evaluation of the sovereign wealth fund. Whereas the previous steps establish the macroeconomic rationale of the Fund, define its objectives, clarify its institutional environment, and determine its strategic asset allocation, the final step examines whether the Fund is achieving its intended purpose in financial, macroeconomic, and institutional terms. Evaluation is essential because a sovereign wealth fund is not only a legal

or financial entity, but also a public policy instrument whose effectiveness must be assessed against its long-term objectives.

The evaluation of the Fund should be conducted using a combination of financial and policy-relevant indicators. At the financial level, this includes long-term return performance, return-risk characteristics, diversification, capital preservation, and growth in net asset value. These indicators assess whether the Fund's strategic asset allocation supports its long-term accumulation objective and whether the portfolio remains consistent with the sovereign mandate established in the earlier stages of the model.

At the macroeconomic and policy level, evaluation should also consider whether the Fund contributes to broader sovereign objectives such as long-term savings, fiscal resilience, and intergenerational wealth preservation. For savings-oriented sovereign wealth funds, this means assessing whether the Fund is effectively transforming exhaustible natural-resource revenues into durable financial wealth over time. For funds with stabilization features, evaluation should also consider whether the Fund helps reduce vulnerability to fiscal and external shocks.

This step is particularly important because the success of a sovereign wealth fund cannot be judged solely by short-term safety or nominal asset preservation. A highly conservative and weakly diversified portfolio may appear prudent in the short run yet still fail to support the Fund's dominant long-term objective if it generates persistently low accumulation outcomes. For this reason, evaluation should consider not only the risks of diversification, but also the long-term opportunity cost of excessive conservatism.

The final step therefore functions as both a performance-assessment mechanism and a feedback mechanism. It allows policymakers to determine whether the current mandate, governance structure, and portfolio strategy remain consistent with the purpose of the Fund, and whether adjustments are required in its strategic asset allocation or institutional design. In this sense, evaluation closes the model by linking long-term outcomes back to the earlier stages of macroeconomic diagnosis, objective setting, institutional design, and portfolio construction.

Taken together, Step 5 ensures that the sovereign wealth fund remains a transparent, accountable, and policy-consistent instrument of long-term public wealth management. In the context of the Future Heritage Fund of Mongolia, this means evaluating whether the Fund's strategic asset allocation is effectively supporting long-term sovereign wealth accumulation within its current investment mandate.

### 2.5 Macro - Institutional and Robust Portfolio Optimization Model for SWFs

This subsection presents the integrated macro–institutional and robust portfolio optimization model that constitutes the operational core of the conceptual framework developed in this dissertation. Building on the macroeconomic rationale and theoretical foundations discussed earlier in this chapter, and responding directly to the knowledge gap identified in the previous section, the proposed framework integrates macroeconomic diagnostics, institutional design principles, robust strategic asset allocation, and evaluation into a unified analytical structure tailored to the realities of developing economies. The model recognizes that sovereign wealth fund design is inherently multidimensional: macroeconomic conditions, policy objectives, governance structures, portfolio construction, and performance evaluation must be treated as

interconnected components of a coherent national wealth management system rather than as independent policy choices.

**Figure 2-4:** Macro–Institutional Design and Robust Portfolio Optimization Model for Sovereign Wealth Funds


*Source: Adapted from Al-Sayed (2023) and extended by Ph. D candidate (2026)*

The framework begins with a systematic diagnostic assessment of the country's macroeconomic environment. This stage evaluates structural characteristics such as resource dependence, commodity revenue volatility, fiscal imbalances, exchange-rate pressures, and long-term savings requirements. The diagnostic process establishes both the economic justification for creating a sovereign wealth fund and the broad functional orientation that the fund should adopt. In contrast to earlier models, which often treat macroeconomic conditions only implicitly, the proposed framework places macroeconomic diagnostics at the front end of the design process. This ensures that institutional and investment decisions are grounded in the structural economic realities facing the country.

Based on this macroeconomic diagnosis, the model proceeds to the identification of the fund's core policy objectives. Depending on the country's economic structure and strategic priorities, these objectives may include stabilization, long-term savings, development, reserve investment, or a hybrid combination of these functions. Once these objectives are clearly defined, the institutional-design stage specifies the governance architecture of the sovereign wealth fund. This stage determines the legal mandate of the fund, reporting and accountability mechanisms, the degree of operational independence, oversight structures, and the alignment of the fund with broader fiscal, monetary, and development policy frameworks.

The next stage of the model is the robust portfolio-optimization and strategic asset-allocation stage. This is the principal extension introduced in this dissertation. While earlier macro–institutional frameworks identify the structural-design stage as the point at which portfolio management should be specified, they do not provide a sufficiently operational method for determining a long-term portfolio under uncertainty. In response to the knowledge gap identified earlier, the model developed here treats strategic asset allocation as a central design problem rather than as a downstream technical exercise. Within the framework, robust

optimization functions as the quantitative engine that translates macroeconomic objectives and institutional constraints into stable and uncertainty-resilient long-term portfolio allocations. This addition is especially important for newly established sovereign wealth funds operating under limited data availability, uncertain risk-return parameters, and volatile macroeconomic conditions.

To ensure accountability and long-term effectiveness, the model also incorporates a systematic evaluation stage. This final stage assesses the performance and impact of the sovereign wealth fund using measurable financial, macroeconomic, and policy-relevant indicators. These may include long-term portfolio performance, return-risk characteristics, fiscal-stabilization outcomes, contributions to economic diversification, and broader sovereign wealth accumulation. Importantly, evaluation is treated not merely as an ex-post reporting exercise, but as an embedded feedback mechanism that supports institutional learning, policy refinement, and continuous improvement.

As illustrated in Figure 2-4, the proposed framework represents an extended and operationalized version of the macro–institutional design model developed by Al-Sayed (2023). While Al-Sayed's framework provides an important foundation for linking macroeconomic conditions to institutional design decisions, the model proposed in this dissertation advances that approach by explicitly incorporating a robust portfolio-optimization stage between institutional design and evaluation. This extension addresses the specific gap identified in the previous section: the absence of a sufficiently developed operational method for determining long-term strategic asset allocation in sovereign wealth funds under uncertainty.

Overall, the proposed model provides a comprehensive representation of the institutional and economic factors that shape sovereign wealth fund development in resource-dependent developing economies. By explicitly linking macroeconomic diagnostics, policy objectives, governance structures, robust portfolio design, and evaluation within a unified analytical framework, the model offers policymakers a structured approach to designing sovereign wealth funds that are both institutionally feasible and financially resilient. In doing so, it extends existing macro–institutional frameworks and provides a context-appropriate roadmap for the establishment and long-term management of sovereign wealth funds in emerging economies.

### 2.5.1 Macroeconomic Conditions and Indicators

Macroeconomics examines the performance, structure, and behavior of an entire economy and therefore provides the fundamental analytical basis for determining whether a sovereign wealth fund (SWF) is necessary and what role it should serve. As Tsai (2019) explains, macroeconomic analysis evaluates aggregate dynamics such as national income, productive capacity, employment, and price stability factors that collectively shape a country's long-term economic trajectory. This perspective differs from microeconomic analysis, which focuses on individual firms or households. Because sovereign wealth funds operate at the national level and are designed to enhance macroeconomic stability, strengthen fiscal sustainability, and accumulate intergenerational wealth, their establishment must be grounded in a clear understanding of macroeconomic fundamentals.

Accordingly, the first component of the proposed conceptual model requires a systematic assessment of national economic conditions to identify both the necessity and feasibility of

establishing a sovereign wealth fund. This assessment relies on a set of macroeconomic indicators that reflect the strength, vulnerability, and long-term sustainability of the economy. Key indicators include GDP growth dynamics, unemployment trends, inflation stability, balance-of-payments conditions, fiscal balance, and capital accumulation patterns. Together, these variables reveal whether an economy faces structural vulnerabilities such as revenue volatility, fiscal imbalances, excessive dependence on resource exports, or external sector pressures.

These indicators play a diagnostic role in determining the appropriate design and mandate of a sovereign wealth fund. For example, sustained GDP growth combined with fiscal surpluses may justify the establishment of long-term savings or development funds, while economies exposed to commodity price volatility may require stabilization funds to smooth fiscal cycles. Conversely, economies with limited domestic investment capacity or shallow financial markets may benefit from establishing externally diversified sovereign investment funds. By anchoring SWF design in macroeconomic diagnostics, policymakers ensure that sovereign wealth funds serve clearly defined national objectives and respond directly to the structural realities of the economy.

### 2.5.2 Gross Domestic Product Growth

Gross Domestic Product (GDP) growth is a key indicator of macroeconomic performance, measuring the rate at which the total value of goods and services produced within an economy expands over time (Djapou Fouthe & Ndedi, 2017). Sustained GDP growth reflects expanding productive capacity, rising national income, and improved economic dynamism, making it one of the most widely used indicators of long-term economic development (Divya & Devi, 2014). The literature identifies several factors that influence GDP growth, including the availability of natural resources, human capital development, technological progress, and the accumulation of physical and financial capital (Singh & Sharma, 2016).

In resource-rich economies such as Kuwait and Qatar, GDP dynamics are strongly influenced by hydrocarbon production. Oil and gas exports generate substantial fiscal revenues and foreign exchange inflows, which drive rapid economic expansion during commodity booms but expose the economy to severe contractions when global energy prices decline. This cyclical volatility highlights one of the principal rationales for establishing sovereign wealth funds. By saving a portion of resource revenues during boom periods and investing them in diversified financial assets, SWFs help stabilize national income, smooth government expenditure, and convert temporary resource windfalls into sustainable long-term wealth.

Beyond natural resource revenues, macroeconomic theory suggests that strong and stable GDP growth is more likely when economies maintain adequate foreign exchange reserves, stable inflation, balanced external accounts, and an enabling environment for investment and technological advancement (Çalışkan, 2015). Technological progress enhances productivity, encourages sectoral diversification, and increases export competitiveness, thereby supporting more resilient economic expansion. Similarly, higher levels of investment and export diversification contribute to stronger GDP growth and greater fiscal capacity (Djapou Fouthe & Ndedi, 2017).

GDP growth also has important implications for the feasibility and design of sovereign wealth funds. Strong economic performance may generate fiscal surpluses that can be transferred into savings or stabilization funds, while volatile or weak growth may indicate the need for countercyclical fiscal mechanisms to protect the economy from external shocks. Consequently, GDP growth functions as an important diagnostic variable within the conceptual framework, helping determine whether a country possesses the economic capacity to capitalize a sovereign wealth fund and what type of SWF structure is most appropriate.

Thus, GDP growth should be understood not merely as a measure of economic performance but as a strategic indicator that informs the rationale, structure, and long-term sustainability of sovereign wealth funds.

### 2.5.3 Resource Dependence

Resource dependence refers to the degree to which a country's economy relies on the extraction and export of natural resources such as oil, gas, or minerals. In macroeconomic analysis, this concept is commonly measured as the share of resource-sector output in total gross domestic product (GDP). High levels of resource dependence indicate that a significant portion of national income and government revenue originates from a single extractive sector, which can create structural vulnerabilities related to price volatility, fiscal instability, and long-term sustainability (Davis et al., 2001; van der Ploeg & Venables, 2013).

Resource-dependent economies frequently experience pronounced macroeconomic fluctuations because commodity prices are determined in global markets and are subject to significant cyclical variation. When commodity prices rise, export revenues, fiscal income, and GDP growth increase rapidly. However, during periods of declining prices, these economies often face fiscal deficits, balance-of-payments pressures, and economic contraction. This volatility complicates fiscal planning and can undermine macroeconomic stability if governments rely heavily on resource revenues to finance public expenditure (Collier & Goderis, 2012).

The presence of strong resource dependence is also associated with the well-documented "resource curse," whereby economies rich in natural resources experience slower long-term economic diversification, weaker institutional development, and greater macroeconomic instability compared with more diversified economies (Auty, 2001; Sachs & Warner, 2001). In such contexts, sovereign wealth funds are often introduced as institutional mechanisms to manage resource revenues prudently, reduce macroeconomic volatility, and convert exhaustible natural assets into diversified financial wealth.

Within the conceptual framework developed in this dissertation, resource dependence functions as a primary diagnostic indicator in Step 1 of the macroeconomic assessment. A high share of mining or hydrocarbon output in GDP signals the need for institutional mechanisms that can stabilize fiscal revenues, smooth commodity price cycles, and preserve wealth for future generations. Consequently, economies with significant resource dependence are strong candidates for establishing sovereign wealth funds designed to transform volatile resource revenues into stable and diversified financial assets.

### 2.5.4 Resource Export Share

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### 2.5.5 External Resilience and Reserve Adequacy

External sector stability is a critical component of macroeconomic resilience, particularly for small open economies exposed to volatile capital flows and commodity price cycles. One of the most widely used indicators of external resilience is the adequacy of foreign exchange reserves relative to external obligations. International financial institutions such as the International Monetary Fund recommend that countries maintain sufficient reserves to cover several months of imports and a significant share of short-term external debt (IMF, 2018).

Two commonly used indicators of reserve adequacy are the import cover ratio and the reserves-to-external debt ratio. The import cover ratio measures the number of months of imports that can be financed using existing foreign exchange reserves. This indicator provides an assessment of a country's ability to maintain essential imports during periods of external shock or sudden declines in export revenues. Traditional benchmarks suggest that reserves equivalent to at least

three months of imports represent a minimum threshold for external stability (World Bank, 2020).

The reserves-to-external-debt ratio evaluates the capacity of a country's reserve assets to meet its external debt obligations. A higher ratio indicates greater resilience to financial stress and reduces the likelihood of balance-of-payments crises. Countries with low reserve coverage relative to external debt are more vulnerable to capital flow reversals, exchange-rate instability, and liquidity crises in international financial markets (Aizenman & Lee, 2007).

For resource-dependent economies, the accumulation of foreign exchange reserves plays a particularly important role in buffering external shocks. Sovereign wealth funds complement traditional reserve management by investing excess reserves in diversified global portfolios, thereby enhancing long-term returns while preserving macroeconomic stability. Reserve investment funds, for example, are often established when countries accumulate reserves beyond the level required for short-term liquidity and crisis protection (Das, Mazarei & van der Hoorn, 2010).

In the conceptual framework developed in this dissertation, external resilience indicators serve as key diagnostic variables for assessing the macroeconomic environment in which a sovereign wealth fund operates. Adequate reserves and strong external positions may justify the creation of reserve investment funds or long-term savings funds, whereas weak reserve positions may require prioritizing stabilization mechanisms. By incorporating reserve adequacy measures into the macroeconomic assessment, policymakers can ensure that sovereign wealth fund design remains aligned with the country's external vulnerability profile and balance-of-payments stability.

### 2.6 Sovereign Wealth Fund Types and Mandates

A central component of the institutional design and strategic planning model is the identification of the sovereign wealth fund (SWF) type and mandate most appropriate to a country's macroeconomic conditions, institutional capacity, and long-term policy objectives. As outlined in Section 2.3, literature commonly distinguishes five principal categories of sovereign wealth funds: stabilization funds, savings or future generation funds, development funds, pension reserve funds, and reserve investment corporations. Each category serves a distinct macroeconomic and policy function. Consequently, selecting the appropriate fund type is essential for ensuring that the SWF's mandate is coherent, feasible, and aligned with national priorities.

Stabilization funds are designed to shield public finances from short-term volatility, particularly in economies exposed to large and unpredictable fluctuations in commodity revenues. Their primary purpose is to smooth government expenditure and preserve macroeconomic stability during external shocks. Al-Hassan et al. (2018) emphasize that stabilization funds are especially appropriate in environments characterized by procyclical fiscal pressure and recurrent revenue instability.

Savings or future generation funds are intended to transform temporary and exhaustible resource revenues into long-term financial assets to support intergenerational equity. Van den Bremer, van der Ploeg, and Wills (2016) argue that such funds are particularly important for

economies dependent on finite natural resources, since they preserve national wealth beyond the period of resource extraction and help address long-term fiscal risks.

Development funds, sometimes referred to as sovereign development funds, support structural transformation by channeling sovereign capital into infrastructure, strategic industries, innovation systems, and domestic capacity building. Clark and Monk (2015) argue that such funds are especially relevant for developing and emerging economies seeking to broaden their productive base, improve competitiveness, and promote employment creation.

Pension reserve funds are established to accumulate savings for future pension obligations and thereby reduce long-term fiscal pressures associated with demographic change. Blundell-Wignall, Hu, and Yermo (2008) note that such funds are particularly appropriate in countries facing ageing populations or rising implicit pension liabilities.

Reserve investment corporations manage surplus foreign exchange reserves once precautionary liquidity requirements have been satisfied. Their objective is to improve returns on excess reserves while preserving sufficient liquidity to support external stability. Such structures are common in economies such as Singapore and China, where persistent external surpluses allow governments to separate precautionary reserve holdings from longer-term investment portfolios (Al-Hassan et al., 2018).

Selecting the appropriate SWF type or combination of types requires a holistic assessment of macroeconomic vulnerability, revenue structure, institutional capacity, and long-term development strategy. Many countries adopt hybrid or multi-fund arrangements to address several policy objectives simultaneously. For example, Qatar combines stabilization and savings functions within its sovereign wealth architecture, while Singapore maintains both a traditional investment fund and a development-oriented holding structure. Such arrangements enable governments to address revenue volatility, long-term asset accumulation, and structural transformation within a coherent institutional framework.

Accordingly, Figure 2-3 situates these SWF types within the broader institutional design and strategic planning model developed in this chapter. It illustrates how macroeconomic diagnostics and policy objectives flow into the selection of an appropriate sovereign wealth fund type and mandate, ensuring consistency with fiscal rules, development strategies, and long-horizon investment constraints. In this way, the model provides policymakers with a structured and context-sensitive basis for determining the most appropriate sovereign wealth fund architecture for their economic environment.

## 2.7 Robust Portfolio Optimization Framework

This section elaborates the quantitative framework that underpins Step 4 of the conceptual model, namely the determination of a robust long-term strategic asset allocation for a sovereign wealth fund. As established earlier in the chapter, the macroeconomic and institutional stages of the framework identify the sovereign purpose of the fund, clarify its mandate environment, and define the admissible constraints within which portfolio decisions must be made. The role of the present section is to translate those macroeconomic objectives and institutional constraints into a stable, resilient, and uncertainty-tolerant investment strategy.

Unlike traditional portfolio approaches, which typically depend on long historical datasets, stable statistical relationships, and clearly specified risk-return preferences, newly established sovereign wealth funds in developing economies such as the Future Heritage Fund of Mongolia operate under conditions of limited information, evolving mandates, and structural volatility. Under such circumstances, classical optimization techniques are often difficult to apply defensibly.

This challenge is compounded by the fact that different types of sovereign wealth funds are associated with different return expectations and risk tolerances. Stabilization funds typically prioritize liquidity and capital preservation, with relatively low acceptable risk. Savings or intergenerational funds generally target higher long-term returns with moderate risk tolerance. Development funds may accept higher risk in pursuit of strategic or domestic economic objectives. In mature sovereign wealth funds, these differentiated mandates may allow the definition of explicit return targets, volatility thresholds, or benchmark portfolios. By contrast, newly established funds often lack historical performance data, institutional track record, and stable macro-fiscal environment needed to define such parameters reliably.

For this reason, robust portfolio optimization is treated in this dissertation as an essential extension of the macro–institutional design framework. It provides a scientifically grounded method for constructing long-term strategic asset allocations when expected returns, variances, covariances, and effective risk preferences cannot be estimated with sufficient confidence. The robust optimization framework seeks to accommodate parameter uncertainty, reduce sensitivity to estimation error, and generate portfolios that remain stable across a wide range of plausible future scenarios.

A central feature of the proposed framework is the incorporation of geometric robustness techniques, particularly sphere-packing and design-centering methods. These approaches identify the largest stability radius that can be inscribed within the feasible portfolio region, thereby providing a global measure of resilience. In contrast to conventional methods that emphasize only local robustness around estimated parameters, the sphere-packing approach evaluates how far a portfolio can deviate before it becomes infeasible or inconsistent with its governing constraints. This gives the framework a transparent geometric interpretation of portfolio resilience under deep uncertainty.

At the same time, robust optimization allows the direct incorporation of constraints derived from the earlier stages of the conceptual model. These include liquidity requirements, currency allocations, legal restrictions, diversification rules, and mandate-specific policy limits. As a result, the portfolio design remains not only financially robust, but also institutionally coherent and aligned with the macroeconomic and governance conditions identified earlier in the chapter.

The central objective of this framework is therefore to generate an uncertainty-resilient strategic asset allocation capable of supporting long-term sovereign savings while remaining consistent with conservative public-management conditions. For newly established sovereign wealth funds, this feature is critical. Rather than relying on unstable parameter estimates or arbitrarily imposed targets, robust optimization produces a defensible, policy-consistent portfolio that is

scientifically grounded and operationally feasible under the realities of developing-economy conditions.

In this way, robust portfolio optimization functions as the quantitative engine of the dissertation's conceptual model. It transforms macroeconomic rationale and institutional architecture into a durable and implementable investment strategy for sovereign wealth funds operating under deep uncertainty and limited data availability. In the specific case of the Future Heritage Fund of Mongolia, it provides the analytical basis for evaluating whether the current government-mandated portfolio can be improved through a more robust and diversified long-term strategic allocation.

**2.8 Validation**

The validity of the proposed model lies in its ability to integrate macroeconomic conditions, institutional design principles, and robust portfolio optimization into a unified analytical and operational framework for sovereign wealth fund development. As established in this dissertation, the central objective of the study is to examine how the long-term strategic asset allocation of the Future Heritage Fund of Mongolia can be improved within its current investment mandate. The model is therefore validated by its capacity to reflect the macroeconomic and institutional realities of Mongolia while also offering a framework that may be adapted to other resource-dependent developing economies facing similar conditions of uncertainty, limited diversification, and public-management constraints.

The first source of validity lies in the sequencing of the model. The framework begins with macroeconomic diagnostics and treats them as the primary inputs for determining whether a sovereign wealth fund is justified and, if so, what type of fund is most appropriate. In the case of Mongolia, this diagnostic stage identifies persistent resource dependence, export concentration, fiscal cyclicality, and exposure to external shocks as the key structural conditions shaping the rationale for the Fund. This logic is consistent with the literature emphasizing the role of sovereign wealth funds in managing macroeconomic volatility, preserving exhaustible resource wealth, and supporting long-term fiscal and intergenerational objectives (Al-Hassan et al., 2018).

A second source of validity lies in the internal coherence of the model across its different stages. The framework does not treat macroeconomic diagnosis, objective setting, institutional design, portfolio construction, and evaluation as separate exercises. Rather, it links them in a sequential manner. Macroeconomic conditions define the sovereign purpose of the fund; institutional design clarifies the mandate, governance structure, and admissible investment environment; robust portfolio optimization translates these constraints into a feasible long-term strategic asset allocation; and evaluation assesses whether the resulting fund structure is consistent with its intended objectives. This sequential logic strengthens the validity of the model by ensuring that each stage is derived from the preceding one.

A third source of validity stems from the inclusion of the robust portfolio-optimization component. While the sovereign wealth fund literature contains extensive discussion of governance, legal design, and macroeconomic alignment, it provides more limited operational guidance on how newly established funds should construct resilient investment portfolios when reliable historical data are unavailable or when long-term risk-return parameters are unstable.

The proposed model addresses this gap by incorporating convex optimization and geometric robustness methods such as sphere-packing. This quantitative layer strengthens the model in three respects: it aligns investment strategy with macroeconomic objectives, translates governance and mandate constraints into implementable allocation rules, and improves long-horizon resilience by generating portfolios capable of withstanding parameter instability and market volatility.

A fourth source of validity lies in the model's policy relevance. The framework is not developed as a purely abstract theory of sovereign wealth fund design, but as a practical method for addressing the strategic asset-allocation problem of a real fund operating under observable constraints. In the case of the Future Heritage Fund of Mongolia, the model provides a structured way of evaluating whether the current government-mandated portfolio is consistent with the Fund's dominant long-term savings objective and whether a more robust and diversified allocation can improve long-term accumulation outcomes. In this sense, the framework is validated not only by conceptual coherence, but also by its practical applicability to an actual sovereign wealth fund setting.

The contribution of the model is therefore multidimensional. First, it provides a systematic and replicable approach for diagnosing the macroeconomic environment in which a sovereign wealth fund operates and for identifying the sovereign objectives that should guide its long-term role. Second, it links macroeconomic analysis, institutional design, and portfolio science within a unified end to end framework that remains insufficiently developed in the existing sovereign wealth fund literature. Third, it introduces a robust optimization pillar that supports long-term financial sustainability by reducing dependence on fragile parameter estimates and by generating strategic asset allocations that remain feasible under uncertainty. Finally, it strengthens policymakers' capacity to evaluate whether a sovereign wealth fund is fulfilling its intended long-term savings function within a given macroeconomic and institutional setting.

Taking together, these features position the proposed framework as both a theoretical refinement and a practical policy tool for designing, governing, and managing sovereign wealth funds in ways that are consistent with national priorities and responsive to real-world economic constraints.

### 2.9 Data Collection

This section outlines the data-collection strategy adopted in the dissertation. Because the study does not investigate personal experiences, perceptions, or behavioral responses, it relies exclusively on secondary data rather than on primary data collected through interviews, surveys, or direct interaction with individuals.

The evidence used in the dissertation was drawn from publicly accessible and institutionally authoritative sources. These include Mongolian government policy documents, Bank of Mongolia publications, fiscal reports, national legislation, official sovereign wealth fund frameworks, international policy reports, macroeconomic databases, and relevant academic literature. In the quantitative component, financial market data for the selected asset classes were obtained from Bloomberg and other international statistical sources.

This secondary-data strategy is consistent with the central research problem of the dissertation. The study focuses on the strategic asset-allocation problem of the Future Heritage Fund of Mongolia and examines how its long-term portfolio can be evaluated and improved within its current investment mandate. For this reason, the dissertation requires documentary evidence on the Fund's legal and policy setting, together with financial market data suitable for portfolio analysis, rather than primary data on the views of individual actors.

The use of secondary sources also strengthens the evidentiary basis of the study by relying on verifiable, systematically compiled, and policy-relevant information. At the same time, it avoids the ethical and practical issues associated with human-subject research.

By combining policy and institutional documents with financial market data, the dissertation establishes a coherent evidentiary base for evaluating the long-term strategic asset allocation of the Future Heritage Fund of Mongolia.

### 2.10 Data Analysis

Data analysis in this dissertation combines qualitative content analysis with quantitative financial modelling, consistent with the five-step sovereign wealth fund design framework adopted in the study.

The qualitative component follows a structured content-analysis procedure. National policy documents, sovereign wealth fund legislation and official frameworks, fiscal rules, strategic reports, IMF Article IV consultations, World Bank assessments, and peer-reviewed academic studies were systematically examined to identify patterns relevant to macroeconomic conditions, institutional design, and sovereign wealth fund governance in Mongolia. In line with the interpretive dimension of the dissertation, documents were reviewed iteratively and coded according to recurrent concepts such as revenue volatility, resource dependence, fiscal procyclicality, governance arrangements, deposit and withdrawal rules, transparency, and intergenerational savings. These coded insights were then synthesized into thematic categories that informed the application of the five-step design model, particularly the identification of fund objectives, mandate structure, and institutional design requirements.

The quantitative component supports the strategic asset-allocation stage of the dissertation. Financial market data comprising long-horizon return series for major international asset classes, including global equities, sovereign bonds, commodities, and cash instruments, were cleaned, normalized, and analyzed to construct a strategic asset-allocation framework for the Future Heritage Fund of Mongolia. Baseline return and covariance estimates were generated and then incorporated into the portfolio analysis.

Convex optimization methods were implemented in R using CVXR to identify asset-allocation vectors that satisfy the return, risk, and budget conditions of the model. These solutions were then evaluated using a geometric robustness approach based on sphere-packing theory, which identifies the largest robustness radius that can be inscribed within the feasible portfolio region. This provides an indicator of the structural stability of the portfolio under uncertainty.

Comparisons between the current government-mandated portfolio and alternative benchmark, convex, and sphere-packing allocations were used to assess differences in diversification,

resilience, and long-term performance. In this way, quantitative analysis supports the strategic asset-allocation and evaluation stages of the framework by examining whether the current portfolio can be improved within the Fund's existing mandate environment.

By integrating qualitative institutional analysis with quantitative portfolio modelling, the dissertation ensures that the analytical results reflect both Mongolia's macroeconomic and institutional realities and the practical asset-management challenges faced by the Future Heritage Fund of Mongolia.

### 2.11 Thesis Ethics

This dissertation adheres strictly to the ethical standards governing social-science research, with particular emphasis on data integrity, transparency, and the responsible use of secondary information. Because the study relies exclusively on publicly available documents and datasets, no human participants were involved, and no procedures relating to informed consent, confidentiality, or participant protection were required.

Despite the absence of human subjects, ethical considerations remain important because the research examines macroeconomic, fiscal, and institutional information related to national wealth management. All materials were collected and used in accordance with academic fair-use principles, accurately cited, and securely stored. The study does not rely on confidential or unpublished government information and uses only open-source, publicly accessible materials.

Care has been taken to present institutional processes, policy frameworks, and financial structures objectively and without political bias. The quantitative modelling component also adheres to ethical standards by ensuring that data sources are accurately represented, analytical procedures are transparent, and results are not selectively interpreted.

This approach satisfies the ethical requirements for non-human-subject research while maintaining high standards of academic integrity and methodological transparency.

### 2.12 Validity and Reliability

Validity and reliability in this dissertation were addressed through a systematic, transparent, and replicable approach to both documentary analysis and quantitative portfolio modelling.

Reliability refers to the consistency and reproducibility of the research procedures. In the qualitative component, reliability was strengthened through a clearly structured document-selection process, consistent thematic coding, and transparent interpretation of macroeconomic, legal, and institutional materials. In the quantitative component, reliability was reinforced using clearly specified financial datasets, explicit portfolio constraints, and reproducible optimization procedures implemented in R environment. The convex optimization and sphere-packing analyses followed predefined mathematical steps, which support procedural consistency and make the results replicable.

Validity refers to the extent to which the research accurately captures the concepts it is intended to examine. In the qualitative component, validity was supported using authoritative and policy-relevant sources, including Mongolian legislation, government policy documents, IMF and World Bank reports, and peer-reviewed academic studies. These sources ensured close

alignment between the documentary evidence and the macroeconomic and institutional concepts examined in the dissertation.

In the quantitative component, validity was addressed through the design of the optimization framework itself. The convex optimization model was constructed to reflect the actual strategic asset-allocation problem of the Future Heritage Fund of Mongolia under its current mandate and portfolio constraints. The sphere-packing approach further strengthened analytical validity by evaluating the geometric robustness of feasible portfolio allocations rather than relying only on point estimates of return and risk. This allowed the analysis to assess not only feasibility, but also the structural stability of alternative portfolios under uncertainty.

Triangulation further supported the credibility of the findings. In the qualitative analysis, national policy documents were compared with international institutional reports and academic literature to reduce interpretive bias. In the quantitative analysis, the results of the benchmark, convex, and sphere-packing portfolios were compared to test the consistency of conclusions across alternative asset-allocation methods.

Taken together, these procedures support the credibility, consistency, and trustworthiness of the dissertation's findings. The qualitative analysis ensures that the study remains grounded in Mongolia's macroeconomic and institutional realities, while the quantitative analysis ensures that the proposed portfolio allocations are evaluated through transparent, valid, and replicable analytical methods.

### 2.13 Chapter summary

This chapter established the methodological and analytical foundations of the dissertation by outlining the philosophical position, research design, and procedures guiding the collection and analysis of evidence. It justified an inductive and exploratory design that combines qualitative documentary analysis with quantitative portfolio modelling.

A central contribution of the chapter was the presentation of the analytical framework, which links macroeconomic conditions, sovereign wealth fund objectives, institutional design, robust portfolio optimization, and evaluation, with particular emphasis on the strategic asset-allocation problem of the Future Heritage Fund of Mongolia. It shows that macroeconomic and institutional analysis serve as inputs into the core problem of improving long-term strategic asset allocation under uncertainty.

The chapter also justified the exclusive reliance on secondary data and strengthened methodological rigor through transparent analytical procedures, source triangulation, and reproducible quantitative modelling, including convex and sphere-packing optimization methods. Overall, it provides the methodological structure for the empirical analysis that follows, which applies this framework to the Future Heritage Fund of Mongolia and assesses alternative portfolio structures for improving its long-term asset allocation.

# Chapter 3: Empirical Analysis

## 3.1 Introduction

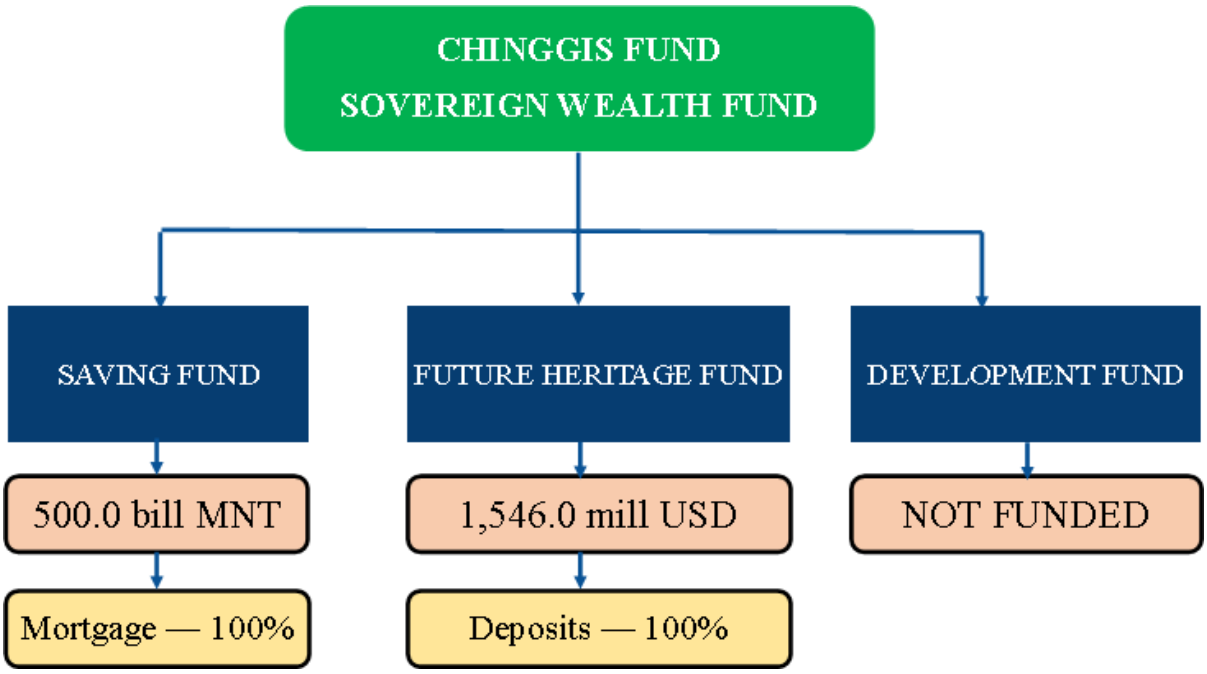
The establishment and effective functioning of a sovereign wealth fund (SWF) are fundamentally shaped by the macroeconomic conditions and institutional structures of the host economy. A substantial body of literature emphasizes that macroeconomic characteristics particularly resource dependence, fiscal volatility, and external vulnerability play a decisive role in determining not only the rationale for establishing an SWF, but also its objectives, governance framework, and asset-management mandate (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013; Al-Sayed, 2023). In developing and resource-dependent economies, these macro–institutional factors are especially consequential, because weak institutional capacity, volatile revenue streams, and pro-cyclical fiscal behavior can undermine fiscal sustainability, macroeconomic stability, and long-term intergenerational equity (Frankel, 2012; van der Ploeg & Venables, 2013; IMF, 2018). As argued in the recent SWF design literature, the key challenge is not merely to justify the existence of a fund, but to align its legal mandate, governance structure, and financial-management framework with the specific macroeconomic conditions of the country in which it operates.

Mongolia represents a particularly relevant case within this broader discussion. Existing studies and policy assessments consistently identify the country's dependence on mineral exports, exposure to global commodity-price fluctuations, and historically pro-cyclical fiscal behavior as major sources of macroeconomic instability. These structural conditions have contributed to repeated boom–bust cycles, external vulnerability, and persistent difficulties in sustaining long-term public savings. Within the broader literature on resource-dependent economies, such characteristics are widely recognized as constituting a strong economic justification for the establishment of a sovereign wealth fund capable of transforming finite natural-resource wealth into sustainable financial assets while supporting long-term fiscal discipline and intergenerational savings objectives.

Against this backdrop, the Future Heritage Fund of Mongolia represents the country's principal institutional mechanism for intergenerational savings and long-term fiscal sustainability. The Fund is designed to ensure the equal distribution of natural resource revenue between present and future generations, thereby reflecting a long-term savings rationale consistent with the intergenerational equity literature. At the same time, its present institutional structure reflects a transitional governance arrangement in which policy oversight, portfolio management, and operational execution are distributed across several public institutions. This institutional configuration is particularly important for understanding the current strengths and limitations of the Fund's asset-management framework.

Figure 3-1 presents the current structure of the Chinggis Fund sovereign wealth fund framework in Mongolia and shows the relative position of the Future Heritage Fund within the broader sovereign fund architecture.

**Figure 3-1:** Institutional Structure of Mongolia's Chinggis Fund Sovereign Wealth Fund Framework




*Source: Ph.D. Candidate (2026)*

As shown in Figure 3-1, the Future Heritage Fund currently represents the only funded long-term savings component within Mongolia's broader sovereign wealth fund architecture, with assets of approximately USD 1,546.0 million. By contrast, the Development Fund remains unfunded, while the Saving Fund is structured separately and remains concentrated on mortgage-related assets. The figure highlights two important features of Mongolia's sovereign wealth framework. First, the Future Heritage Fund occupies a central position in the country's long-term sovereign savings strategy. Second, its current asset structure remains highly conservative, with deposits accounting for 100 percent of the portfolio. This reinforces the argument that the key issue is no longer whether the Fund should exist, but whether its strategic asset allocation is appropriate for its long-term savings objective.

To clarify this institutional setting before proceeding to the broader macro–institutional analysis, Table 3-1 summarizes the principal institutional and financial characteristics of the Future Heritage Fund of Mongolia. As shown, the Fund operates under an investment mandate approved by the Government, with portfolio management assigned to the Ministry of Finance until 2030 and expected to be transferred thereafter to the Future Heritage Fund Corporation, while daily operations remain the responsibility of the Bank of Mongolia during the transition period. At the time of writing, the Fund's assets under management amount to USD 1,546.00 million, and its one-year return on assets stands at 3.474 percent. These features indicate that the Fund already has material macroeconomic significance in terms of asset accumulation, while its governance arrangement remains institutionally transitional.

**Table 3-1:** Institutional and financial profile of the Future Heritage Fund of Mongolia

| | **Future Heritage Fund of Mongolia** |
|---|---|
| Fund's objectives: | Equal distribution of natural resource revenue for present and future generations. |
| Asset manager: | Ministry of Finance |

| | |
|---|---|
| Asset under management: | 1,546.00 million USD |
| Return on Assets: | 3.474% (1 year) |
| Herfindahl–Hirschman Index (HHI) | 1 |

*Source: Ph.D. Candidate (2026)*

To clarify this institutional setting before proceeding to the broader macro–institutional analysis, Table 3-1 summarizes the principal institutional and financial characteristics of the Future Heritage Fund of Mongolia. As shown, the Fund operates under an investment mandate approved by the Government, with portfolio management assigned to the Ministry of Finance until 2030 and expected to be transferred thereafter to the Future Heritage Fund Corporation, while daily operations remain the responsibility of the Bank of Mongolia during the transition period. At the time of writing, the Fund's assets under management amount to USD 1,546.00 million, and its one-year return on assets stands at 3.474 percent. These features indicate that the Fund already has material macroeconomic significance in terms of asset accumulation, while its governance arrangement remains institutionally transitional.

The importance of these observations becomes clearer when viewed considering the broader sovereign wealth fund literature. Sovereign wealth funds tend to function most effectively when their macroeconomic purpose, governance structure, and financial-management framework are mutually consistent. Where these dimensions are weakly integrated, funds may exist formally yet fail to perform their intended savings, stabilization, or developmental roles effectively. In Mongolia's case, the existence of a clear legal foundation and a growing asset base represents an important institutional achievement. However, the transitional nature of portfolio management responsibilities and the highly conservative structure of the current investment framework suggest that the Future Heritage Fund has not yet fully evolved into a mature, independently managed long-term investment institution.

Against this background, this chapter applies a macro–institutional perspective to the Future Heritage Fund of Mongolia to examine how the country's structural economic conditions shape the Fund's objectives, governance arrangements, and asset-management implications. The analysis proceeds from the premise that sovereign wealth fund design cannot be understood solely in terms of financial portfolio construction but must instead be grounded in the broader macroeconomic rationale, legal mandate, and institutional framework within which the fund operates. Accordingly, the following sections evaluate the macroeconomic justification for the Fund, its institutional design, and the implications of these features for the development of a more coherent long-term asset-management framework.

### 3.2 Macroeconomic Diagnostics

The first step of the framework evaluates the macroeconomic conditions that justify the establishment of a sovereign wealth fund. Resource-rich economies frequently face structural macroeconomic challenges arising from the exhaustible nature of natural-resource revenues. These challenges include revenue volatility, external vulnerability, and intergenerational equity concerns associated with transforming finite natural-resource wealth into sustainable financial assets (Davis et al., 2001; Barnett & Ossowski, 2003; van der Ploeg & Venables, 2013; IMF, 2018). Accordingly, the sovereign wealth fund literature emphasizes the importance of macroeconomic diagnostics capable of assessing resource dependence, fiscal stability, and

external resilience prior to institutional fund design (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013; Al-Sayed, 2023).

To evaluate these structural conditions, this study constructs a set of diagnostic indicators derived from the macroeconomic dataset. These indicators are intended to capture the relative importance of the mining sector in the domestic economy, the concentration of exports in mineral commodities, the sustainability of fiscal conditions, and the adequacy of foreign-exchange reserves in relation to external obligations. In this way, the indicators provide an empirical basis for assessing whether Mongolia exhibits the macroeconomic characteristics commonly associated with the economic rationale for a sovereign wealth fund.

The indicators are defined as follows:

$$RD_t = \frac{Mining_t}{GDP_t}$$

$$RX_t = \frac{MiningExport_t}{TotalExport_t}$$

$$FB_t = \frac{FiscalBalance_t}{GDP_t}$$

$$ImportCover_t = \frac{Reserve_t}{Imports_t/3}$$

$$Res\_Debt_t = \frac{Reserve_t}{External\_Debt_t}$$

where $t$ denotes the quarterly observation period.
These indicators jointly summarize the main macroeconomic exposures relevant to sovereign wealth fund design. Resource dependence and export concentration capture structural exposure to commodity cycles, the fiscal-balance indicator captures the degree of fiscal instability associated with resource dependence, and the two reserve-based indicators evaluate the economy's capacity to absorb external shocks.

The resource dependence indicator measures the share of mining in gross domestic products. Higher values indicate stronger reliance on natural-resource extraction as a driver of national output. In the resource-economics literature, elevated resource dependence is associated with revenue volatility, procyclical fiscal behavior, and heightened exposure to global commodity-price fluctuations (Sachs & Warner, 1995; Frankel, 2012; van der Ploeg & Venables, 2013). In such settings, sovereign wealth funds are commonly justified as institutional mechanisms for smoothing macroeconomic volatility and transforming exhaustible rents into diversified financial wealth (Davis et al., 2001; Gelb et al., 2014). The resource export share indicator measures the proportion of mineral exports in total exports. This ratio captures the degree to which the external sector is concentrated in commodity trade. High export concentration is widely associated with greater vulnerability to terms-of-trade shocks and external demand instability (Auty, 2001; Lederman & Maloney, 2007; Frankel, 2012; van der Ploeg & Venables,

2013). In this context, a sovereign wealth fund may help reduce external-sector fragility by accumulating financial buffers during periods of high commodity revenues (IMF, 2018; Al-Hassan et al., 2013).

The fiscal balance-to-GDP indicator evaluates the sustainability and cyclicality of public finances. In resource-rich economies, government revenues are often tightly linked to commodity-price cycles, which can induce procyclical spending and sharp fluctuations in fiscal balances (Talvi & Végh, 2005; Frankel, 2012). Persistent deficits and high fiscal volatility weaken macroeconomic stability and increase debt vulnerability. The public-finance literature therefore emphasizes that sovereign wealth funds may serve as fiscal-stabilization devices by saving excess revenues during commodity booms and supporting the budget during downturns (Davis et al., 2001; Barnett & Ossowski, 2003; IMF, 2018). The import-cover indicator measures the adequacy of foreign exchange reserves relative to import requirements. In reserve-adequacy analysis, a conventional lower-bound benchmark is three months of imports (IMF, 2015). Adequate import cover supports external stability during balance-of-payments stress, particularly in economies where export revenues and external financing conditions are volatile (Aizenman & Lee, 2007; IMF, 2018). The reserves-to-external debt indicator provides an additional perspective by comparing reserve holdings to external debt obligations. This ratio is relevant because a country may appear comfortable in terms of import cover while remaining vulnerable in terms of debt-related external financing needs. Stronger reserve coverage relative to debt is generally associated with greater resilience to external shocks (Guidotti, 1999; Greenspan, 1999; IMF, 2015).

Taken together, these indicators provide a structured diagnostic framework for assessing the macroeconomic environment in which the Future Heritage Fund of Mongolia operates. High resource dependence and export concentration indicate structural exposure to commodity cycles; fiscal-balance weakness reveals the relevance of intertemporal revenue management; and reserve-adequacy measures provide insight into the economy's capacity to withstand external stress. Within the logic of this dissertation, these diagnostics form the empirical basis for identifying the sovereign objectives that will later guide long-term strategic asset allocation.

To summarize the benchmark values and theoretical interpretation of these indicators, Table 3-2 reports their means, standard deviations, theory basis, decision thresholds, and implications for Mongolia

**Table 3-2:** Macroeconomic Diagnostic Indicators and Decision Thresholds for Sovereign Wealth Fund Design

| Indicator | Mean | SD | Theory basis | Critical value / decision rule | Interpretation for Mongolia |
|---|---|---|---|---|---|
| Resource Dependence (RD) | 0.22 | 0.06 | Permanent Income Hypothesis | Values above 0.15–0.20 typically indicate a resource-dependent economy | Mongolia shows significant dependence on resource revenues |
| Resource Export Share (RX) | 0.90 | 0.04 | Resource-curse and export-concentration theory | Values above 0.50 indicate high export concentration; values near 0.90 indicate extreme dependence on commodities | Mongolia's export structure is highly concentrated in mineral commodities |

| | | | | | |
|---|---|---|---|---|---|
| Fiscal Balance / GDP | -0.07 | 0.12 | Tax-smoothing theory and pro-cyclical fiscal-policy literature | High fiscal-balance volatility, reflected in a large standard deviation relative to GDP, indicates fiscal instability in commodity economies | Mongolia exhibits significant fiscal volatility linked to commodity cycles |
| Import Cover (months) | 5.83 | 1.81 | Reserve-adequacy theory | A minimum of 3 months of imports is commonly treated as the lower bound of adequacy; 3–6 months is generally considered an adequate liquidity buffer | Mongolia's reserves provide adequate short-term import coverage |
| Reserves / External Debt | 0.51 | 0.30 | Guidotti–Greenspan reserve-adequacy rule | Reserve coverage should approach 1.0 of short-term external debt to provide strong precautionary protection | Mongolia shows moderate external resilience but remains below the stronger adequacy benchmark |

*Source: Ph. D Candidate (2026)*

Table 3-2 indicates that Mongolia exhibits the main structural characteristics commonly associated with resource-dependent economies. The mean resource-dependence ratio of 0.22 exceeds the thresholds often used to identify a resource-based economy (Auty, 2001; Sachs & Warner, 1995). The resource export share of 0.90 implies an export structure that is highly concentrated in mineral commodities, indicating substantial exposure to external commodity-price shocks. Fiscal balance relative to GDP is negative on average and displays considerable dispersion, consistent with the procyclical fiscal dynamics observed in many commodity-exporting economies (Alesina et al., 2008; Frankel, 2012). At the same time, import cover remains above the conventional reserve-adequacy threshold, suggesting that short-term external liquidity conditions are relatively comfortable. However, the reserves-to-external-debt ratio remains well below unity, indicating that Mongolia's external resilience is more limited when assessed against debt-related vulnerabilities. Taken together, these findings support the conclusion that Mongolia exhibits the macroeconomic conditions commonly associated with the economic rationale for a sovereign wealth fund.

To provide a fuller statistical profile of these indicators, Table 3-3 reports their descriptive statistics over the sample period 2010Q1–2025Q4.

**Table 3-3:** Descriptive statistics of macroeconomic diagnostic indicators, 2010Q1–2025Q4

| Indicator | N | Mean | SD | Min | Max | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Resource Dependence (RD) | 64 | 0.223 | 0.058 | 0.120 | 0.367 | 0.444 | -0.501 |
| Resource Export Share (RX) | 64 | 0.903 | 0.036 | 0.819 | 0.966 | -0.736 | -0.341 |
| Fiscal Balance / GDP | 64 | -0.069 | 0.120 | -0.531 | 0.132 | -1.376 | 2.538 |
| Import Cover (months) | 64 | 5.832 | 1.806 | 2.466 | 10.574 | 0.590 | -0.379 |
| Reserves / External Debt | 64 | 0.509 | 0.298 | 0.145 | 1.279 | 1.157 | 0.249 |

*Source: Ph. D Candidate (2026)*

Table 3.3 reinforces the view that Mongolia's macroeconomic structure remains persistently resource dependent. Resource dependence averages 0.223, indicating that mining accounts for

slightly more than one-fifth of GDP on average, while the resource export share averages 0.903, showing that mineral exports dominate total exports. Fiscal balance relative to GDP has a negative mean of -0.069, indicating persistent fiscal deficits and considerable fiscal volatility. Import cover averages 5.832 months, suggesting generally adequate reserve coverage relative to imports, although the reserves-to-external-debt ratio averages only 0.509, indicating weaker reserve adequacy when assessed against external debt obligations. Overall, the descriptive statistics suggest that Mongolia combines high resource dependence and export concentration with persistent fiscal weakness and uneven external resilience.

To assess these findings against benchmark values more formally, Table 3-4 reports one-sample benchmark tests for the macroeconomic diagnostic indicators.

**Table 3-4:** One-sample benchmark tests of macroeconomic diagnostic indicators

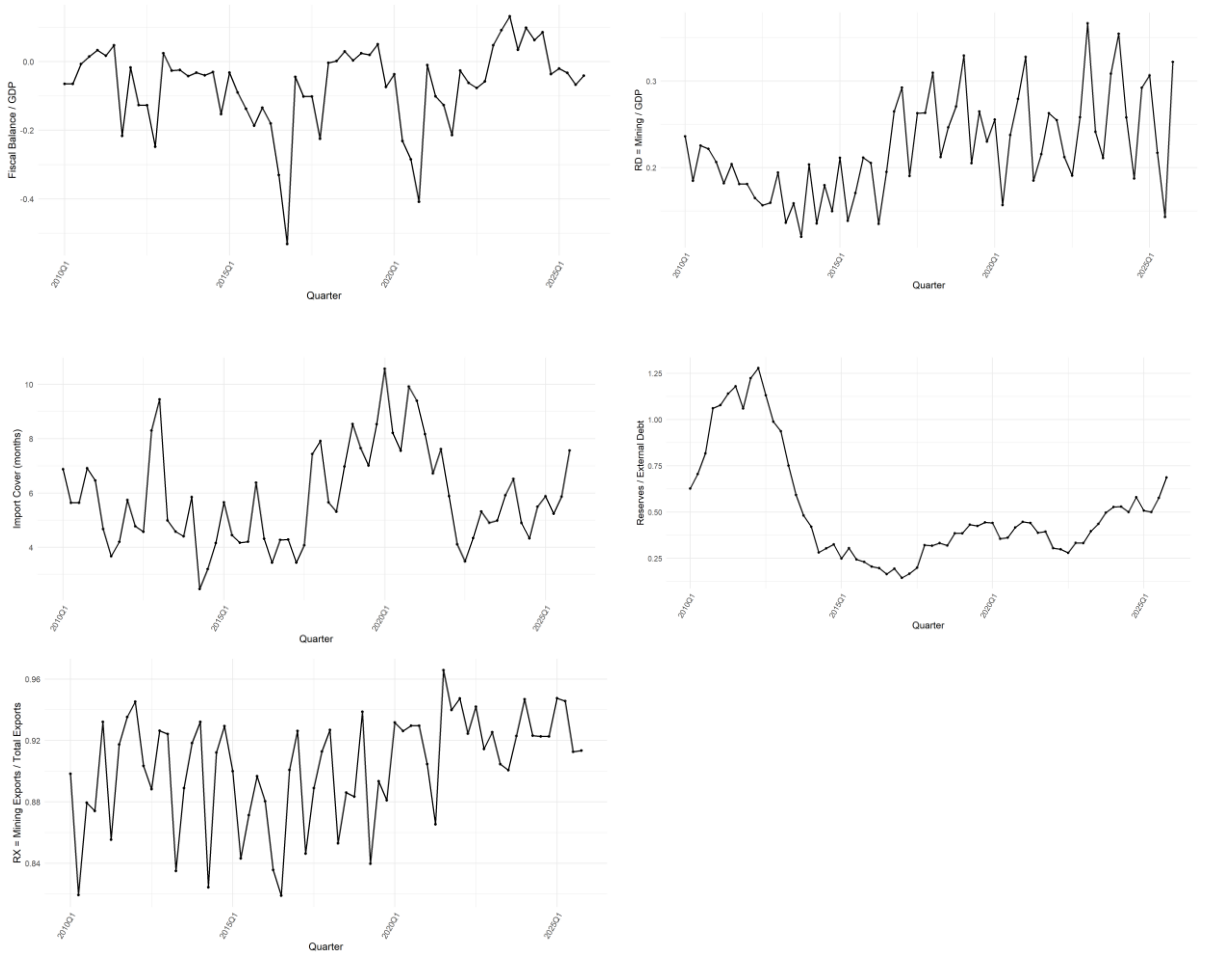
| Indicator | Benchmark | Mean | t-statistic | t p-value | Wilcoxon p-value | Conclusion |
|---|---|---|---|---|---|---|
| Resource Dependence (RD) | 0.20 | 0.223 | 3.088 | 0.0015 | 0.0061 | Significantly above benchmark |
| Resource Export Share (RX) | 0.90 | 0.903 | 0.606 | 0.2735 | 0.1019 | Not significantly above benchmark |
| Fiscal Balance / GDP | 0.00 | -0.069 | -4.584 | 0.0000 | 0.0000 | Significantly below benchmark |
| Import Cover (months) | 3.00 | 5.832 | 12.547 | 0.0000 | 0.0000 | Significantly above benchmark |
| Reserves / External Debt | 1.00 | 0.509 | -13.182 | 0.0000 | 0.0000 | Significantly below benchmark |

*Source: Ph. D Candidate (2026)*

Table 3-4 shows that resource dependence is significantly above the benchmark value of 0.20, confirming the structural importance of the mining sector in the Mongolian economy. By contrast, although the resource export share is high in absolute terms, it is not statistically above the benchmark of 0.90. Fiscal balance as a share of GDP is significantly below zero, indicating persistent fiscal deficits over the sample period. Import cover is significantly above the three-month adequacy threshold, suggesting that reserve coverage of imports is generally satisfactory. However, the reserves-to-external-debt ratio is significantly below one, implying that reserve adequacy is weaker when evaluated against external debt obligations. Taken together, these benchmark results reinforce the conclusion that Mongolia satisfies the macroeconomic conditions typically associated with the rationale for a sovereign wealth fund, while also revealing clear fiscal and external vulnerabilities.

The dynamic evolution of the principal indicators is shown in Figure 3-2, which presents the time-series behavior of fiscal balance relative to GDP, resource dependence, resource export share, import cover, and reserves relative to external debt over 2010Q1–2025Q4.

**Figure 3-2:** Time-series evolution of macroeconomic diagnostic indicators in Mongolia, 2010Q1–2025Q4




*Source: Ph. D Candidate (2026)*

Figure 3-2 complements the descriptive and benchmark-test evidence by showing the temporal persistence and volatility of the underlying macroeconomic conditions. Resource dependence and export concentration remain persistently high throughout the period, confirming the structural importance of the mining sector in both output and trade. Fiscal balance relative to GDP displays pronounced volatility, including several episodes of sharp deterioration, which is consistent with the procyclical fiscal dynamics identified in the resource-economy literature. Import cover generally remains above conventional adequacy thresholds, although it varies over time, while the reserves-to-external-debt ratio is weaker and more uneven. These patterns reinforce the conclusion that Mongolia's macroeconomic environment is characterized by strong resource dependence, fiscal instability, and mixed external-buffer adequacy.

Taken together, the descriptive statistics, benchmark tests, and time-series evidence indicate that Mongolia displays the core macroeconomic characteristics commonly associated with the economic rationale for a sovereign wealth fund. High resource dependence and extreme export concentration confirm persistent structural exposure to commodity cycles, while recurrent fiscal deficits and weaker reserve coverage relative to external debt reveal continuing fiscal and external vulnerabilities. Although short-term import-cover adequacy appears satisfactory, the broader macroeconomic pattern remains consistent with the need for an institutional mechanism capable of transforming volatile and exhaustible mineral revenues into stable long-term financial savings. In the logic of this dissertation, these results provide the empirical foundation

for the next stage of the analysis: identifying the sovereign objectives that should guide the Future Heritage Fund of Mongolia and, ultimately, translating those objectives into long-term strategic asset-allocation decisions.

### 3.3 Determination of Macroeconomic Objectives

Based on the macroeconomic diagnostics presented in the previous section, the macroeconomic objectives of the sovereign wealth fund can now be determined using established theories from public finance and resource economics. The purpose of this stage is to move from empirical diagnosis to sovereign objective identification. In the logic of this dissertation, the significance of this step is that the macroeconomic conditions observed in Mongolia are not left as descriptive findings; rather, they are interpreted through theory in order to identify the sovereign objectives that will later be translated into long-term strategic asset-allocation decisions.

Three theoretical perspectives are especially relevant in the case of a resource-dependent developing economy such as Mongolia. The first is the Permanent Income Hypothesis (PIH), originally developed by Friedman (1957) and later applied to natural-resource management by Barnett and Ossowski (2003). The PIH holds that revenues derived from exhaustible natural resources should be treated as temporary rather than permanent income. Instead of being consumed immediately, such revenues should be transformed into financial assets capable of generating a stable flow of returns over time. In the context of sovereign wealth funds, this theory provides the strongest justification for long-term savings or future generation objectives. For Mongolia, where mineral revenues are finite and highly cyclical, the PIH implies that a core purpose of the Future Heritage Fund of Mongolia should be the preservation of national wealth across generations through long-term financial accumulation.

The second relevant framework is tax-smoothing theory, developed by Barro (1979). This theory suggests that governments should seek to minimize the distortionary effects of taxation by smoothing fiscal policy over time rather than allowing expenditure and taxation to fluctuate sharply with short-term revenue movements. In economies dependent on commodity exports, where public revenues rise and fall with global price cycles, sovereign wealth funds can support this objective by saving windfall revenues during booms and providing a buffer during downturns. Applied to Mongolia, tax-smoothing theory suggests that the sovereign wealth fund should also perform a macroeconomic resilience function, even if its primary mandate remains long-term savings. In the present dissertation, this is interpreted not as a full stabilization-fund mandate, but as a secondary objective related to fiscal and macroeconomic resilience.

A third theoretical perspective comes from the resource-curse and economic-diversification literature (Sachs & Warner, 2001; van der Ploeg, 2011). This literature emphasizes that excessive dependence on natural-resource exports can generate structural vulnerability through exchange-rate pressure, export concentration, weak diversification, and exposure to external shocks. One policy response is to invest a portion of resource revenues in diversified foreign financial assets rather than allowing all mineral income to pass directly into domestic expenditure. In this sense, foreign asset accumulation serves not only as a savings mechanism, but also to reduce macroeconomic fragility and protect national wealth from domestic concentration risk. For Mongolia, this perspective reinforces the importance of a sovereign wealth fund objective centered on external financial diversification and long-term resilience.

The implications of these theoretical perspectives for Mongolia's sovereign wealth fund objectives are summarized in Table 3-5.

**Table 3-5:** Theoretical Basis for Sovereign Wealth Fund Objectives

| Theory | Objective | Implication for Mongolia |
|---|---|---|
| Permanent Income Hypothesis | Intergenerational savings | Long-term savings fund |
| Tax smoothing | Fiscal stabilization | Limited Stabilization mechanism |
| Resource curse theory | Diversification | Foreign asset investment |

*Source: Ph. D Candidate (2026)*

The establishment and effective functioning of a sovereign wealth fund (SWF) are fundamentally shaped by the macroeconomic conditions and institutional structures of the host economy. A substantial body of literature emphasizes that macroeconomic characteristics—particularly resource dependence, fiscal volatility, and external vulnerability—play a decisive role in determining not only the rationale for establishing an SWF, but also its objectives, governance framework, and asset-management mandate (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013; Al-Sayed, 2023). In developing and resource-dependent economies, these macro–institutional factors are especially consequential, because weak institutional capacity, volatile revenue streams, and pro-cyclical fiscal behavior can undermine fiscal sustainability, macroeconomic stability, and long-term intergenerational equity (Frankel, 2012; van der Ploeg & Venables, 2013; IMF, 2018). As argued in the recent SWF design literature, the key challenge is not merely to justify the existence of a fund, but to align its legal mandate, governance structure, and financial-management framework with the specific macroeconomic conditions of the country in which it operates.

Mongolia represents a particularly relevant case within this broader discussion. Existing studies and policy assessments consistently identify the country's dependence on mineral exports, exposure to global commodity-price fluctuations, and historically pro-cyclical fiscal behavior as major sources of macroeconomic instability. These structural conditions have contributed to repeated boom–bust cycles, external vulnerability, and persistent difficulties in sustaining long-term public savings. Within the broader literature on resource-dependent economies, such characteristics are widely recognized as constituting a strong economic justification for the establishment of a sovereign wealth fund capable of transforming finite natural-resource wealth into sustainable financial assets while supporting long-term fiscal discipline and intergenerational savings objectives.

Against this backdrop, the Future Heritage Fund of Mongolia represents the country's principal institutional mechanism for intergenerational savings and long-term fiscal sustainability. The Fund is designed to ensure the equal distribution of natural resource revenue between present and future generations, thereby reflecting a long-term savings rationale consistent with the intergenerational equity literature. At the same time, its present institutional structure reflects a transitional governance arrangement in which policy oversight, portfolio management, and operational execution are distributed across several public institutions. This institutional

configuration is particularly important for understanding the current strengths and limitations of the Fund's asset-management framework.

To clarify this institutional setting before proceeding to the broader macro–institutional analysis, Table 3-6 summarizes the principal institutional and financial characteristics of the Future Heritage Fund of Mongolia. As shown, the Fund operates under an investment mandate approved by the Government, with portfolio management assigned to the Ministry of Finance until 2030 and expected to be transferred thereafter to the Future Heritage Fund Corporation, while daily operations remain the responsibility of the Bank of Mongolia during the transition period. At the time of writing, the Fund's assets under management amount to USD 1,546.00 million, and its one-year return on assets stands at 3.474 percent. These features indicate that the Fund already has material macroeconomic significance in terms of asset accumulation, while its governance arrangement remains institutionally transitional.

**Table 3-6:** Institutional and financial profile of the Future Heritage Fund of Mongolia

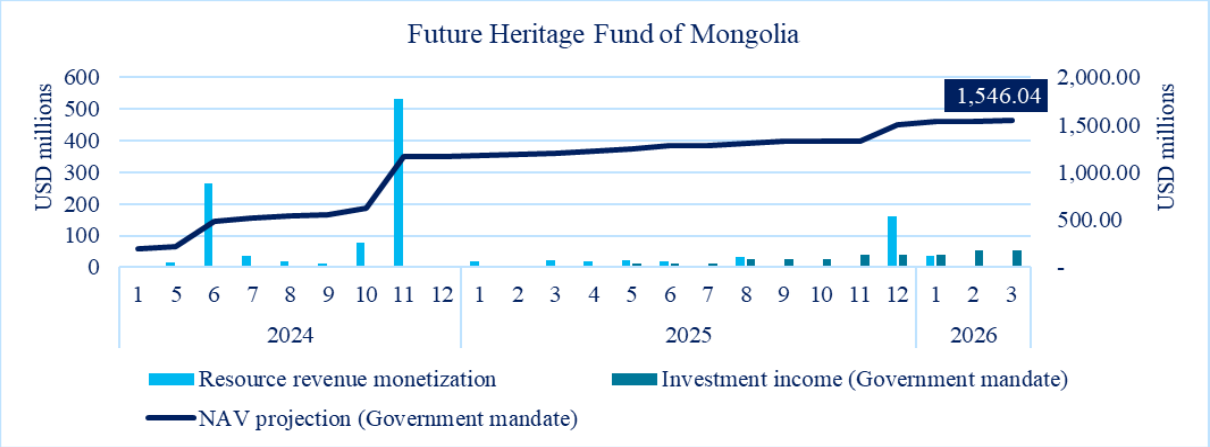
| | **Future Heritage Fund of Mongolia** |
|---|---|
| Fund's objectives: | Equal distribution of natural resource revenue for present and future generations. |
| Investment mandate: | Approved by Government |
| Portfolio manager until 2030: | Ministry of Finance |
| Portfolio manager from 2030: | Future Heritage Fund Corporations |
| Daily operations until 2030: | Bank of Mongolia |
| Asset under management: | 1,546.00 million USD |
| Return on Assets: | 3.474% (1 year) |
| Herfindahl–Hirschman Index (HHI) | 1 |

*Source: Ph.D. Candidate (2026)*

Table 3-6 shows that the Future Heritage Fund of Mongolia is not simply a passive savings vehicle, but a public financial institution embedded within a broader legal and administrative framework. Its structure reflects an early-stage governance model in which strategic authority, investment responsibility, and operational management remain only partially separated. From an institutional-design perspective, this is significant because the effectiveness of a sovereign wealth fund depends not solely on the volume of assets accumulated, but also on the coherence between fund objectives, governance arrangements, and financial-management responsibilities. In this sense, the current profile of the Fund suggests that Mongolia has established the legal and administrative foundations of a long-term savings fund, but that the long-run effectiveness of the Fund will depend on how successfully these arrangements evolve into a more integrated and analytically grounded asset-management framework.

Beyond the institutional profile presented in Table 3-6, the recent accumulation dynamics of the Fund are illustrated in Figure 3-3, which combines resource revenue monetization, investment income, and the projected net asset value path of the Future Heritage Fund of Mongolia.

**Figure 3-3:** Resource revenue monetization, investment income, and net asset value projection of the Future Heritage Fund of Mongolia, 2024–2026

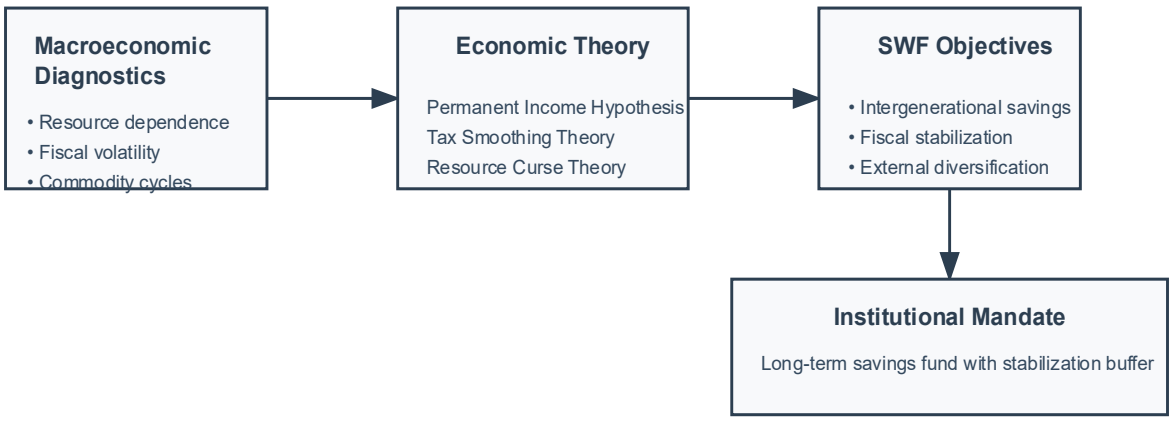



*Source: Ph.D. Candidate (2026)*

Table 3-6 shows that the macroeconomic objectives relevant to Mongolia's sovereign wealth fund are not derived from a single theory alone. Rather, they emerge from the interaction of intergenerational savings, fiscal resilience, and external diversification considerations. Among these, the strongest objective is long-term savings, since Mongolia's mineral wealth is exhaustible and the Future Heritage Fund of Mongolia is explicitly intended to preserve national wealth for future generations. At the same time, the fiscal volatility associated with commodity dependence implies that the fund should also contribute to broader macroeconomic resilience. Finally, the diversification literature supports the allocation of resource wealth into external financial assets as a means of reducing vulnerability associated with export concentration and domestic absorption pressure.

The overall theoretical determination of these objectives is illustrated in Figure 3-4.

**Figure 3-4:** Theoretical determination of sovereign wealth fund objectives




Source: Author's conceptual framework based on Friedman (1957), Barro (1979), Barnett & Ossowski (2003), and Sachs & Warner (2001)

As shown in Figure 3-4, the macroeconomic objectives of the sovereign wealth fund are derived from the interaction between resource exhaustibility, fiscal volatility, and structural dependence on mineral exports. In the framework of this dissertation, these objectives are not treated as abstract policy statements. Instead, they form the basis for the next analytical step, namely the

translation of sovereign macroeconomic purpose into operational long-term asset-allocation conditions.

Taken together, these theoretical perspectives indicate that the Future Heritage Fund of Mongolia should be understood primarily as a long-term savings fund designed to preserve national wealth across generations, while also supporting macroeconomic resilience through a limited stabilization function and external diversification through foreign asset accumulation. This combination of objectives is consistent with Mongolia's macroeconomic characteristics as a resource-dependent economy exposed to substantial volatility in global mineral markets. In the sequence of this dissertation, these findings complete the objective-identification stage and provide the direct basis for the next step: translating these macroeconomic objectives into long-term strategic asset-allocation constraints.

### 3.4 Sovereign Wealth Funds Typology

The classification of sovereign wealth funds according to their primary macroeconomic objectives constitutes an important analytical tool in the sovereign wealth fund literature because fund type influences governance arrangements, investment horizons, liquidity requirements, and tolerance for risk (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013). Building on earlier typologies, Al-Sayed (2023) classifies sovereign wealth funds into stabilization funds, savings funds, development funds, reserve-investment funds, and hybrid structures according to the relative emphasis placed on short-term stabilization, long-term wealth accumulation, and domestic investment objectives. This typological framework is especially useful for analyzing sovereign wealth funds in resource-dependent developing economies, where multiple macroeconomic objectives often coexist and require explicit institutional trade-offs.

Within this framework, the Future Heritage Fund of Mongolia is most appropriately classified as a savings-oriented sovereign wealth fund with secondary stabilization features. The dominant purpose of the Fund is the preservation of national wealth for future generations through the accumulation of financial assets derived from non-renewable mineral revenues. This orientation is consistent with the permanent income and intergenerational equity literature, which emphasizes that the central function of a savings-oriented sovereign wealth fund is to transform exhaustible resource rents into sustainable financial wealth over time (Davis et al., 2001; Barnett & Ossowski, 2003; Al-Sayed, 2023). At the same time, the Fund retains a limited stabilization role, reflecting Mongolia's exposure to commodity-price volatility, fiscal procyclicality, and recurrent external shocks.

This dual orientation places the Future Heritage Fund of Mongolia within Al-Sayed's hybrid category, combining long-term savings with limited stabilization functions within a rules-based framework. Importantly, however, the stabilization role remains subordinate to the long-term savings objective. This distinguishes the Fund from a pure stabilization fund, which would prioritize short-term fiscal smoothing, higher liquidity, and more frequent withdrawals. The hybrid classification should therefore not be interpreted as an ambiguous or transitional label, but as a deliberate institutional response to Mongolia's need to balance intergenerational savings with macroeconomic resilience.

The limited suitability of alternative sovereign wealth fund types reinforces this conclusion. A purely stabilization-oriented fund, while useful in smoothing short-term fiscal volatility, would not adequately address the intergenerational wealth challenge created by the exhaustible nature of Mongolia's mineral resources (van der Ploeg & Venables, 2013; Al-Hassan et al., 2018). A development-oriented sovereign wealth fund, characterized by domestic investment mandates and quasi-fiscal activity, would entail greater governance risk and a higher likelihood of political interference or crowding-out effects in a setting of evolving institutional capacity (Gelb et al., 2014; IMF, 2018). A reserve-investment fund, although relevant for enhancing returns on excess foreign reserves, would serve at most a complementary role and would not by itself satisfy the core objective of long-term intergenerational savings.

Accordingly, the classification of the Future Heritage Fund of Mongolia as a savings-oriented sovereign wealth fund with stabilization features reflects a deliberate institutional response to the country's stage of development, macroeconomic volatility, and governance constraints. By prioritizing long-term wealth accumulation while retaining limited stabilization capacity, the Fund's typological positioning is consistent with the experience of resource-rich developing economies seeking to balance fiscal resilience with intergenerational equity (Truman, 2010; Al-Hassan et al., 2013; Al-Sayed, 2023). In the context of this dissertation, this classification is analytically important because it clarifies the sovereign objective that will later be translated into long-term strategic asset-allocation conditions.

To summarize this interpretation, Table 3-7 classifies the Future Heritage Fund of Mongolia within Al-Sayed's sovereign wealth fund typology.

**Table 3-7**: Classification of the Future Heritage Fund of Mongolia within Al-Sayed's SWF Typology

| SWF Type | Primary Objective | Typical Characteristics | Applicability to Mongolia | Assessment |
|---|---|---|---|---|
| Stabilization Fund | Smooth fiscal revenues and absorb short-term commodity shocks | High liquidity; short investment horizon; frequent withdrawals linked to budget cycles | Relevant due to commodity price volatility and fiscal procyclicality | Secondary role |
| Savings Fund | Preserve wealth for future generations | Long investment horizon; accumulation of foreign financial assets; limited withdrawals | Strongly relevant given finite mineral resources and intergenerational equity concerns | Primary role |
| Development Fund | Finance, domestic investment and economic diversification | Domestic asset focus; higher political involvement; quasi-fiscal activities | Limited relevance due to governance risks and potential crowding-out effects | Not core |
| Reserve Investment Fund | Enhance returns on excess foreign reserves | Close integration with central bank reserve management; conservative risk profile | Partially relevant given institutional arrangements | Complementary |

| | | | | |
|---|---|---|---|---|
| Hybrid Fund | Combine stabilization and savings objectives | Rules-based allocation between short-term and long-term objectives | Matches Mongolia's macro-institutional needs | Most appropriate classification |

*Source: Ph. D candidate (2026)*

After establishing the broader typological classification, Table 3-8 summarizes the specific positioning of the Future Heritage Fund of Mongolia in terms of its dominant objective, secondary objective, investment horizon, withdrawal rules, and typological identity.

**Table 3-8**: Positioning of the Future Heritage Fund of Mongolia

| **Classification Dimension** | **Future Heritage Fund of Mongolia** |
|---|---|
| Dominant objective | Long-term savings and intergenerational wealth preservation |
| Secondary objective | Macroeconomic and fiscal stabilization |
| Investment horizon | Long-term |
| Withdrawal rules | Rules-based and legally constrained |

*Source: Ph. D candidate (2026)*

Taken together, Tables 3-7 and 3-8 show that the Future Heritage Fund of Mongolia is most appropriately understood not as a pure stabilization fund or a development fund, but as a long-term savings fund with limited stabilization characteristics. This conclusion is important for the next stage of the dissertation because the type of fund determines the broad investment logic of the portfolio. A savings-oriented fund implies a long-horizon strategic asset-allocation structure focused on accumulation, preservation, and resilience rather than on short-term liquidity or quasi-fiscal domestic deployment. In this way, typological classification becomes a necessary step in moving from macroeconomic diagnosis to operational portfolio design.

### 3.4.1 Institutional Design and Governance Implications

The institutional design of a sovereign wealth fund is a critical determinant of its effectiveness, sustainability, and credibility. A well-established body of literature emphasizes that the objectives, governance structure, and operational rules of a sovereign wealth fund should be derived from the macroeconomic conditions and fiscal challenges that justify its establishment (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013). Within this logic, Al-Sayed's institutional design framework is particularly relevant because it links macroeconomic conditions, fund objectives, fund type, structural design, and impact evaluation in a sequential model of sovereign wealth fund design.

In this framework, institutional design functions as the transmission mechanism through which macroeconomic diagnostics are translated into legal mandates, governance arrangements, withdrawal rules, and investment strategies. These diagnostics include revenue volatility, fiscal vulnerability, savings constraints, and intergenerational equity considerations. Weak or misaligned institutional arrangements can undermine the stabilization and savings functions of sovereign wealth funds, even when substantial natural-resource revenues are available (Gelb et al., 2014; IMF, 2018). Therefore, effective sovereign wealth fund design requires a coherent

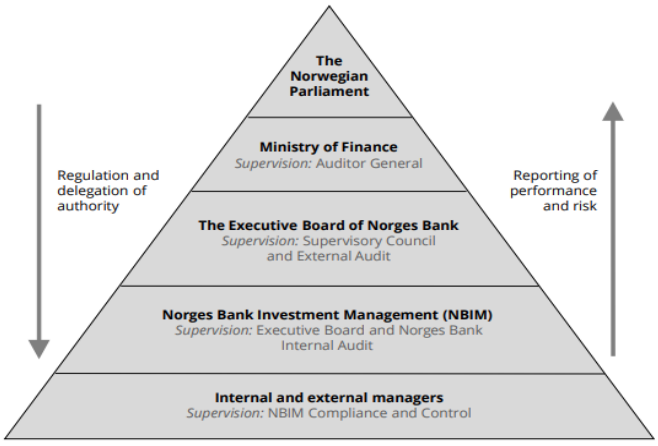
institutional framework that aligns macroeconomic objectives, legal mandates, governance structures, and investment policies.

Within this analytical structure, the articulation of clear and coherent fund objectives constitutes the cornerstone of institutional design. The literature consistently emphasizes that sovereign wealth fund objectives must reflect long-term national priorities and remain insulated from short-term political pressures to ensure intertemporal consistency, fiscal discipline, and credibility (Davis et al., 2001; Barnett & Ossowski, 2003; Al-Hassan et al., 2013). In resource-dependent economies, these objectives usually combine three related functions: mitigating macroeconomic volatility, accumulating long-term financial savings, and preserving national wealth for future generations (Truman, 2010; Al-Sayed, 2023). The relative weight assigned to these objectives determines the fund's classification, governance structure, withdrawal rules, investment horizon, and portfolio strategy.

In Mongolia's case, the institutional design of the Future Heritage Fund of Mongolia reflects a direct response to the macroeconomic vulnerabilities identified in the earlier sections of this chapter. As codified in the National Wealth Fund Law and the Future Heritage Fund of Mongolia Law, the Fund's primary objective is to preserve and accumulate national wealth for future generations, while its secondary objective is to contribute to macroeconomic and fiscal stability. This objective hierarchy is consistent with the international experience of savings-oriented sovereign wealth funds in resource-rich developing economies, where the transformation of exhaustible natural-resource revenues into diversified financial assets is prioritized over short-term fiscal financing or domestic development spending (IMF, 2018; Al-Hassan et al., 2013; Al-Sayed, 2023).

A useful international benchmark for understanding this institutional logic is the governance structure of Norway's sovereign wealth fund. The Norwegian model illustrates how ownership, supervision, operational management, and performance reporting can be institutionally separated within a coherent long-term savings framework. Although Mongolia cannot mechanically replicate Norway's institutional model because of differences in fiscal capacity, institutional development, and economic structure, the Norwegian case remains analytically useful. It demonstrates the importance of clear delegation, transparent reporting, and disciplined long-term investment governance.

**Figure 3-5:** Governance hierarchy and delegation structure of Norway's sovereign wealth fund




*Source: Ph. D candidate (2026)*

### 3.4.2 Governance Structure and Institutional Independence

Institutional governance and operational independence represent a second critical dimension of sovereign wealth fund design. The literature emphasizes that effective sovereign wealth funds require a clear separation between ownership, strategic oversight, and operational management, supported by transparent accountability and reporting mechanisms (Truman, 2010; IWG, 2008; Balding, 2012). Such separation is particularly important in developing economies, where political interference, limited institutional capacity, and short-term fiscal pressures may weaken investment discipline and reduce public confidence in the fund (Gelb et al., 2014; IMF, 2018).

Al-Sayed (2023) further emphasizes that governance arrangements must be aligned with the fund's macroeconomic mandate and risk tolerance. Savings-oriented sovereign wealth funds generally require stronger insulation from short-term fiscal and political pressures than stabilization-oriented funds because their investment horizons extend across multiple decades and their mandates focus on intergenerational wealth preservation rather than immediate budgetary support. This point is especially relevant for the Future Heritage Fund of Mongolia, whose long-term savings objective implies the need for stable rules, disciplined withdrawals, prudent risk management, and a strategic asset-allocation framework consistent with long-term accumulation.

The governance framework of the Future Heritage Fund of Mongolia reflects these principles, although it operates within the constraints of an evolving institutional environment. The Fund is legally established as a distinct public financial mechanism with rules governing inflows, withdrawals, and reporting requirements. At the same time, its operational independence remains closely linked to broader public-sector governance structures and coordination with fiscal and monetary authorities. This is common among newly established sovereign wealth funds in developing economies, where legal mandates may be clear, but investment governance, institutional capacity, and operational autonomy develop gradually over time (IMF, 2018; Al-Sayed, 2023).

This institutional context underscores the importance of a governance model that is both conservative and forward-looking. For the Future Heritage Fund of Mongolia, institutional credibility is not only a legal or administrative issue; it is directly connected to portfolio design. A long-term savings fund cannot achieve its intergenerational mandate if its investment strategy remains excessively short-term, weakly diversified, or disconnected from its legal objective. Therefore, the Fund's institutional design must support a portfolio structure capable of preserving capital, accumulating wealth, and withstanding macroeconomic and market uncertainty.

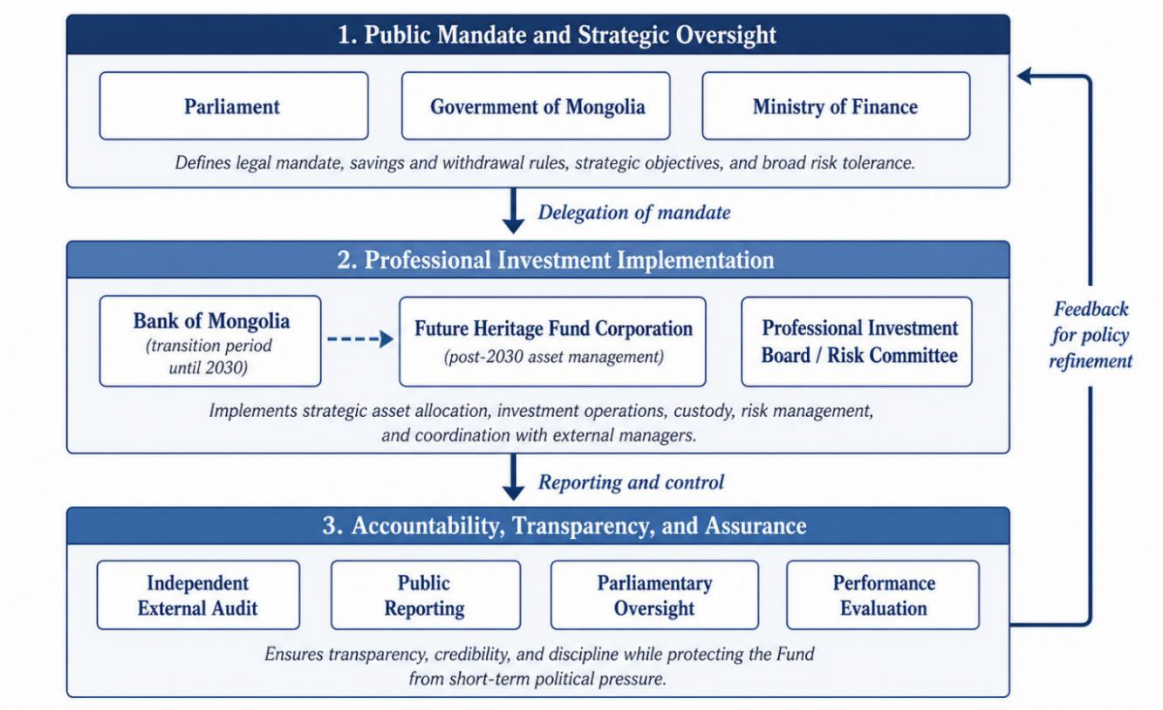
The degree of institutional independence directly affects strategic asset allocation. When a sovereign wealth fund lacks sufficient operational independence, portfolio decisions may become overly influenced by short-term fiscal needs, administrative caution, or changing political preferences. In practice, this can result in persistent concentration in low-risk short-term instruments, delayed diversification, and weak alignment between the portfolio and the Fund's long-term intergenerational savings mandate. By contrast, stronger institutional independence allows asset allocation to be guided by a stable investment horizon, clearly defined risk tolerance, and disciplined long-term portfolio policy.

For the Future Heritage Fund of Mongolia, such independence should be ensured through institutional safeguards rather than complete separation from public accountability. These safeguards include a legally stable mandate, clear division between ownership, strategic oversight, and operational investment management, rule-based deposit and withdrawal arrangements, formal investment policy statement, independent audit, transparent public reporting, and benchmark-based performance evaluation. Together, these mechanisms can protect long-term strategic asset allocation from ad hoc intervention while preserving democratic oversight and public accountability.

Accordingly, this dissertation proposes a hybrid governance model for the Future Heritage Fund of Mongolia. The proposed model combines three institutional layers. The first layer is the public mandate and strategic oversight layer, in which Parliament, the Government of Mongolia, and the Ministry of Finance define the legal mandate, savings and withdrawal rules, strategic objectives, and broad risk tolerance of the Fund. The second layer is the professional investment implementation layer, in which investment operations are gradually delegated to technically capable institutions. During the transition period until 2030, the Bank of Mongolia may continue to provide operational support in areas such as custody, settlement, liquidity management, and conservative investment execution. After 2030, the Future Heritage Fund Corporation should gradually assume a more independent asset-management role, supported by a professional investment board and risk committee. The third layer is the accountability, transparency, and assurance layer, which includes independent external audit, public reporting, parliamentary oversight, and performance evaluation.

This hybrid model seeks to balance public accountability with professional investment discipline. It recognizes that the Future Heritage Fund of Mongolia is a public institution managing national wealth, but it also requires sufficient operational independence to implement a long-term strategic asset allocation consistent with its savings mandate. In this sense, institutional independence is not a goal separate from portfolio management; it is a necessary condition for maintaining a stable, diversified, and mandate-consistent investment strategy over time.

**Figure 3-6:** Proposed Hybrid Governance Model for the Future Heritage Fund of Mongolia




*Source: Ph. D candidate (2026)*

The proposed hybrid governance model is suitable for Mongolia because it balances public accountability with gradual professional independence. It avoids the weakness of a fully government-controlled model, which may expose the Fund to short-term fiscal and political pressures. At the same time, it avoids the risks of premature full independence before sufficient investment governance, risk-management capacity, and institutional expertise have been developed. In this sense, hybrid governance provides a practical transition path from a legally established savings fund toward a professionally managed sovereign wealth fund.

This governance model also creates the institutional basis for strategic asset allocation. The public mandate layer defines the Fund's objective and risk tolerance; the professional implementation layer converts these objectives into investment operations; and the accountability layer ensures that portfolio decisions remain consistent with the Fund's long-term mandate. Therefore, governance design and portfolio design should not be treated separately. For the Future Heritage Fund of Mongolia, the quality of governance directly affects the quality and credibility of strategic asset allocation.

This leads directly to the next stage of the dissertation. Once the Future Heritage Fund of Mongolia has been classified as a long-term savings fund with limited stabilization characteristics, and once its governance structure has been understood as a hybrid and evolving arrangement, the key analytical question becomes how this institutional identity should be translated into strategic asset allocation. In other words, the Fund's macroeconomic rationale, legal mandate, and governance framework must be converted into an operational portfolio structure. The following section therefore moves from institutional classification and governance design to empirical strategic asset-allocation analysis. It examines whether the current investment structure of the Future Heritage Fund of Mongolia is consistent with its long-

term savings objective and whether a more robust and diversified allocation can better support its intergenerational mandate.

### 3.5 Strategic Asset Allocation

Strategic asset allocation is one of the most important components of sovereign wealth fund design because it determines how the macroeconomic purpose of the fund is translated into a long-term investment structure. The sovereign wealth fund literature consistently emphasizes that fund objectives, governance arrangements, and operational rules should be derived from the macroeconomic conditions and fiscal challenges that justify the establishment of the fund (Truman, 2010; Balding, 2012; Al-Hassan et al., 2013). In this sense, strategic asset allocation is not merely a technical financial decision. Rather, it represents the point at which sovereign purpose becomes operational portfolio policy.

This logic is consistent with Al-Sayed's institutional design framework, in which the structural design stage links macroeconomic diagnostics, fund objectives, governance arrangements, portfolio management, capital allocation, and withdrawal policies. Al-Sayed's framework emphasizes that the design of a sovereign wealth fund should be aligned with the country's macroeconomic objectives and institutional capacity, rather than being treated as a stand-alone investment exercise. Accordingly, strategic asset allocation can be understood as the operational expression of the Fund's mandate, risk tolerance, investment horizon, and institutional readiness.

From this comparative perspective, the institutional positioning of the Future Heritage Fund of Mongolia reflects a cautious and sequenced approach to sovereign wealth fund development. Given Mongolia's evolving governance environment, continued exposure to commodity-price volatility, and the transitional role of public institutions in fund management, the Fund is currently associated with a conservative strategic asset-allocation orientation. This orientation emphasizes liquidity, transparency, capital preservation, and prudent risk control. Such caution is understandable during the early stage of institutional development, particularly where investment governance, reporting systems, and risk-management capacity are still maturing.

However, the Fund's long-term savings and intergenerational wealth-preservation objective also requires a portfolio structure that can support wealth accumulation over time. A purely liquidity-oriented allocation may be appropriate during the initial transition period, but it may become inconsistent with the Fund's long-term mandate if maintained permanently. As institutional capacity strengthens and governance mechanisms mature, the Future Heritage Fund of Mongolia may gradually broaden its investment scope in line with the experience of established savings-oriented sovereign wealth funds. This does not imply an immediate shift toward aggressive or complex investment strategies. Rather, it suggests the need for a disciplined and gradual movement toward a more diversified strategic asset allocation consistent with the Fund's long-term purpose.

**Table 3-9:** Comparison of Current Management Portfolio with Benchmark Portfolio Allocations

| | Given Mandate | Max return portfolio | Min risk portfolio | Equal weight portfolio | Markowitz Portfolio |
|---|---|---|---|---|---|
| | Given Mandate | Max return | Min risk | Equal weight | Max sharpe ratio |
| 0-5 Year US Treasury | 0.00% | 0.00% | 1.36% | 25.00% | 20.23% |
| SP500 | 0.00% | 100.00% | 0.42% | 25.00% | 2.70% |
| Libor 3m | 100.00% | 0.00% | 98.22% | 25.00% | 77.06% |
| Fed overnight | 0.00% | 0.00% | 0.00% | 25.00% | 0.00% |
| Total weight | 100% | 100% | 100% | 100% | 100% |

| Portfolios | Given Mandate | Max return | Min risk | Equal weight | Markowitz Portfolio |
|---|---|---|---|---|---|
| Portfolio return | 2.27% | 7.22% | 2.30% | 3.54% | 2.50% |
| Portfolio risk | 0.58% | 15.23% | 0.58% | 3.75% | 0.72% |
| Sharpe ratio | 0.61 | 0.35 | 0.66 | 0.43 | 0.81 |
| Risk Free rate | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% |

*Source: Ph. D candidate (2026)*

Table 3-9 compares the current management portfolio with alternative benchmark portfolio allocations. The current management portfolio is fully allocated to LIBOR 3M, indicating a highly conservative investment structure centered on liquidity preservation and minimal volatility. The portfolio has an expected return of 2.27 percent and a risk level of 0.58 percent, placing it close to the minimum-risk portfolio and significantly below the return potential of more growth-oriented allocations.

This result shows that the current portfolio is consistent with the Fund's transitional governance environment, where capital preservation and operational caution dominate long-term return seeking. At the same time, the comparison with benchmark portfolios suggests that the existing allocation may be overly conservative relative to the Fund's long-term savings objective. A full allocation to a short-term money-market instrument limits the Fund's ability to accumulate intergenerational wealth and may generate a long-term opportunity cost if maintained over an extended period.

Therefore, the empirical comparison reinforces the need for a more explicit strategic asset-allocation framework for the Future Heritage Fund of Mongolia. Such a framework should remain consistent with the Fund's legal mandate, public-management constraints, and conservative institutional environment, while also allowing gradual diversification toward higher-return assets as governance capacity improves. In this way, strategic asset allocation becomes the key mechanism through which the Fund's long-term savings mandate can be translated into a practical investment policy.

The following empirical analysis therefore evaluates whether the current investment structure is consistent with the Fund's long-term objective and examines how alternative benchmark allocations may provide a more appropriate balance between capital preservation, return generation, and portfolio resilience. This provides the analytical basis for developing a more robust strategic asset-allocation framework for the Future Heritage Fund of Mongolia.

*Convex and Sphere packing approaches to portfolio optimization*

**Markowitz optimization formulation**

The classical mean–variance portfolio theory of Markowitz models portfolio selection as a quadratic optimization problem balancing expected return and risk. Let $\mu = (r_1, r_2, \dots, r_n)$

denote the vector of expected asset returns, let $C = (c_{ij})$ be the positive definite covariance matrix of returns, and let $x = (x_1, x_2, \dots, x_n)$ denote the vector of portfolio weights satisfying $\sum_{i=1}^{n} x_i = 1$ and $x_i \geq 0$. The expected return and variance of a portfolio are given by

$$R(x) = \langle \mu, x \rangle, \qquad \sigma^2(x) = \langle Cx, x \rangle, \qquad C \succ 0.$$

Depending on the investor's objective, the mean–variance model admits several equivalent formulations.

Problem M1 (Minimum-variance portfolio)
Determine the portfolio with minimum variance under full investment. This problem identifies the lower bound of the efficient frontier.

$$\begin{aligned} \text{minimize} \quad & \langle Cx, x \rangle \\ \text{subject to} \quad & \sum_{i=1}^{n} x_i = 1. \end{aligned}$$

Problem M2 (Minimum variance with target return)
Minimize portfolio variance subject to achieving a required return level $r_0$.

$$\begin{aligned} \text{minimize} \quad & \frac{1}{2}\langle Cx, x \rangle, \\ \text{subject to} \quad & \langle \mu, x \rangle \geq r_0, \\ & \sum_{i=1}^{n} x_i = 1. \end{aligned}$$

Problem M3 (Mean–variance utility maximization)
Maximize a quadratic utility function balancing expected return and variance.

$$\begin{aligned} \text{maximize} \quad & \langle \mu, x \rangle - \frac{1}{2}\langle Cx, x \rangle, \\ \text{subject to} \quad & \sum_{i=1}^{n} x_i = 1. \end{aligned}$$

Problem M4 (Return maximization under risk constraint)
Maximize expected return subject to an upper bound on allowable variance.

$$\begin{aligned} \text{maximize} \quad & \langle \mu, x \rangle, \\ \text{subject to} \quad & \langle Cx, x \rangle \leq \sigma_0^2, \\ & \sum_{i=1}^{n} x_i = 1. \end{aligned}$$

These formulations characterize exact efficient frontier portfolios under the classical full investment constraint $\sum_{j=1}^{n} x_j = 1$. In practice, however, institutional investors frequently operate under mandate constraints and benchmark allocations that require feasibility restoration rather than complete re-optimization of an extremal objective. Moreover, stability considerations may favor allocations that remain sufficiently interior to the admissible region so as to tolerate moderate perturbations without immediate violation of mandate limits.

Section 3 adopts the relaxed budget constraint $\langle \mathbf{1}, x \rangle \leq 1$ to allow partial investment (liquidity buffers), while Section 2 reviews the classical fully invested frontier $\langle \mathbf{1}, x \rangle = 1$. The next

section introduces two complementary constructions: convex programming–based feasibility restoration and sphere packing–based geometric interior maximization that address these practical considerations while preserving the quadratic structure of the mean–variance framework.

**Convex and sphere packing approaches portfolio optimization**

We consider $\varepsilon$–approximate formulations that permit controlled tolerances in the constraints and reinterpret the portfolio selection problem from two complementary perspectives: convex programming and sphere packing approach.

Let $\varepsilon > 0$ denote a small tolerance parameter. The approximate feasible region can be written as

$$D = \left\{ x \in \mathbb{R}^n : \langle Cx, x \rangle \leq \sigma^2 + \varepsilon,\ \langle \mu, x \rangle \geq \mu_0,\ \sum_{j=1}^{n} x_j \leq 1 \right\}.$$

Equivalently, one may find a feasible $x$ satisfying

$$\begin{aligned} &\langle Cx, x \rangle \leq \sigma^2 + \varepsilon, \\ &\langle \mu, x \rangle \geq \mu_0, \\ &\sum_{j=1}^{n} x_j \leq 1, \end{aligned}$$

where $C \succcurlyeq 0$ denotes the covariance matrix of asset returns in the quadratic variance constraint of Markowitz. The inequality budget constraint allows partial investment, reflecting the practical possibility of holding liquidity buffers rather than imposing full investment at all times. The quantity $\sigma^2$ is defined as

$$\sigma^2 = \min \left\{ \langle Cx, x \rangle : \sum_{j=1}^{n} x_j = 1,\ x \geq 0 \right\},$$

i.e., the minimum achievable portfolio variance under the classical full investment constraint. The minimization defining $\sigma^2$ is performed under the classical full investment constraint $\sum_{j=1}^{n} x_j = 1$. Thus, $\sigma^2$ represents the theoretical minimum-variance benchmark associated with the fully invested portfolio. The tolerance parameter $\varepsilon > 0$ allows controlled deviation from this lower bound while preserving consistency with the classical mean–variance framework.

**Convex programming formulation**

The reference portfolio $y$ is assumed to be given exogenously, for example as a benchmark or mandate derived allocation that may become infeasible under updated risk or return constraints. We view the convex formulation as projecting a reference portfolio $y \in \mathbb{R}^n$ onto the feasible region:

$$\begin{aligned} \text{minimize} \quad & u(x) = \| x - y \|^2 \\ \text{subject to} \quad & \langle Cx, x \rangle \leq \sigma^2 + \varepsilon, \\ & \langle \mu, x \rangle \geq \mu_0, \\ & \langle \mathbf{1}, x \rangle \leq 1, \\ & x \geq 0. \end{aligned}$$

It is clear that problem is a convex quadratic program. The objective is strictly convex, so the minimizer is unique whenever the feasible region is nonempty.

***Sphere packing approach***

Following the sphere packing approach developed in (Enkhbat 2020), we analyze the robustness of a feasible region by inscribing the largest possible Euclidean ball within it. Let $B(x_0, r)$ denote a Euclidean ball with center $x_0 \in \mathbb{R}^n$ and radius $r \geq 0$:

$$B(x_0, r) = \{ x \in \mathbb{R}^n : \| x - x_0 \| \leq r \},$$

where $\|\cdot\|$ is the Euclidean norm. The $n$-dimensional volume of $B(x_0, r)$ is

$$V\big(B(x_0, r)\big) = \frac{\pi^{n/2}}{\Gamma(n/2 + 1)} r^n,$$

where $\Gamma(\cdot)$ denotes Euler's gamma function.

Consider the polyhedral set

$$\overline{D} = \{x \in \mathbb{R}^n : \langle a_i, x \rangle \leq b_i,\ i = 1, \dots, m\},$$

where $a_i \in \mathbb{R}^n$ and $b_i \in \mathbb{R}$, $i = 1, \dots, m$. For a point $x \in \mathbb{R}^n$ and radius $r \geq 0$, define the closed ball

$$B(x, r) = \{z \in \mathbb{R}^n : \| z - x \| \leq r\}.$$

The inclusion condition $B(x, r) \subset \overline{D}$ can be written in the following equivalent form (see, e.g., Enkhbat 2020):

$$B(x, r) \subset \overline{D} \quad \Leftrightarrow \quad \langle a_i, x \rangle + r \| a_i \| \leq b_i,\ i = 1, \dots, m.$$

Geometric interpretation of the robustness radius. Let $\overline{D} \subset \mathbb{R}^n$ be the nonempty closed convex polyhedral set defined in equation polyhedral set. The optimal radius $r^*$ obtained from the linear program associated with inclusion condition defines the largest Euclidean ball $B(x^*, r^*) \subset \overline{D}$.

Consequently,

$$r^* = \operatorname{dist}\big(x^*, \partial\overline{D}\big),$$

where $\partial\overline{D}$ denotes the boundary of $\overline{D}$.

Thus, for any perturbation $\Delta$ satisfying $\| \Delta \| \leq r^*$, the perturbed allocation $x^* + \Delta$ remains feasible. The quantity $r^*$ therefore provides a geometric measure of allocation robustness with respect to portfolio weight perturbations under the Euclidean norm.

Thus, the one sphere packing problem in the polyhedral set $D$ reduces to linear programming:

$$\begin{array}{ll} \text{maximize} & r \\ \text{subject to} & \langle a_i, x \rangle + r \| a_i \| \leq b_i, \quad i = 1, \dots, m, \\ & r \geq 0. \end{array}$$

The optimal solution $(x^*, r^*)$ gives the center $x^*$ and radius $r^*$ of the largest ball that can be inscribed in the polyhedral set $D$.

Now we apply sphere packing approach to portfolio optimization.
Consider the system

$$\begin{aligned} &\langle Cx, x\rangle \le \sigma^2 + \varepsilon, \\ &\langle \mu, x\rangle \ge \mu_0, \\ &\sum_{j=1}^{n} x_j \le 1, \quad x \ge 0. \end{aligned}$$

In practice, rather than solving the extremal formulation of Problem M2, we seek a portfolio that satisfies prescribed return, variance, and relaxed budget thresholds without minimizing variance or maximizing expected return.

To construct such a feasible allocation, we decompose the admissible region into two convex sets.

For this purpose, define two convex sets:

$$D_1 = \{\, x : \langle \mu, x\rangle \ge \mu_0\,, \quad \sum_{j=1}^{n} x_j \le 1\,, \quad 0 \le x_j \le 1 \,\}$$

$$D_2 = \{\, x : \langle Cx, x\rangle \le \sigma^2 + \varepsilon \,\}$$

To find a feasible solution $x^0 \in D_1 \cap D_2$, we first determine a feasible point in $D_1$ by solving the following linear program:

$$\begin{aligned} \text{maximize} \quad & r \\ \text{subject to} \quad & \langle \mu, x\rangle - r \parallel \mu \parallel \ge \mu_0, \\ & \sum_{j=1}^{n} x_j + r\sqrt{n} \le 1, \\ & x_j + r \le 1, \quad j = 1, \dots, n, \\ & x_j \ge 0, \quad r \ge 0. \end{aligned}$$

The optimal pair $(x^0, r^*)$ provides the center $x^0$ and radius $r^*$ of the largest sphere contained in $D_1$. Since $D_1$ is a bounded polyhedral convex set, problem computes its Chebyshev center, i.e., the unique point that maximizes the minimum Euclidean distance to all supporting hyperplanes defining $D_1$. Consequently, $r^*$ equals the maximal uniform perturbation radius such that every point in the ball $B(x^0, r^*)$ remains feasible with respect to the linear constraints in $D_1$.

Next, we determine $x^h$ such that $x^h \in D_2$. Construct points $x^h = x^0 + \alpha h$ such that $x^h \in D_2$ for some $h \in \mathbb{R}^n$.
Compute

$$\langle Cx^0, x^0\rangle + 2\alpha\,\langle Cx^0, h\rangle + \alpha^2\langle Ch, h\rangle \le \sigma^2 + \varepsilon.$$

Denote by

$$a = \langle Ch, h\rangle, \qquad b = 2\langle Cx^0, h\rangle, \qquad c = \langle Cx^0, x^0\rangle - \sigma^2 - \varepsilon.$$

Then, $\alpha$ must satisfy $a\alpha^2 + b\alpha + c \le 0$, whose discriminant $\Delta = b^2 - 4ac > 0$ ensures the feasibility. The corresponding roots are

$$\alpha_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}, \qquad \alpha_1 < \alpha_2.$$

Hence, $\alpha$ is feasible whenever $\alpha_1 \leq \alpha \leq \alpha_2$, and for $x = x(\alpha)$, we have

$$x_i^0 + \alpha_1 h_i \leq x_i \leq x_i^0 + \alpha_2 h_i, \qquad i = 1, \dots, n.$$

No post-hoc normalization or rescaling is applied; feasibility with respect to the quadratic constraint is ensured directly through the interval condition on $\alpha$. For a fixed direction $h$, any $\alpha \in [\alpha_1, \alpha_2]$ yields $x(\alpha) = x^0 + \alpha h$, satisfying the quadratic constraint defining $D_2$.

Feasible portfolios are therefore obtained by intersecting the directional interval $[\alpha_1, \alpha_2]$ (ensuring $D_2$-feasibility) with the additional requirement that $x(\alpha) \in D_1$. The overall feasible region of the sphere packing portfolio problem remains $D_1 \cap D_2$.

The optimal $r^*$ from sphere-packing measures the maximal uniform perturbation radius with respect to the linear constraint set $D_1$, i.e., the largest Euclidean distance from $x^0$ to the supporting hyperplanes defining $D_1$. This robustness measure does not incorporate the quadratic variance constraint $D_2$, which is subsequently enforced through the directional construction. Accordingly, $x^0$ represents the Chebyshev center of $D_1$ and serves as a geometrically stable reference allocation relative to the linear admissible region.

In practice, the direction vector $h$ is not predetermined but is selected from admissible directions, for example through Monte Carlo sampling or structured search procedures within $D_1 \cap D_2$, to reflect desired patterns of portfolio adjustment while preserving feasibility.

Data Analysis for Computational Experiments

Before conducting the computational experiments, this study prepares the financial input data used in the portfolio optimization model. The dataset consists of monthly return observations for four investment instruments: U.S. Treasury 0–5Y, S&P 500, LIBOR 3M, and the Federal overnight rate. The sample covers the period from January 2000 to September 2025 and contains 309 usable monthly observations for each asset. These instruments are selected to represent the main investment choices available within the current mandate environment of the Future Heritage Fund of Mongolia, including short-duration fixed-income exposure, equity exposure, and short-term money-market instruments.

The monthly return series are used to estimate the expected return vector and the covariance matrix required for portfolio optimization. The expected return vector is calculated as the historical average monthly return of each asset, while the covariance matrix is estimated from the same monthly return series. In the optimization model, the covariance matrix serves as the risk matrix C in the portfolio variance expression ⟨Cx, x⟩. The estimated mean return vector and covariance matrix therefore provide the empirical basis for constructing and comparing alternative strategic asset-allocation portfolios.

**Table 3-3:** Data summary

| Item | Value |
|---|---|
| Start date | 1999-12-31 |
| End date | 2025-09-30 |
| Number of observations | 310 |
| Number of assets | 4 |
| Usable return observations per asset | 309 |

*Source: Ph. D Candidate (2026)*

**Table 3-4:** Descriptive statistics for monthly returns

| Asset | Observations | Median | Standard_ Deviation | Minimum | Maximum | Skewness | Kurtosis | Jarque_Bera _Statistic | Jarque_Bera _p_value | Normality_Result |
|---|---|---|---|---|---|---|---|---|---|---|
| UST_0_5Y | 309 | 0.00 | 0.01 | (0.01) | 0.02 | 0.10 | 3.77 | 8.11 | 0.02 | Reject normality |
| SP500 | 309 | 0.01 | 0.04 | (0.17) | 0.13 | (0.51) | 3.82 | 21.85 | 0.00 | Reject normality |
| LIBOR_3M | 309 | 0.00 | 0.00 | 0.00 | 0.01 | 0.67 | 2.04 | 35.28 | 0.00 | Reject normality |
| FED_OVERNIGHT | 309 | 0.00 | 0.00 | - | 0.01 | 0.73 | 2.10 | 37.75 | 0.00 | Reject normality |

*Source: Ph. D Candidate (2026)*

The descriptive statistics show that the S&P 500 has the highest average monthly return, but it also has the highest volatility. In contrast, LIBOR 3M and the Federal overnight rate have much lower volatility, reflecting their money-market characteristics. The Jarque–Bera test rejects normality for all four series, suggesting that the return distributions are not normally distributed. This supports the need for a robust portfolio optimization framework rather than relying only on standard mean–variance assumptions.

**Table 3-5:** Annualized return and risk

| Asset | Mean Monthly Return | Annualized Return | Monthly Standard Deviation | Annualized Standard Deviation |
|---|---|---|---|---|
| UST_0_5Y | 0.002277 | 0.027319 | 0.005031 | 0.017427 |
| SP500 | 0.006019 | 0.072223 | 0.043810 | 0.151762 |
| LIBOR_3M | 0.001894 | 0.022724 | 0.001698 | 0.005882 |
| FED_OVERNIGHT | 0.001597 | 0.019167 | 0.001719 | 0.005954 |

*Source: Ph. D Candidate (2026)*

The annualized statistics show a clear risk-return trade-off. The S&P 500 generated the highest annualized return of approximately 7.22 percent, but with annualized volatility of approximately 15.18 percent. U.S. Treasury 0–5Y generated lower return and much lower volatility. LIBOR 3M and the Federal overnight rate produced relatively low returns with very low volatility. These results show that an overly conservative allocation may reduce long-term accumulation potential, while excessive equity exposure may increase risk.

**Table 3-6:** ADF Stationary test

| Asset | ADF Statistic | p-value | Lag Order | Result |
|---|---|---|---|---|
| UST_0_5Y | -5.318095 | 0.010000 | 6 | Stationary |
| SP500 | -6.210648 | 0.010000 | 6 | Stationary |
| LIBOR_3M | -2.768912 | 0.252223 | 6 | Non-stationary |
| FED_OVERNIGHT | -3.221407 | 0.084647 | 6 | Non-stationary |

*Source: Ph. D Candidate (2026)*

The ADF test results show that the U.S. Treasury 0–5Y and S&P 500 monthly return series are stationary at the 5 percent significance level. However, LIBOR 3M and the Federal overnight rate are not stationary at the 5 percent level. This suggests that these two variables behave more like short-term interest-rate or money-market return proxies rather than conventional risky asset return indices. Therefore, they are interpreted carefully as short-term cash-rate instruments in the optimization framework.

**Table 3-7:** Correlation matrix

| Asset | UST_0_5Y | SP500 | LIBOR_3M | FED_OVERNIGHT |
|---|---|---|---|---|
| UST_0_5Y | 1.000000 | -0.195562 | 0.320378 | 0.330405 |

| | | | | |
|---|---|---|---|---|
| SP500 | -0.195562 | 1.000000 | -0.064111 | -0.042412 |
| LIBOR_3M | 0.320378 | -0.064111 | 1.000000 | 0.989631 |
| FED_OVERNIGHT | 0.330405 | -0.042412 | 0.989631 | 1.000000 |

*Source: Ph. D Candidate (2026)*

The correlation matrix shows that the S&P 500 has weak negative correlations with U.S. Treasury 0–5Y, LIBOR 3M, and the Federal overnight rate. This indicates that equity exposure may provide diversification benefits within the portfolio. In contrast, LIBOR 3M and the Federal overnight rate have an almost perfect positive correlation of 0.9896, suggesting that these two instruments represent very similar short-term money-market exposure.

**Table 3-8:** Covariance matrix

| Asset | UST_0_5Y | SP500 | LIBOR_3M | FED_OVERNIGHT |
|---|---|---|---|---|
| UST_0_5Y | 0.00002531 | -0.00004310 | 0.00000274 | 0.00000286 |
| SP500 | -0.00004310 | 0.00191932 | -0.00000477 | -0.00000319 |
| LIBOR_3M | 0.00000274 | -0.00000477 | 0.00000288 | 0.00000289 |
| FED_OVERNIGHT | 0.00000286 | -0.00000319 | 0.00000289 | 0.00000295 |

*Source: Ph. D Candidate (2026)*

The covariance matrix confirms the substantial difference in risk across the selected instruments. The S&P 500 has the highest variance, indicating the largest contribution to portfolio risk. LIBOR 3M and the Federal overnight rate have very low variances, reflecting their money-market characteristics. This covariance matrix is used as the matrix C in the portfolio variance expression $\langle Cx, x \rangle$.

**Table 3-9:** ARCH-LM volatility clustering Test

| Asset | ARCH-LM Statistic | p-value | Lags | Result |
|---|---|---|---|---|
| UST_0_5Y | 48.833781 | 0.000002 | 12 | ARCH effect exists |
| SP500 | 41.278155 | 0.000044 | 12 | ARCH effect exists |
| LIBOR_3M | 291.886369 | 0.000000 | 12 | ARCH effect exists |
| FED_OVERNIGHT | 292.995409 | 0.000000 | 12 | ARCH effect exists |

*Source: Ph. D Candidate (2026)*

The ARCH-LM test results indicate statistically significant volatility clustering in all four series. This means that volatility is time-varying rather than constant over the sample period. This finding supports the use of a robust portfolio construction framework, because the risk structure faced by the Future Heritage Fund of Mongolia may change across market regimes.

**Table 3-10:** Ljung-Box Autocorrelation Test

| Asset | Ljung–Box Statistic | p-value | Lags | Result |
|---|---|---|---|---|
| UST_0_5Y | 85.899577 | 0.000000 | 12 | Autocorrelation exists |
| SP500 | 14.547656 | 0.267110 | 12 | No significant autocorrelation |
| LIBOR_3M | 2604.052207 | 0.000000 | 12 | Autocorrelation exists |
| FED_OVERNIGHT | 2648.197770 | 0.000000 | 12 | Autocorrelation exists |

*Source: Ph. D Candidate (2026)*

The Ljung–Box test results show mixed evidence of autocorrelation. The S&P 500 return series does not exhibit statistically significant autocorrelation at the 5 percent level, suggesting that equity returns are not strongly serially dependent on the monthly data. In contrast, U.S. Treasury 0–5Y, LIBOR 3M, and the Federal overnight rate show significant autocorrelation. For the short-term rate instruments, this reflects the persistence of interest-rate conditions over time.

**Table 3-11:** Pairwise regression summary

| Asset Pair | Main Relationship | R-squared | Interpretation |
|---|---|---|---|
| UST_0_5Y - SP500 | Negative relationship | 0.038245 | Weak diversification relationship |
| SP500 - LIBOR_3M | Not significant | 0.004110 | Weak relationship |
| SP500 - FED_OVERNIGHT | Not significant | 0.001799 | Weak relationship |
| LIBOR_3M - FED_OVERNIGHT | Positive and highly significant | 0.979370 | Strong overlapping exposure |

*Source: Ph. D Candidate (2026)*

The pairwise regression results confirm the diversification structure observed in the correlation matrix. The relationship between U.S. Treasury 0–5Y and the S&P 500 is negative but weak. The S&P 500 is not strongly explained by LIBOR 3M or the Federal overnight rate. The strongest relationship is observed between LIBOR 3M and the Federal overnight rate, confirming that the two instruments represent highly overlapping short-term interest-rate exposure.

**Table 3-12:** Pairwise Newey-West HAC regression summary

| Asset Pair | HAC Coefficient | HAC p-value | OLS R-squared | Interpretation |
|---|---|---|---|---|
| UST_0_5Y on SP500 | -0.022456 | 0.081108 | 0.038245 | Weak negative relationship |
| SP500 on UST_0_5Y | -1.703072 | 0.114594 | 0.038245 | Not significant at 5 percent |
| SP500 on LIBOR_3M | -1.654135 | 0.233588 | 0.004110 | Not significant |
| SP500 on FED_OVERNIGHT | -1.081135 | 0.416193 | 0.001799 | Not significant |
| LIBOR_3M on FED_OVERNIGHT | 0.977732 | 0.000000 | 0.979370 | Strong overlapping exposure |
| FED_OVERNIGHT on LIBOR_3M | 1.001674 | 0.000000 | 0.979370 | Strong overlapping exposure |

*Source: Ph. D Candidate (2026)*

The Newey–West HAC regression results provide a more conservative test of the relationships among the selected assets by adjusting standard errors for autocorrelation and heteroskedasticity. After this correction, the negative relationship between U.S. Treasury 0–5Y and the S&P 500 becomes statistically weaker. However, the relationship between LIBOR 3M and the Federal overnight rate remains highly significant, confirming that these two instruments represent strongly overlapping money-market exposure.

**Table 3-13:** Multiple regression coefficients

| Dependent Asset | Explanatory Variable | Coefficient | p-value | Interpretation |
|---|---|---|---|---|
| UST_0_5Y | SP500 | -0.022229 | 0.000351 | Significant negative relationship |
| UST_0_5Y | LIBOR_3M | -1.563444 | 0.157579 | Not significant |
| UST_0_5Y | FED_OVERNIGHT | 2.471732 | 0.023924 | Significant positive relationship |
| SP500 | UST_0_5Y | -1.848416 | 0.000351 | Significant negative relationship |
| SP500 | LIBOR_3M | -29.439001 | 0.003345 | Significant, but affected by multicollinearity |
| SP500 | FED_OVERNIGHT | 29.489995 | 0.003040 | Significant, but affected by multicollinearity |
| LIBOR_3M | UST_0_5Y | -0.004182 | 0.157579 | Not significant |
| LIBOR_3M | SP500 | -0.000947 | 0.003345 | Significant negative relationship |
| LIBOR_3M | FED_OVERNIGHT | 0.980753 | 0.000000 | Strong overlapping exposure |

| | | | | |
|---|---|---|---|---|
| FED_OVERNIGHT | UST_0_5Y | 0.006720 | 0.023924 | Significant positive relationship |
| FED_OVERNIGHT | SP500 | 0.000964 | 0.003040 | Significant positive relationship |
| FED_OVERNIGHT | LIBOR_3M | 0.996891 | 0.000000 | Strong overlapping exposure |

*Source: Ph. D Candidate (2026)*

The multiple regression results should be interpreted with caution because LIBOR 3M and the Federal overnight rate are highly correlated. This high collinearity may affect the stability of individual regression coefficients. Therefore, the regression results are used mainly as diagnostic evidence of diversification and overlapping exposure rather than as a causal model.

**Table 3-14:** Multiple regression fit statistics

| Dependent Asset | R-squared | Adjusted R-squared | F-statistic | F p-value | Interpretation |
|---|---|---|---|---|---|
| UST_0_5Y | 0.147795 | 0.139413 | 17.631720 | 0.000000 | Low explanatory power; diversification benefit likely exists |
| SP500 | 0.065592 | 0.056401 | 7.136666 | 0.000120 | Low explanatory power; diversification benefit likely exists |
| LIBOR_3M | 0.979992 | 0.979795 | 4979.671904 | 0.000000 | High explanatory power; overlapping exposure may exist |
| FED_OVERNIGHT | 0.980149 | 0.979954 | 5019.828003 | 0.000000 | High explanatory power; overlapping exposure may exist |

*Source: Ph. D Candidate (2026)*

The regression fit statistics show that U.S. Treasury 0–5Y and S&P 500 returns have low explanatory power when regressed on the remaining assets. This indicates that these two instruments provide relatively distinct sources of return and risk within the asset universe. In contrast, LIBOR 3M and the Federal overnight rate have very high R-squared values of approximately 0.98, suggesting that these two instruments represent strongly overlapping short-term interest-rate exposure.

**Table 3-15:** Multiple Newey-West HAC regression summary

| Dependent Asset | Explanatory Variable | HAC Coefficient | HAC p-value | Interpretation |
|---|---|---|---|---|
| UST_0_5Y | SP500 | -0.022229 | 0.068512 | Weakly significant at 10 percent |
| UST_0_5Y | LIBOR_3M | -1.563444 | 0.403830 | Not significant |
| UST_0_5Y | FED_OVERNIGHT | 2.471732 | 0.190494 | Not significant |
| SP500 | UST_0_5Y | -1.848416 | 0.094531 | Weakly significant at 10 percent |
| SP500 | LIBOR_3M | -29.439001 | 0.085137 | Weakly significant, affected by multicollinearity |
| SP500 | FED_OVERNIGHT | 29.489995 | 0.083605 | Weakly significant, affected by multicollinearity |
| LIBOR_3M | UST_0_5Y | -0.004182 | 0.329186 | Not significant |

| | | | | |
|---|---|---|---|---|
| LIBOR_3M | SP500 | -0.000947 | 0.199596 | Not significant |
| LIBOR_3M | FED_OVERNIGHT | 0.980753 | 0.000000 | Strong overlapping exposure |
| FED_OVERNIGHT | UST_0_5Y | 0.006720 | 0.098329 | Weakly significant at 10 percent |
| FED_OVERNIGHT | SP500 | 0.000964 | 0.202676 | Not significant |
| FED_OVERNIGHT | LIBOR_3M | 0.996891 | 0.000000 | Strong overlapping exposure |

*Source: Ph. D Candidate (2026)*

The multiple Newey–West HAC regression results show that, after adjusting for autocorrelation and heteroskedasticity, most cross-asset relationships become statistically weaker. The negative relationship between U.S. Treasury 0–5Y and the S&P 500 remains, but it is only weakly significant at the 10 percent level. In contrast, the relationship between LIBOR 3M and the Federal overnight rate remains highly significant, confirming that these two instruments represent strongly overlapping short-term money-market exposure.

**Table 3-16:** Summary of econometric evidence for optimization

| Test Area | Main Finding | Relevance for Optimization |
|---|---|---|
| Descriptive statistics | Assets differ substantially in return and risk | Supports comparison of alternative asset allocations |
| Normality test | All series reject normality | Supports robust analysis |
| ADF test | Treasury and equity are stationary; short-term rates are non-stationary | Short-term rates should be interpreted carefully |
| Correlation matrix | Equity has weak negative correlations with other assets | Supports diversification benefits |
| Covariance matrix | S&P 500 has the highest variance | Provides matrix C for portfolio risk |
| ARCH-LM test | All series show volatility clustering | Supports robust optimization |
| Ljung–Box test | Autocorrelation exists in several series | Supports robust inference and diagnostics |
| Rolling volatility | Risk changes over time | Supports time-varying uncertainty argument |
| Regression analysis | LIBOR 3M and FED overnight strongly overlap | Shows that not all instruments add diversification |
| HAC regression | Most relationships weaken after robust correction | Supports cautious interpretation of OLS results |

*Source: Ph. D Candidate (2026)*

Overall, the data input stage serves two purposes. First, it transforms the historical monthly return series into the mean vector and covariance matrix required for computational experiments. Second, it provides econometric evidence that the selected assets are exposed to uncertainty, time-varying volatility, autocorrelation, non-normality, and overlapping risk factors. These findings justify the use of convex programming and sphere-packing-based robust portfolio optimization in the following computational experiment section.

Computational experiments

To illustrate the proposed convex programming and sphere packing framework, we consider a four-asset universe aligned with the investment categories of the Sovereign Wealth Fund of Mongolia. The assets correspond to the mandate defined allocation segments:

- 0–5 Year U.S. Treasury: fixed-income portfolio,
- S&P 500 index: equity portfolio,
- 3-Month LIBOR: deposit portfolio,
- Federal Reserve overnight rate: liquidity portfolio.

Monthly return data covering January 2000 to September 2025 were used to construct the empirical inputs of the model. The mean return vector $\mu$ and covariance matrix $C$ were estimated from monthly return observations and subsequently annualized by multiplying the sample monthly estimates by 12. Tables 3-24 and 3-25 report the resulting statistical input employed in the portfolio analysis.

**Table 3-17:** Estimated expected returns for the four-asset portfolio

| Asset class | Expected return (%) | Vector component ($\mu_j$) |
|---|---|---|
| 0–5 Year U.S. Treasury | 2.73 | 0.0273 |
| S&P 500 Index | 7.22 | 0.0722 |
| 3-Month LIBOR | 2.27 | 0.0227 |
| Federal Reserve Overnight Rate | 1.92 | 0.0192 |

*Source: Ph. D Candidate (2026)*

**Table 3-18:** Estimated covariance matrix of annualized asset returns

| Covariance | 0–5 Year UST | S&P 500 | LIBOR 3M | Fed overnight |
|---|---|---|---|---|
| 0–5 Year U.S. Treasury | 0.00030 | -0.00052 | 0.00003 | 0.00003 |
| S&P 500 | -0.00052 | 0.02303 | -0.00006 | -0.00004 |
| LIBOR 3M | 0.00003 | -0.00006 | 0.00003 | 0.00003 |
| Fed Overnight | 0.00003 | -0.00004 | 0.00003 | 0.00004 |

*Source: Ph. D Candidate (2026)*

The government mandate specifies admissible asset categories but does not prescribe explicit numerical targets for expected return or volatility. Accordingly, the admissible portfolio region is defined through the feasibility thresholds introduced in Section 3:

- return requirement: $\langle \mu, x \rangle \geq u_0$,
- variance cap: $\langle Cx, x \rangle \leq \sigma_{\max}^2 + \varepsilon$,
- relaxed budget constraint: $\langle \mathbf{1}, x \rangle \leq 1$.

The feasibility parameters $(u_0, \sigma_{\max})$ are calibrated internally from the investable asset universe. Let $(R_{\max}, \sigma_{\max}^R)$ denote the expected return and standard deviation of the maximum-return portfolio and let $(R_{\min}, \sigma_{\min})$ denote those of the minimum-variance portfolio. The feasibility thresholds are selected as interior midpoints between these two extremal portfolios. This calibration identifies a moderate region of the attainable risk–return set and is used solely to illustrate the feasibility–based construction methods, without extremizing either expected return or variance.

Under the baseline calibration,

$$u_0 = 0.0476, \qquad \sigma_{\max} = 0.0788, \qquad \varepsilon = 10^{-4}.$$

All portfolios reported below satisfy the corresponding feasibility conditions defined above.

**Convex optimization**

To construct a locally stable, feasible portfolio, we first formulate a convex quadratic programming problem. Specifically, a given reference allocation is adjusted by minimizing its deviation subject to the admissible return, variance, and relaxed budget constraints introduced in Section 3.1. This leads to the strictly convex quadratic program, which guarantees existence and uniqueness of the solution whenever the feasible set is nonempty. The resulting allocation restores feasibility while remaining close to the benchmark and is positioned stably within the prescribed constraint region.

Objective function and constraint setup: The convex quadratic program minimizes the squared Euclidean distance $\| x - y \|^2$ from a reference portfolio $y$, selected as the maximum-return allocation. This formulation determines the minimal adjustment required to restore feasibility under the prescribed return and variance constraints. The target return $\mu_0$ is chosen as the midpoint between the returns of the maximum-return and minimum-variance portfolios, while the admissible risk level $\sigma$ is defined as the average of their corresponding standard deviations. These choices place the feasibility thresholds in an interior region between the two extremal benchmark portfolios, thereby avoiding boundary effects. Table 3-26 reports the optimal objective value together with the active constraints at the solution.

**Table 3-19:** Objective value and constraints of the convex programming portfolio

| Component | Description | Value |
|---|---|---|
| Objective value | $\min \| x - y \|^2$ (squared distance) | 0.2868 |
| Return threshold | $u_0$ in $\langle \mu, x \rangle \geq u_0$ | 4.76% |
| Risk cap | $\sigma_{\max}$ in $\sqrt{\langle Cx, x \rangle} \leq \sigma_{\max}$ | 7.88% |
| Budget constraint (relaxed) | $\langle \mathbf{1}, x \rangle \leq 1$ | $\leq 100\%$ |

*Source: Ph. D Candidate (2026)*

Optimization results: The convex quadratic program was implemented in MATLAB to obtain a numerical solution. Tables 3-27 and 3-28 compare the resulting convex programming portfolio with several benchmark allocations, including the maximum-return portfolio, the minimum-variance portfolio, the equal-weight portfolio, and the classical maximum Sharpe (Markowitz) portfolio. The convex solution represents the unique Euclidean projection of the reference portfolio onto the convex feasible region defined by the calibrated return threshold, variance cap, and relaxed budget constraint. Since the objective function is strictly convex and the feasible region is convex (provided the covariance matrix is positive semi-definite), the projection solution exists and is unique whenever the feasible set is nonempty.

**Table 3-20:** Comparison of portfolio allocations across benchmark strategies

| Asset / Portfolio | Max Return | Min Risk | Equal Weight | Markowitz | Convex (min $\| x - y \|^2$) |
|---|---|---|---|---|---|
| 0–5 Year U.S. Treasury | 0.00% | 1.36% | 25.00% | 20.23% | 17.27% |
| S&P 500 | 100.00% | 0.42% | 25.00% | 2.70% | 52.31% |
| LIBOR 3M | 0.00% | 98.22% | 25.00% | 77.06% | 13.18% |

| | | | | | |
|---|---|---|---|---|---|
| Fed Overnight | 0.00% | 0.00% | 25.00% | 0.00% | 11.08% |
| **Total weight** | 100% | 100% | 100% | 100% | 93.8% |

*Source: Ph. D Candidate (2026)*

**Table 3-21:** Portfolio performance measures

| Portfolio | Max return | Min risk | Equal weight | Markowitz | Convex min $\| x - y \|^2$ |
|---|---|---|---|---|---|
| Portfolio return (%) | 7.22 | 2.30 | 3.54 | 2.50 | 4.76 |
| Portfolio risk (%) | 15.18 | 0.58 | 3.74 | 0.72 | 7.88 |
| Sharpe ratio | 0.35 | 0.65 | 0.43 | 0.81 | 0.36 |
| Risk-free rate (%) | 1.92 | 1.92 | 1.92 | 1.92 | 1.92 |

*Source: Ph. D Candidate (2026)*

**Sphere packing portfolio optimization**

We now implement the sphere packing framework developed in Section 3.2. The admissible region is decomposed into two components:

- the linear return–budget region $D_1$, and
- the quadratic variance region $D_2$.

The portfolio construction proceeds in two stages.

*Stage 1: Determining the robustness radius in $D_1$*

In the first stage, the sphere packing linear program is solved to determine the largest inscribed Euclidean ball within the return–budget region $D_1$. This yields the stable portfolio center $x^0$ and the associated robustness radius $r^*$:

$$x^0 = (0,\ 0.783236,\ 0,\ 0), \qquad r^* = 0.108382.$$

Here, $x^0$ is the Chebyshev center of $D_1$, and $r^*$ represents the maximal uniform perturbation radius such that all points within distance $r^*$ from $x^0$ remain feasible with respect to the linear constraints defining $D_1$.

By construction, Stage 1 incorporates only the linear return and budget constraints; the quadratic variance constraint is enforced separately in Stage 2. The corresponding linear constraints used in the sphere packing formulation are summarized in Table 3-29.

**Table 3-22:** Stage 1 constraints used in the sphere packing linear program.

| Constraint | Specification |
|---|---|
| Return threshold | $\langle \mu, x \rangle - r \parallel \mu \parallel \geq 0.0476$ |
| Budget constraint | $\sum_{j=1}^{n} x_j + r\sqrt{n} \leq 1$ |
| Box constraint | $x_j + r \leq 1$ |
| Non-negativity | $x \geq 0,\ r \geq 0$ |

*Source: Ph. D Candidate (2026)*

*Stage 2: Directional feasibility with respect to $D_2$*

In the second stage, the center $x^0$ obtained from the linear admissible region $D_1$ is directionally adjusted toward the variance feasible region $D_2$ along rays of the form

$$x(\alpha) = x^0 + \alpha h,$$

where $h \in \mathbb{R}^n$ is a candidate direction, and $\alpha \in \mathbb{R}$ is a scalar step size.

Substituting $x(\alpha)$ into the quadratic variance constraint defining $D_2$,

$$\langle Cx, x\rangle \leq \sigma_{\max}^2 + \varepsilon,$$

yields a quadratic inequality in $\alpha$ of the form derived in Section 3.2. If the discriminant is non-negative, the admissible parameters form a closed interval $[\alpha_1, \alpha_2]$. By construction, the unmodified portfolio $x^0 + \alpha h$ satisfies the variance constraint if and only if $\alpha \in [\alpha_1, \alpha_2]$.

For numerical conditioning, directions $h$ may be rescaled, for example, so that $\langle Ch, h\rangle = 1$. Such normalization merely reparameterizes $\alpha$ and does not alter the feasible set or the quadratic boundary of $D_2$.

*Monte Carlo directional search.*
To obtain feasible portfolios in $D_1 \cap D_2$, a Monte Carlo search over candidate directions $h$ is performed. Directions are generated using both stochastic and economically motivated constructions, including Dirichlet sampling, Gaussian perturbations, return aligned directions ($h \propto \mu$), variance reducing directions ($h \propto -Cx^0$), and $C^{-1}\mu$ directions.

For each direction, the admissible interval $[\alpha_1, \alpha_2]$ is computed analytically from

$$\langle C(x^0 + \alpha h),\, x^0 + \alpha h\rangle \leq \sigma_{\max}^2.$$

If no real solution exists or $\alpha_2 \leq 0$, the direction is discarded. Otherwise, the initial step size is set to $\alpha = \alpha_2$, corresponding to the analytic intersection of the ray $x^0 + \alpha h$ with the quadratic boundary of $D_2$.

The tentative portfolio

$$\tilde{x}(\alpha) = x^0 + \alpha h$$

is then constructed, and non–negativity is enforced component wise:

$$x(\alpha) = [\,\tilde{x}(\alpha)\,]_+.$$

While the interval $[\alpha_1, \alpha_2]$ guarantees variance feasibility for the unmodified portfolio $\tilde{x}(\alpha)$, componentwise clipping modifies the portfolio vector. Accordingly, the variance, return, and budget constraints defining $D_1 \cap D_2$ are explicitly re–evaluated.

If any constraint is violated, the step size $\alpha$ is reduced via backtracking and the clipped portfolio is recomputed until full feasibility is restored. This produces a verified step size

$$\alpha_{\text{used}} \in (0, \alpha_2],$$

and a verified feasible portfolio

$$x_{\text{ver}} = [\,x^0 + \alpha_{\text{used}} h\,]_+, \qquad x_{\text{ver}} \in D_1 \cap D_2.$$

Among all verified feasible portfolios generated by the directional search, the final allocation is selected via

$$x^* \in \text{argmax}\{\langle \mu, x \rangle : x \text{verified feasible}\}.$$

In the baseline implementation $K = 1$, so no aggregation across multiple candidates is performed.

*Proposition (Correctness of Stage 2 construction).*

Let

$$D_2 = \{ x \in \mathbb{R}^n : \langle Cx, x \rangle \leq \sigma_{max}^2 + \varepsilon \}$$

denote the quadratic variance admissible region. Let $x^0 \in D_1$ denote the Chebyshev center of the linear admissible region and let $h \in \mathbb{R}^n$ satisfy $\langle Ch, h \rangle > 0$. Suppose that substitution of

$$x(\alpha) = x^0 + \alpha h$$

into the quadratic constraint

$$\langle Cx, x \rangle \leq \sigma_{\max}^2 + \varepsilon$$

yields a quadratic inequality whose admissible set of parameters is a non-empty closed interval $[\alpha_1, \alpha_2]$. Then:

*(i)* For every $\alpha \in [\alpha_1, \alpha_2]$, the unmodified portfolio $x^0 + \alpha h$ satisfies $x^0 + \alpha h \in D_2$.

*(ii)* If component wise clipping is applied and feasibility with respect to the return, budget, and variance constraints is enforced via the backtracking procedure of Algorithm, then whenever the algorithm terminates with $\alpha > \delta$, the resulting portfolio $x_{\text{ver}}$ satisfies

$$x_{\text{ver}} \in D_1 \cap D_2.$$

*Proof.* Substitution of $x(\alpha) = x^0 + \alpha h$ into the quadratic form $\langle Cx, x \rangle$ produces a scalar quadratic inequality in $\alpha$. Whenever the discriminant is non-negative, the admissible parameters form a closed interval $[\alpha_1, \alpha_2]$, which establishes part (i).

For part (ii), component wise clipping modifies the ray $x^0 + \alpha h$, so Algorithm explicitly re-evaluates the return, budget, and variance constraints after clipping. If any constraint is violated, the step size $\alpha$ is reduced via backtracking until either feasibility is restored or $\alpha \leq \delta$.

By construction, whenever the algorithm accepts a portfolio (i.e., $\alpha > \delta$ at termination), all defining inequalities of $D_1$ and $D_2$ are satisfied. Hence $x_{\text{ver}} \in D_1 \cap D_2$.

***Algorithm: Verified Monte Carlo Directional Search within $D_1 \cap D_2$***

*Require:*
*Covariance matrix $C$; center portfolio $x^0$; variance cap $\sigma_{max}$; variance tolerance $\varepsilon > 0$; return threshold $u_0$; mean return vector $\mu$; number of trials $N$; direction styles $S$; backtracking factor $\beta \in (0,1)$; backtracking tolerance $\delta > 0$.*
*Procedure*

1. *For each direction style $s \in S$*
2. *For $k = 1$ to $N/|S|$*
3. *Generate candidate direction $h^{(k)}$.*
4. *Optionally rescale $h^{(k)}$ so that*
   $\langle Ch^{(k)}, h^{(k)} \rangle = 1$
   *(this rescales the step size $\alpha$ and improves numerical conditioning).*
5. *Compute $(\alpha_1, \alpha_2)$ from inequality*
   $$\langle C(x^0 + \alpha h^{(k)}), x^0 + \alpha h^{(k)} \rangle \leq \sigma_{max} + \varepsilon$$
6. *If no real solution exists or $\alpha_2 \leq 0$, discard this direction.*
7. *Otherwise set*
   $\alpha \leftarrow \alpha_2$
8. *Compute the clipped portfolio*
   $$x \leftarrow [\, x^0 + \alpha h^{(k)} \,]_+$$
9. *While*
   - $\langle \mathbf{1}, x \rangle > 1$ ***or***
   - $\langle \mu, x \rangle < u_0$ ***or***
   - $\langle Cx, x \rangle > \sigma_{max} + \varepsilon$

   *and $\alpha > \delta$*
   *do*
10. $\alpha \leftarrow \beta\alpha$
11. $x \leftarrow [\, x^0 + \alpha h^{(k)} \,]_+$
12. *End while*
13. *If $\alpha > \delta$*
14. *Set $\alpha_{used} \leftarrow \alpha$*
15. *Set $x_{ver} \leftarrow x$*
16. *Store $(x_{ver}, \alpha_{used})$ and its return value*
    $\langle \mu, x_{ver} \rangle$
17. *End if*
18. *End for*
19. *End for*

***Selection step***

*Choose*

$$x^* \in arg\ max\ \{\langle \mu, x \rangle : x \text{ stored as verified feasible}\}$$

***Output***

*Return $x^*$ and the associated search direction.*

*Remark.* Algorithm 1 implements a heuristic Monte Carlo directional search; however, by construction, every accepted portfolio is explicitly verified to satisfy the defining constraints of $D_1 \cap D_2$, thereby ensuring feasibility preservation at each step.

**Stress test and numerical robustness**

To assess numerical stability of the two-stage construction, the full procedure (Stage 1 and Stage 2) was recomputed under systematic perturbations of: (i) the variance cap $\sigma_{\max}$ ($\pm 5\%$), (ii) the return threshold $u_0$ ($\pm 5\%$), and (iii) the Monte Carlo random seed. For each scenario, the sphere packing radius $r^*$, the projected weights, and the associated performance measures were recomputed from scratch. Feasibility was verified explicitly whenever $D_1 \cap D_2$ remained non-empty. The resulting stress test outcomes are summarized in Table 3-30.

**Table 3-23:** Stress test results under parameter perturbations

| Case | $u_0$ | $\sigma_{\max}$ | $\sum_j x_j$ | $\langle \mu, x \rangle$ | $\sqrt{\langle Cx, x \rangle}$ | $r^*$ |
|---|---|---|---|---|---|---|
| $\sigma_{\max}$ (low) | 0.0476 | 0.07486 | 0.96927 | 0.04827 | 0.07247 | 0.10838 |
| $\sigma_{\max}$ (base) | 0.0476 | 0.07880 | 0.97329 | 0.04809 | 0.07149 | 0.10838 |
| $\sigma_{\max}$ (high) | 0.0476 | 0.08274 | 0.96410 | 0.04837 | 0.08102 | 0.10838 |
| $u_0$ (low) | 0.04522 | 0.07880 | 0.99015 | 0.04807 | 0.06983 | 0.11886 |
| $u_0$ (base) | 0.0476 | 0.07880 | 0.97329 | 0.04809 | 0.07149 | 0.10838 |
| $u_0$ (high) | 0.04998 | 0.07880 | – | – | – | – |
| Seed (low) | 0.0476 | 0.07880 | 0.99998 | 0.04898 | 0.07200 | 0.10838 |
| Seed (base) | 0.0476 | 0.07880 | 0.97329 | 0.04809 | 0.07149 | 0.10838 |
| Seed (high) | 0.0476 | 0.07880 | 0.97473 | 0.04820 | 0.07173 | 0.10838 |

*Source: Ph. D Candidate (2026)*

The results exhibit three key stability properties.

First, the robustness radius $r^*$ is invariant to perturbations in $\sigma_{\max}$ and to changes in the Monte Carlo seed, reflecting the fact that Stage 1 depends only on the return–budget region $D_1$. Variations in $u_0$ affect $r^*$ smoothly, as expected from the linear constraint defining $D_1$.

Second, whenever $D_1 \cap D_2$ is non-empty, the projected portfolio satisfies the variance constraint

$$\langle Cx, x \rangle \leq \sigma_{\max}^2,$$

demonstrating that quadratic feasibility is ensured by the analytic characterization of admissible step sizes combined with explicit post clipping verification. For sufficiently high values of $u_0$ (see $u_0$ (high) scenario), the intersection becomes empty and no feasible projection exists, which is economically consistent with the imposed return requirement.

Third, variations in the Monte Carlo seed lead to only minor changes in portfolio return, risk, and total invested weight, indicating numerical stability of the direction selection mechanism.

Implementation note: The second stage was implemented in R. The stable center $x^0$ obtained from Stage 1 was projected into $D_2$ using a Monte Carlo direction selection procedure.

A total of $N = 8000$ candidate directions were generated across multiple styles, including Dirichlet sampling (concentration parameter $\kappa = 60$), Gaussian perturbations, return aligned directions ($h \propto \mu$), variance reducing directions ($h \propto -Cx^0$), and $C^{-1}\mu$ directions. In the reported experiment, candidate directions were risk normalized so that $\langle Ch, h\rangle = 1$. This normalization improves numerical conditioning of the quadratic step size computation without modifying the geometry of the feasible region or the location of the variance boundary.

For each candidate direction, the admissible step interval $(\alpha_1, \alpha_2)$ was computed analytically from the quadratic variance constraint

$$\langle C(x^0 + \alpha h),\, x^0 + \alpha h\rangle \le \sigma_{\max}^2 + \varepsilon,$$

as described in Section 3.2. The upper bound $\alpha_2$ was used as the initial projection step. After enforcing non-negativity componentwise, the resulting portfolio was explicitly verified to satisfy the return, budget, and variance constraints defining $D_1 \cap D_2$. If any constraint was violated, the step size $\alpha$ was reduced via backtracking (with stopping tolerance $\delta$) until full feasibility was restored or the minimum step size threshold was reached.

Among all verified feasible portfolios, the final allocation was selected according to the maximum-return criterion subject to the variance bound $\langle Cx, x\rangle \le \sigma_{\max}^2 + \varepsilon$. Although aggregation of the top $K$ feasible portfolios via the componentwise median is available in the implementation, in the present baseline experiment the optimal solution was unique ($K = 1$), and no aggregation was required. The optimal projection direction obtained in Stage 2 is reported in Table 3-31.

**Table 3-24:** Optimal projection direction $\boldsymbol{h^*}$ selected in Stage 2

| Asset | $h_i^*$ |
|---|---|
| 0–5 Year U.S. Treasury | 10.237843 |
| S&P 500 | -6.302487 |
| LIBOR 3M | -15.763143 |
| Fed Overnight | -1.550688 |

*Source: Ph. D Candidate (2026)*

The values reported in the column $x_{\text{ver}}$ correspond to the verified-feasible and component-wise non-negative projection

$$x_{\text{ver}} = [x^0 + \alpha_{\text{used}} h^*]_+,$$

where $\alpha_{\text{used}} \le \alpha_2$ is obtained after feasibility verification via backtracking in Algorithm.

The lower bound $x_{\min}^{\text{ray}}$ corresponds to $x^0 + \alpha_1 h^*$ prior to non-negativity clipping, and $x_{\max}^{\text{ray}}$ corresponds to $x^0 + \alpha_2 h^*$ before feasibility verification. The directional projection bounds and the verified feasible portfolio are reported in Table 3-32.

**Table 3-25:** Directional projection bounds and verified feasible portfolio along the optimal direction $\boldsymbol{h^*}$

| Asset | $x^0$ | $h^*$ | $x_{\min}^{\text{ray}}$ | $x_{\max}^{\text{ray}}$ | $x_{\text{ver}}$ |
|---|---|---|---|---|---|
| 0–5 Year U.S. Treasury | 0.000000 | 10.237843 | 0.419718 | 0.494430 | 0.494430 |
| S&P 500 | 0.783236 | -6.302487 | 0.524855 | 0.478861 | 0.478861 |
| LIBOR 3M | 0.000000 | -15.763143 | -0.646237 | -0.761271 | 0.000000 |
| Fed Overnight | 0.000000 | -1.550688 | -0.063573 | -0.074890 | 0.000000 |

| | |
|---|---|
| **Total weight of verified portfolio** | 0.973291 |

*Source: Ph. D Candidate (2026)*

Note: $x_{\min}^{\text{ray}}$ and $x_{\max}^{\text{ray}}$ denote analytic intersections of the directional ray with the quadratic boundary prior to non-negativity clipping. The verified portfolio $x_{\text{ver}} = [x^0 + \alpha_{\text{used}} h^*]_+$ satisfies $\langle C x_{\text{ver}}, x_{\text{ver}} \rangle \leq \sigma_{\max}^2 + \varepsilon$ and is obtained after feasibility verification via Algorithm.

**Comparative optimization results:**

To evaluate the economic implications of the proposed sphere packing construction, the resulting allocation is compared with five benchmark strategies: (i) the maximum return portfolio, (ii) the minimum variance portfolio, (iii) the equal-weight portfolio, (iv) the Markowitz maximum Sharpe ratio portfolio, and (v) the convex programming portfolio solving $\min \| x - y \|^2$ under identical return and risk constraints.

Table 3-15 reports portfolio weights, expected returns, risk levels (standard deviation), and Sharpe ratios for all strategies.

The sphere packing portfolio satisfies simultaneously

$$\langle \mu, x \rangle \geq u_0, \qquad \langle Cx, x \rangle \leq \sigma_{\max}^2, \qquad \sum_{j=1}^{n} x_j \leq 1,$$

and therefore, lies in the feasible region $D_1 \cap D_2$ constructed in Stages 1 and 2. Quantitatively, the sphere packing allocation achieves:

- expected return: 4.81%,
- risk (standard deviation): 7.15%,
- total invested weight: 97.33%.

Relative to the maximum return portfolio, which exhibits a risk level of 15.18%, the sphere packing allocation reduces volatility by more than 50% while remaining strictly within the imposed variance bound. Relative to the minimum variance portfolio (return 2.30%), the sphere packing solution delivers substantially higher expected return while respecting the same risk ceiling.

Compared with the Markowitz maximum Sharpe ratio portfolio, the sphere packing allocation exhibits a more balanced asset structure. The Markowitz solution allocates heavily to LIBOR (77.06%), whereas the sphere packing portfolio distributes capital primarily between U.S. Treasuries (49.44%) and the S&P 500 (47.89%), reflecting the geometric centering property established in Stage 1, which maximizes uniform distance to the supporting hyperplanes of the linear admissible region.

Although the Sharpe ratio of the Markowitz portfolio is higher (0.81), that solution is obtained from an unconstrained global mean–variance optimization and does not incorporate the joint feasibility constraints defining the admissible region $D_1 \cap D_2$. In contrast, the proposed sphere packing method operates strictly within this constrained region and prioritizes structural robustness and interior stability over unconstrained mean–variance efficiency.

The convex programming portfolio ($\min \| x - y \|^2$) satisfies the same return and variance constraints as the sphere packing solution. However, it remains closer to the reference portfolio $y$, while the sphere packing approach begins from a geometrically stable center $x^0$ that

maximizes the inscribed robustness radius in $D_1$. The resulting allocation therefore reflects a feasibility driven design rather than proximity to an exogenous benchmark.

Overall, the sphere packing portfolio represents a constraint consistent, geometrically robust allocation that balances return and risk within the jointly admissible region $D_1 \cap D_2$. The construction does not aim to dominate classical mean–variance optimizers in unconstrained settings, but rather to provide a stable portfolio anchored in the maximal feasible neighborhood of the return–budget region.

**Table 3-26:** Comparison of portfolio allocations and performance across optimization models

| Asset / Portfolio | Max Return | Min Variance | Equal Weight | Markowitz | Convex | Sphere Packing |
|---|---|---|---|---|---|---|
| 0–5 Year U.S. Treasury | 0.00% | 1.36% | 25.00% | 20.23% | 17.27% | 49.44% |
| S&P 500 | 100.00% | 0.42% | 25.00% | 2.70% | 52.31% | 47.89% |
| LIBOR 3M | 0.00% | 98.22% | 25.00% | 77.06% | 13.18% | 0.00% |
| Fed Overnight | 0.00% | 0.00% | 25.00% | 0.00% | 11.08% | 0.00% |
| Total weight | 100.0% | 100.0% | 100.0% | 100.0% | 93.8% | 97.33% |
| Expected return | 7.22% | 2.30% | 3.54% | 2.50% | 4.76% | 4.81% |
| Portfolio risk | 15.18% | 0.58% | 3.74% | 0.72% | 7.88% | 7.15% |
| Sharpe ratio | 0.35 | 0.65 | 0.43 | 0.81 | 0.36 | 0.40 |
| Risk-free rate | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% |
| Objective | Max return | Min variance | Equal weight | Max Sharpe ratio | min‖x − y‖² | Feasible projection from x⁰ |
| Return constraint | – | – | – | – | ≥ 4.76% | ≥ 4.76% |
| Risk constraint | – | – | – | – | ≤ 7.88% | ≤ 7.88% |
| Budget constraint | =100% | =100% | =100% | =100% | ≤100% | ≤100% |

*Source: Ph. D Candidate (2026)*

Discussion: The empirical results clarify the complementary roles of convex feasibility restoration and sphere packing based geometric centering within the classical mean–variance framework.

Under the baseline calibration ($u_0 = 4.76\%$, $\sigma_{\max} = 7.88\%$), the convex programming formulation yields a portfolio with

$$\text{Expected return} = 4.76\%, \quad \text{Risk} = 7.88\%, \quad \langle \mathbf{1}, x \rangle = 0.938.$$

The associated objective value $\| x - y \|^2 = 0.2868$ quantifies the minimal quadratic adjustment required to restore feasibility from the maximum-return reference allocation. By construction, the solution lies in the admissible region defined by the joint return, variance, and relaxed budget constraints, equivalently the intersection $D_1 \cap D_2$, and therefore serves as a benchmark–consistent feasible allocation without incorporating geometric centering.

The sphere packing construction adds a structural design centering layer. In Stage 1, the portfolio $x^0$ maximizes the admissible Euclidean radius $r^* = 0.108382$ within the linear return–budget region $D_1$, thereby identifying its Chebyshev center. In Stage 2, analytic directional feasibility adjustment ensures compliance with the quadratic variance constraint $\langle Cx, x \rangle \leq \sigma_{\max}^2 + \varepsilon$. The resulting allocation attains

$$\text{Expected return} = 4.81\%, \quad \text{Risk} = 7.15\%, \quad \langle \mathbf{1}, x \rangle = 0.9733,$$

remaining strictly interior to the relaxed budget constraint while satisfying the prescribed return floor.

The two constructions therefore address distinct stability criteria. The convex programming portfolio prioritizes minimal deviation from an exogenous benchmark, whereas the sphere-packing allocation maximizes geometric interior stability as measured by the admissible perturbation radius $r^*$. Relative to the maximum-return portfolio, which exhibits a risk level of 15.18 percent, both approaches substantially reduce volatility. At the same time, compared with the minimum-variance portfolio, which yields an expected return of 2.30 percent, they deliver materially higher expected return while remaining consistent with the mandated constraints.

Stress tests further confirm the numerical stability of the proposed framework. Moderate perturbations of $\sigma_{\max}$, $u_0$, and the Monte Carlo seed induce only minor variations in the key performance measures. As expected, the robust radius $r^*$remains invariant to changes in the quadratic variance bound, since it is determined exclusively by the linear return-budget region $D_1$in Stage 1. Taking together, these results indicate that the proposed framework introduces a complementary perspective on robustness, grounded in the intrinsic geometry of the feasible allocation region rather than in distributional ambiguity or worst-case optimization.

## Improving Strategic Asset Allocation

From this comparative perspective, the institutional positioning of the Future Heritage Fund of Mongolia reflects a cautious and sequenced approach to sovereign wealth fund development. Given Mongolia's evolving governance environment and continued exposure to commodity-price volatility, the Fund is more appropriately associated with a relatively conservative strategic asset-allocation orientation emphasizing liquidity, transparency, and prudent risk control. As institutional capacity strengthens and governance mechanisms mature, the Fund may gradually broaden its investment scope in line with the experience of established long-term savings-oriented sovereign wealth funds. These institutional characteristics have direct implications for strategic asset allocation, which is the central concern of this dissertation.

The current management orientation becomes clearer when the existing government-mandated portfolio is compared with alternative benchmark allocations. As shown in Table 3-34, the current portfolio is concentrated entirely in LIBOR 3M, indicating an extremely conservative asset-allocation approach centred on liquidity preservation and minimal volatility rather than long-term wealth accumulation.

**Table 3-27:** Comparison of Current Management Portfolio with Benchmark Portfolio Allocations

| | Given Mandate | Max return portfolio | Min risk portfolio | Equal weight portfolio | Markowitz Portfolio |
|---|---|---|---|---|---|
| | Given Mandate | Max return | Min risk | Equal weight | Max sharpe ratio |
| 0-5 Year US Treasury | 0.00% | 0.00% | 1.36% | 25.00% | 20.23% |
| SP500 | 0.00% | 100.00% | 0.42% | 25.00% | 2.70% |
| Libor 3m | 100.00% | 0.00% | 98.22% | 25.00% | 77.06% |
| Fed overnight | 0.00% | 0.00% | 0.00% | 25.00% | 0.00% |
| Total weight | 100% | 100% | 100% | 100% | 100% |

| Portfolios | Given Mandate | Max return | Min risk | Equal weight | Markowitz Portfolio |
|---|---|---|---|---|---|
| Portfolio return | 2.27% | 7.22% | 2.30% | 3.54% | 2.50% |
| Portfolio risk | 0.01 | 0.15 | 0.01 | 0.04 | 0.01 |
| Sharpe ratio | 0.61 | 0.35 | 0.66 | 0.43 | 0.81 |
| Risk Free rate | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% |
| Herfindahl–Hirschman Index | 1.00 | 1.00 | 0.96 | 0.25 | 0.64 |

*Source: Ph. D Candidate (2026)*

Table 3-34 shows that the government-mandated portfolio delivers an expected return of 2.27 percent with portfolio risk of 0.58 percent, placing it very close to the minimum-risk portfolio and far below the return potential of more growth-oriented allocations. This confirms that the current management structure prioritizes short-term safety and capital preservation. While such an approach may be understandable in a transitional governance setting, it appears overly

conservative for a fund whose primary purpose is long-term savings and intergenerational wealth preservation. In this sense, the current allocation reflects institutional caution more strongly than the long-horizon accumulation logic implied by the macroeconomic objective of the Future Heritage Fund of Mongolia.

To extend this comparison, Table 3-35 reports the benchmark allocations alongside the two optimized portfolios developed in this dissertation, namely the convex portfolio and the sphere-packing portfolio. This comparison makes it possible to assess whether the proposed portfolios provide a more appropriate balance between long-term return, admissible risk, and strategic consistency than both the current management portfolio and the standard benchmark allocations.

**Table 3-28:** Comparison of Government-Mandated, Benchmark, and Proposed Optimized Portfolios

| | Given Mandate | Max return portfolio | Min risk portfolio | Equal weight portfolio | Markowitz Portfolio | Convex portfolio | Sphere Packing portfolio |
|---|---|---|---|---|---|---|---|
| | Given Mandate | Max return | Min risk | Equal weight | Max sharpe ratio | min \|x-y\|^2 | R - max |
| 0-5 Year US Treasury | 0.00% | 0.00% | 1.36% | 25.00% | 20.23% | 17.27% | 49.44% |
| SP500 | 0.00% | 100.00% | 0.42% | 25.00% | 2.70% | 52.31% | 47.89% |
| Libor 3m | 100.00% | 0.00% | 98.22% | 25.00% | 77.06% | 13.18% | 0.00% |
| Fed overnight | 0.00% | 0.00% | 0.00% | 25.00% | 0.00% | 11.06% | 0.00% |
| Total weight | 100% | 100% | 100% | 100% | 100% | 94% | 97% |

| Portfolios | Given Mandate | Max return | Min risk | Equal weight | Markowitz Portfolio | Convex min x -y | R - max |
|---|---|---|---|---|---|---|---|
| Portfolio return | 2.27% | 7.22% | 2.30% | 3.54% | 2.50% | 4.76% | 4.81% |
| Portfolio risk | 0.01 | 0.15 | 0.01 | 0.04 | 0.01 | 0.08 | 0.07 |
| Sharpe ratio | 0.61 | 0.35 | 0.66 | 0.43 | 0.81 | 0.36 | 0.40 |
| Risk Free rate | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% | 1.92% |
| Herfindahl–Hirschman Index | 1.00 | 1.00 | 0.96 | 0.25 | 0.64 | 0.33 | 0.47 |

*Source: Ph. D Candidate (2026)*

Table 3.35 shows that the convex and sphere-packing portfolios provide a substantially different allocation structure from the current government-mandated portfolio. Both optimized portfolios reduce the excessive concentration in LIBOR 3M and introduce greater exposure to U.S. Treasuries and equities, thereby improving the balance between preservation and long-term accumulation. The convex portfolio generates an expected return of 4.76 percent with portfolio risk of 7.88 percent, while the sphere-packing portfolio achieves a slightly higher return of 4.81 percent with lower portfolio risk of 7.15 percent. Although both portfolios remain more conservative than the maximum-return allocation, they are materially more growth-oriented than the government-mandated portfolio and are more closely aligned with the Fund's long-term savings objective. In particular, the sphere-packing portfolio appears to offer the stronger balance between return improvement and internal portfolio stability.

**Table 3-29:** Opportunity Cost of the Government-Mandated Portfolio Relative to the Robust Portfolio

| | Government mandate | Robust portfolio | Opportunity cost |
|---|---|---|---|
| 2026 | 53,702,792.34 | 74,351,978.51 | 20,649,186.17 |
| 2027 | 65,988,947.69 | 91,362,266.40 | 25,373,318.71 |
| 2028 | 78,701,872.68 | 108,963,420.54 | 30,261,547.86 |
| 2029 | 91,856,391.50 | 127,175,965.14 | 35,319,573.64 |
| 2030 | 105,467,843.27 | 146,021,137.35 | 40,553,294.08 |
| Total | | | **152,156,920.46** |

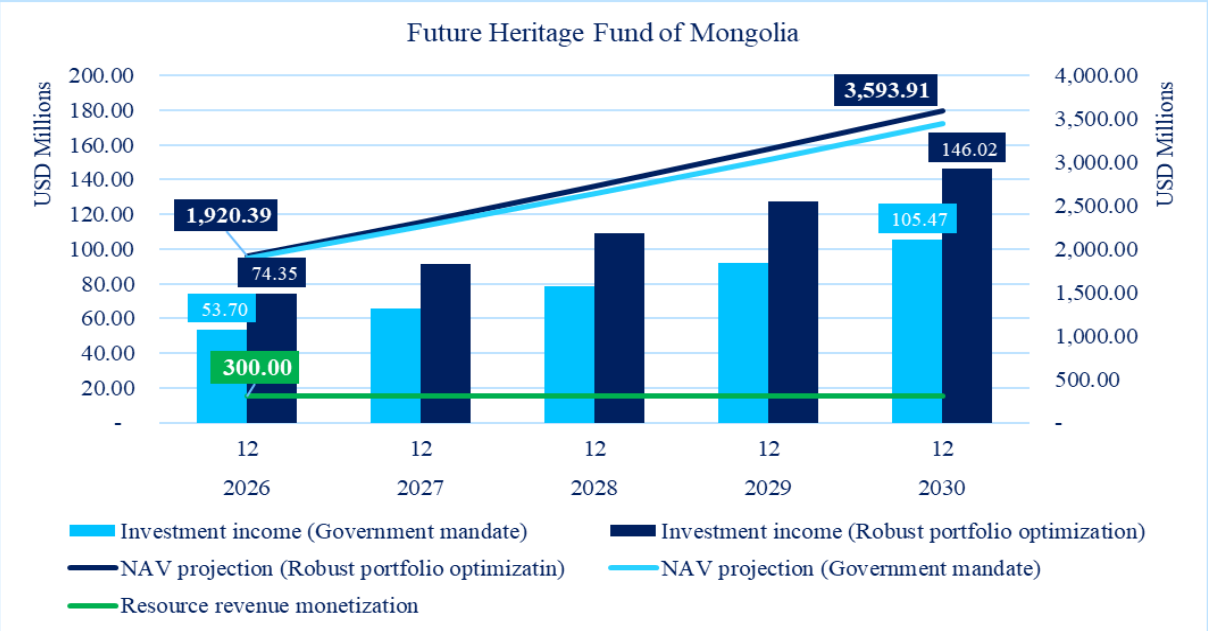
*Source: Ph. D Candidate (2026)*

Table 3-36 shows that the government-mandated portfolio produces consistently lower outcomes than the robust portfolio throughout the projection horizon. The annual opportunity cost rises from 20.65 million in 2026 to 40.55 million in 2030, indicating that the cumulative cost of maintaining an overly conservative allocation increases over time. Over the full period, the total opportunity cost reaches 152.16 million. This result suggests that, although the current

management portfolio minimizes short-term risk, it does so at the expense of long-term accumulation. For a sovereign wealth fund whose dominant objective is long-term savings, this trade-off is significant. It implies that the present allocation may preserve liquidity and stability in the short run but may not be fully aligned with the broader macroeconomic objective of transforming exhaustible mineral revenues into sustainable financial wealth for future generations.

The dynamic effect of this difference is illustrated further in Figure 3-7, which compares projected investment income and net asset value under the government mandate and the robust portfolio over the period 2026–2030.

**Figure 3-7:** Projected investment income and net asset value of the Future Heritage Fund of Mongolia under the government mandate and the robust portfolio, 2026–2030.




*Source: Ph. D Candidate (2026)*

As shown in Figure 3-7, the robust portfolio produces higher projected investment income throughout the projection horizon. This stronger annual performance leads to a steeper projected net asset value path and a higher terminal fund value by 2030. However, the figure should be interpreted as an analytical projection, not as a definitive empirical prediction. Its purpose is to illustrate the potential long-term accumulation effect that may arise when the Future Heritage Fund of Mongolia adopts a more diversified and robust strategic asset allocation.

Taken together, these analytical results provide a direct justification for the next stage of the dissertation. If the current government-mandated portfolio is excessively conservative relative to the Fund's long-term savings objective, then a more explicit framework is required for translating macroeconomic purpose into strategic asset allocation. The robust portfolios developed in this dissertation are intended to address this problem by providing analytically derived allocation structures that remain consistent with sovereign objectives while improving projected long-term accumulation outcomes under uncertainty.

### 3.6 Evaluating the impact of the fund

The final step of the conceptual framework is the evaluation stage. If the earlier stages identify the macroeconomic conditions of the economy, determine the sovereign objectives of the fund, clarify its type and mandate, and translate those objectives into strategic asset allocation, then

the evaluation stage assesses whether the resulting framework is coherent, feasible, and capable of supporting the intended sovereign purpose over time. In this dissertation, evaluation is not treated as a broad attempt to measure every macroeconomic and developmental effect of the sovereign wealth fund. Rather, it is used more specifically to assess whether the proposed asset-allocation framework remains consistent with the macroeconomic objectives identified for the Future Heritage Fund of Mongolia.

A first dimension of evaluation concerns financial coherence. Since the Future Heritage Fund of Mongolia is primarily justified as a long-term savings fund with limited stabilization features, the relevant question is whether the proposed portfolio structure supports sustainable accumulation of financial wealth while maintaining acceptable levels of risk. Financial evaluation therefore focuses on broad indicators such as expected return, admissible portfolio risk, and the long-term growth path of fund assets. In this dissertation, these indicators are used to judge whether the asset-allocation structure is consistent with the dominant savings objective of the fund rather than to evaluate short-term market performance alone.

A second dimension concerns strategic consistency with sovereign purpose. A sovereign wealth fund should not be evaluated only in terms of investment return, because its asset-allocation logic is derived from macroeconomic objectives rather than from generic portfolio preferences. For this reason, the proposed allocation must also be assessed considering whether it reflects the purpose identified in the earlier stages of the framework. In Mongolia's case, this means asking whether the resulting portfolio is consistent with long-term savings, intergenerational wealth preservation, and broader macroeconomic resilience. If an allocation is excessively conservative, it may preserve short-term stability but weaken long-term accumulation. Conversely, if it is too growth-oriented, it may conflict with the prudential and institutional constraints of the fund. The evaluation stage therefore examines whether the proposed portfolio achieves a credible balance between these considerations.

A third-dimension concerns policy relevance. The purpose of the framework developed in this dissertation is not merely to generate a mathematical portfolio, but to provide a policy-consistent basis for sovereign wealth fund management. The evaluation stage therefore considers whether the operationalized framework offers an improvement over the current government-mandated portfolio and whether it provides a more coherent basis for long-term strategic asset allocation under the conditions faced by the Future Heritage Fund of Mongolia. In this sense, the evaluation stage links portfolio design back to the original policy problem of the dissertation.

It is important to note that the Future Heritage Fund of Mongolia is still a relatively recent institutional arrangement. For this reason, the full macroeconomic and developmental effects of the fund cannot yet be observed in a complete empirical sense. The dissertation therefore does not claim to measure the total economy-wide impact of the fund on growth, diversification, employment, or fiscal outcomes. Such questions would require a different empirical strategy and a longer evaluation horizon. Instead, the present study provides a structured basis for future assessment by identifying the financial and policy indicators through which the long-term performance of the fund may later be evaluated.

In this sense, the evaluation stage completes the logic of the conceptual framework developed in this chapter. It links macroeconomic diagnosis, sovereign objective identification, fund typology, and strategic asset allocation to a set of measurable outcomes through which the coherence of the proposed framework can be judged. For the purposes of this dissertation, the main value of this stage lies in showing whether the operationalized asset-allocation framework remains aligned with the macroeconomic role of the Future Heritage Fund of Mongolia.

Taken together, the evaluation stage provides the final connection between sovereign macroeconomic purpose and measurable portfolio outcomes. It therefore reinforces the central contribution of the dissertation: the operationalization of sovereign wealth fund structural design through the translation of macroeconomic objectives into long-term strategic asset-allocation decisions.

### 3.7 Chapter summary

This chapter applied the conceptual framework of the dissertation to the Future Heritage Fund of Mongolia. Consistent with the sequential logic of the study, the analysis proceeded from macroeconomic diagnosis to the identification of sovereign objectives, the classification of fund type and mandate, the examination of governance and strategic asset allocation, and finally the evaluation of the resulting portfolio framework. In this way, the chapter showed how the macroeconomic conditions of a resource-dependent developing economy can be translated into long-term strategic asset-allocation decisions for a sovereign wealth fund.

First, the macroeconomic diagnostics provided an empirical basis for the operation of a sovereign wealth fund in Mongolia. The results showed that Mongolia remains highly resource dependent and export concentrated, while also exhibiting fiscal instability and vulnerability to commodity-price cycles. These characteristics are consistent with the established literature on macroeconomic volatility, procyclicality, and external vulnerability in resource-dependent economies. At the same time, reserve adequacy indicators suggest that Mongolia has maintained a degree of external liquidity, supporting the feasibility of long-term sovereign savings within a rules-based fund structure.

Second, the chapter translated these macroeconomic diagnostics into sovereign objectives using established public-finance and resource-economics theories. The Permanent Income Hypothesis supports an intergenerational savings objective, tax-smoothing theory supports a limited stabilization role, and the resource-curse literature supports diversification through foreign asset accumulation. Taken together, these perspectives indicate that the Future Heritage Fund of Mongolia should be guided primarily by long-term savings and wealth preservation, while also contributing more broadly to macroeconomic resilience.

Third, using the sovereign wealth fund typology literature, the Future Heritage Fund of Mongolia was classified as a savings-oriented fund with limited stabilization features. This classification is important because the type of fund determines the broad investment logic of the portfolio. A long-term savings fund implies an asset-allocation structure focused on accumulation, preservation, and resilience rather than on short-term liquidity management or direct domestic development spending. In this way, fund typology provides the necessary bridge between sovereign objective and portfolio design.

Fourth, the chapter examined the institutional and governance setting of the Fund and showed that mandate clarity, governance separation, accountability, and transparency remain important conditions for credible long-term asset allocation. At the same time, the analysis indicated that the current government-mandated portfolio is highly conservative and concentrated in short-term instruments. Comparison with benchmark, convex, and sphere-packing portfolios showed that the existing allocation is closely aligned with minimum-risk positioning but appears overly conservative relative to the Fund's dominant long-term savings objective. The opportunity-cost comparison further demonstrated that maintaining the current allocation may lead to significant foregone accumulation over time.

Fifth, the chapter showed that the robust portfolio framework developed in this dissertation provides a more explicit and objective-consistent basis for long-term strategic asset allocation. By translating macroeconomic objectives into portfolio constraints, the framework generates allocations that remain more closely aligned with the sovereign purpose of the Future Heritage Fund of Mongolia than the current government-mandated portfolio. In this sense, the chapter operationalized the structural-design stage of sovereign wealth fund development by moving from macroeconomic diagnosis and sovereign objective identification to implementable long-term asset-allocation logic.

Finally, the chapter established an evaluation logic for judging the coherence of the proposed framework. Because the Future Heritage Fund of Mongolia remains a relatively recent institutional arrangement, the full macroeconomic and developmental effects of the fund cannot yet be measured in a comprehensive empirical sense. Nevertheless, the chapter showed that the proposed framework provides a structured basis for evaluating whether long-term asset-allocation decisions remain consistent with the fund's savings objective, prudential requirements, and broader macroeconomic role.

Overall, this chapter provides the empirical foundation for the dissertation's core contribution. It demonstrates that the Future Heritage Fund of Mongolia can be understood not only as a legal or fiscal institution, but as a sovereign investment vehicle whose strategic asset allocation should be derived from its macroeconomic purpose. By moving from macroeconomic conditions to sovereign objectives and from sovereign objectives to portfolio design, the chapter establishes the practical relevance of the dissertation's central claim: that the structural-design stage of sovereign wealth fund development can be operationalized through macroeconomic-objective-based long-term asset allocation.

# CONCLUSION

This dissertation was conducted to address the problem of how a sovereign wealth fund in a resource-dependent developing economy can be designed and managed so that its long-term strategic asset allocation is consistent with its macroeconomic purpose. The study used the Future Heritage Fund of Mongolia as the empirical case because Mongolia's economy remains highly exposed to mineral revenue dependence, export concentration, fiscal procyclicality, and external shocks. These conditions create a policy challenge that is common among resource-dependent economies: how to transform volatile and exhaustible natural-resource revenues into durable financial wealth for current and future generations.

The main problem identified in the dissertation is that the existing literature on sovereign wealth funds has widely discussed macroeconomic rationale, fund typology, institutional governance, and policy mandates, but has paid less attention to the practical asset-allocation problem faced by newly established or developing sovereign wealth funds. This gap is particularly important in the case of the Future Heritage Fund of Mongolia, where the current government-mandated portfolio remains highly conservative and concentrated in short-term instruments. While such an allocation may be understandable in a transitional institutional environment, it is not fully consistent with the Fund's long-term savings and intergenerational wealth-preservation objective.

The dissertation was grounded in public-finance, resource-economics, and institutional perspectives. The Permanent Income Hypothesis was used to justify the long-term savings function of the Fund; tax-smoothing theory supported the need for limited stabilization capacity; and the resource-curse literature explained the importance of external diversification and financial asset accumulation. These theoretical perspectives were integrated with Al Sayed's sovereign wealth fund design framework, which links macroeconomic diagnosis, sovereign objectives, fund type and mandate, structural design, and performance evaluation. The dissertation extended this framework by treating the structural-design stage as an explicit strategic asset-allocation problem.

Methodologically, the study applied a sequential analytical framework using secondary data, documentary analysis, macroeconomic assessment, institutional analysis, and quantitative portfolio modelling. The macroeconomic and institutional analysis was used to identify the rationale, objectives, and mandate environment of the Future Heritage Fund of Mongolia. The quantitative part then applied convex optimization and sphere-packing approaches to examine whether a more diversified and robust strategic asset allocation could improve the Fund's long-term return-risk profile compared with the current government-mandated portfolio and standard benchmark allocations.

The findings show that Mongolia has a clear macroeconomic rationale for maintaining a sovereign wealth fund. The country's dependence on mineral revenues and exposure to external shocks support the need for a savings-oriented sovereign wealth fund with secondary stabilization features. The institutional analysis further shows that the Fund's current governance and mandate environment remain transitional, which helps explain the conservative nature of the existing portfolio. However, the empirical portfolio analysis indicates that a more

diversified and robust strategic asset allocation can produce stronger long-term accumulation outcomes while remaining consistent with a conservative sovereign mandate.

The opportunity-cost analysis also shows that maintaining the current highly conservative government-mandated portfolio may lead to significant foregone accumulation over time. This finding is important because it demonstrates that excessive conservatism is not risk-free for a long-horizon sovereign wealth fund. Although short-term instruments reduce market volatility, they may also weaken the Fund's ability to preserve and grow national wealth over the long term. Therefore, the central finding of the dissertation is that the effectiveness of the Future Heritage Fund of Mongolia depends not only on its legal existence or general governance structure, but also on the appropriateness of its long-term strategic asset allocation.

Overall, the dissertation contributes to the sovereign wealth fund literature by linking macroeconomic rationale, institutional design, and robust portfolio optimization within a single analytical framework. It also contributes methodologically by applying convex and sphere-packing optimization approaches to the strategic asset-allocation problem of a sovereign wealth fund. For Mongolia, the dissertation provides policy-relevant evidence that the Future Heritage Fund of Mongolia should gradually move from a narrowly conservative allocation toward a more diversified and robust long-term portfolio that better reflects its savings-oriented mandate and intergenerational purpose.

## RECOMMENDATIONS

Based on the findings of the dissertation, several recommendations are proposed.

First, the long-term mandate of the Future Heritage Fund of Mongolia should be clarified and protected. The Fund should be understood primarily as a savings-oriented sovereign wealth fund designed to preserve and grow national wealth for future generations. Its secondary stabilization role should remain limited and clearly defined, so that short-term fiscal pressures do not undermine its long-term accumulation objective.

Second, the current government-mandated portfolio should be gradually revised. The existing allocation is overly concentrated in short-term and low-risk instruments. While this approach provides short-term safety, it creates a long-term opportunity cost. A more diversified strategic asset allocation should therefore be introduced progressively, with careful attention to risk tolerance, liquidity needs, institutional capacity, and the Fund's long-term investment horizon.

Third, robust portfolio optimization should be incorporated into the Fund's strategic asset-allocation process. Since newly established sovereign wealth funds often lack clearly defined return targets, risk limits, and long historical experience, traditional mean-variance optimization may not be sufficient. Convex and sphere-packing approaches can support more stable and policy-consistent allocation decisions under uncertainty.

Fourth, the institutional governance framework of the Fund should be strengthened. Clearer separation of roles is needed among the institutions responsible for policy direction, oversight, investment management, reporting, and accountability. A stronger governance structure would reduce uncertainty, improve investment discipline, and support the gradual transition from a passive and conservative portfolio to a more strategic long-term allocation.

Fifth, the Fund should develop explicit performance indicators that reflect its mandate. These indicators should not be limited to short-term accounting returns. They should include long-term real return, portfolio diversification, risk-adjusted performance, intergenerational wealth accumulation, liquidity adequacy, and compliance with the Fund's mandate. These indicators would allow policymakers to evaluate whether the Fund is achieving its intended macroeconomic and financial objectives.

Sixth, the Future Heritage Fund of Mongolia should avoid becoming a short-term fiscal financing tool. Excessive withdrawals or politically driven investment decisions would weaken the Fund's credibility and reduce its ability to serve future generations. Withdrawal rules, contribution rules, and investment rules should therefore be transparent, stable, and consistent with the Fund's long-term purpose.

Finally, Mongolia should build the technical and operational capacity required for sovereign wealth fund management. This includes strengthening internal expertise in asset allocation, risk management, external manager selection, performance evaluation, and reporting. Over time, improved technical capacity would allow the Fund to adopt a more sophisticated investment model while maintaining prudence, transparency, and public accountability.

## DIRECTIONS FOR FUTURE RESEARCH

The findings of this dissertation suggest several directions for future research.

First, future studies could examine more rigorously the trade-off between external financial savings and domestic development spending in resource-dependent developing economies. This issue is especially important for countries where sovereign wealth funds are expected to support both long-term intergenerational savings and broader national development objectives. Further research could develop analytical frameworks to determine how much resource revenue should be saved externally, how much should be used for stabilization purposes, and how much may be allocated to domestic development spending without weakening fiscal discipline or long-term wealth accumulation.

Second, future research could develop more detailed policy models for allocating resource revenues among savings, stabilization, and domestic investment functions. Such models would be particularly relevant for countries in which sovereign wealth funds are expected to perform multiple roles within the public financial system. Future studies could examine how rule-based allocation mechanisms, withdrawal rules, fiscal anchors, and macroeconomic thresholds can be designed to reduce political discretion and improve the consistency of sovereign wealth fund operations over time.

Third, future work should investigate more deeply the governance model of sovereign wealth funds in resource-dependent developing economies. While this dissertation emphasizes the importance of institutional design, further research could examine alternative governance arrangements in greater detail, including the division of responsibilities among parliament, government, the Ministry of Finance, the central bank, the fund manager, external asset managers, and independent oversight bodies. This would help clarify how accountability, transparency, operational independence, reporting standards, and investment decision-making authority should be structured in countries with relatively weak institutional capacity. Such

research would also extend Al-Sayed's institutional design approach, which emphasizes the alignment between macroeconomic objectives, mandate, governance, and fund structure.

Fourth, future studies could develop a more advanced governance evaluation framework for the Future Heritage Fund of Mongolia. This framework could compare Mongolia's current arrangements with international practices, such as the governance models of Norway, Chile, Kazakhstan, Botswana, and other resource-dependent economies. Attention could be given to whether the current institutional arrangement provides sufficient independence for long-term investment management, while still maintaining public accountability and democratic oversight. This would be useful for evaluating the transition from the current management structure to the Future Heritage Fund Corporation after 2030.

Fifth, future research could extend the econometric analysis of sovereign wealth fund readiness and performance. Longer time-series data could be used to estimate the relationship between commodity price volatility, fiscal balance, foreign exchange reserves, external debt, exchange rate pressure, and sovereign wealth fund accumulation. Econometric methods such as vector autoregression, structural VAR, regime-switching models, GARCH-based volatility models, and panel-data analysis across resource-dependent economies could provide stronger empirical evidence on the macroeconomic conditions under which sovereign wealth funds become most effective.

Sixth, further research could develop more advanced optimization models for sovereign wealth fund asset allocation under uncertainty. This dissertation applies a robust portfolio optimization framework to the Future Heritage Fund of Mongolia, but future studies could extend this approach by incorporating dynamic asset allocation, stochastic programming, scenario-based optimization, Bayesian estimation, shrinkage covariance estimation, and downside-risk diagnostics. Such extensions would be particularly valuable for newly established sovereign wealth funds that face limited data, narrow investment mandates, uncertain return expectations, and evolving risk-management capacity.

Seventh, future research could integrate econometric forecasting with portfolio optimization. For example, macroeconomic forecasts of commodity prices, fiscal balances, reserve adequacy, exchange rate pressure, and global interest rates could be linked directly to strategic asset allocation decisions. This would allow the investment strategy of the Future Heritage Fund of Mongolia to respond more systematically to changes in the macroeconomic environment while preserving its long-term savings objective. Such a framework would help bridge the gap between macroeconomic diagnostics and operational portfolio construction.

Finally, the opportunity-cost framework developed in this dissertation could be extended to other public funds in Mongolia. By comparing the long-term accumulation effects of alternative asset-allocation strategies across sovereign or quasi-sovereign funds, future research could determine whether overly conservative and weakly diversified portfolio structures generate similar long-term losses elsewhere in the public sector. This would broaden the policy relevance of the present study beyond the Future Heritage Fund of Mongolia and contribute to a wider understanding of public fund asset management under macroeconomic, institutional, and governance constraints.

## Appendix A. Economic indicators

| Date | GDP /USD/ | Mining sector /USD/ | Reserve /USD/ | External debt /USD/ | Fiscal deficit /USD/ |
|---|---|---|---|---|---|
| 2010-1 | 1,224,907,863.36 | 289,281,837.47 | 1,304,800,000.00 | 2,081,010,000.00 | (79,878,209.35) |
| 2010-2 | 1,887,037,043.80 | 348,711,387.13 | 1,421,500,000.00 | 2,013,230,000.00 | (122,388,558.07) |
| 2010-3 | 1,974,787,151.38 | 445,234,137.25 | 1,659,100,000.00 | 2,029,650,000.00 | (14,835,507.21) |
| 2010-4 | 2,292,086,694.03 | 508,454,620.66 | 2,288,000,000.00 | 2,155,770,000.00 | 33,232,313.59 |
| 2011-1 | 2,121,092,489.56 | 437,862,424.39 | 2,343,500,000.00 | 2,171,750,000.00 | 69,632,216.99 |
| 2011-2 | 2,744,662,024.09 | 499,529,754.34 | 2,541,600,000.00 | 2,227,970,000.00 | 45,885,956.27 |
| 2011-3 | 2,822,731,262.25 | 576,211,653.34 | 2,606,000,000.00 | 2,208,780,000.00 | 133,053,576.43 |
| 2011-4 | 2,545,834,907.65 | 460,728,102.15 | 2,450,600,000.00 | 2,311,030,000.00 | (551,330,807.74) |
| 2012-1 | 2,420,478,101.30 | 438,547,148.92 | 2,904,600,000.00 | 2,373,400,000.00 | (42,300,955.41) |
| 2012-2 | 3,385,176,407.92 | 558,639,957.38 | 2,908,200,000.00 | 2,274,540,000.00 | (428,086,393.54) |
| 2012-3 | 3,129,722,740.54 | 489,658,300.29 | 2,903,800,000.00 | 2,565,800,000.00 | (399,355,525.76) |
| 2012-4 | 3,295,958,070.54 | 525,649,982.04 | 4,125,800,000.00 | 4,170,830,000.00 | (816,484,878.96) |
| 2013-1 | 2,487,451,358.56 | 483,487,860.91 | 3,796,600,000.00 | 4,052,240,000.00 | 59,301,009.70 |
| 2013-2 | 3,511,028,025.75 | 478,724,700.42 | 3,107,500,000.00 | 4,133,300,000.00 | (91,933,866.70) |
| 2013-3 | 3,190,530,855.84 | 506,229,884.50 | 2,679,600,000.00 | 4,520,950,000.00 | (79,058,377.23) |
| 2013-4 | 3,198,177,769.47 | 384,003,398.94 | 2,248,000,000.00 | 4,665,040,000.00 | (135,366,290.21) |
| 2014-1 | 2,369,283,281.24 | 482,291,401.28 | 1,943,300,000.00 | 4,618,580,000.00 | (77,216,513.94) |
| 2014-2 | 3,270,085,170.94 | 443,157,404.67 | 1,317,500,000.00 | 4,669,950,000.00 | (131,791,218.90) |
| 2014-3 | 3,458,524,479.74 | 621,515,065.92 | 1,542,700,000.00 | 5,061,510,000.00 | (104,547,696.52) |
| 2014-4 | 3,001,318,654.55 | 449,227,669.40 | 1,649,900,000.00 | 5,071,150,000.00 | (459,616,985.45) |
| 2015-1 | 2,236,222,266.45 | 472,588,343.77 | 1,323,900,000.00 | 5,297,890,000.00 | (72,845,431.78) |
| 2015-2 | 3,025,799,262.56 | 419,192,487.12 | 1,685,600,000.00 | 5,525,030,000.00 | (272,394,324.59) |
| 2015-3 | 3,166,460,765.31 | 540,462,327.79 | 1,412,700,000.00 | 5,785,010,000.00 | (434,357,807.12) |
| 2015-4 | 3,103,141,888.54 | 656,574,980.83 | 1,323,100,000.00 | 5,719,500,000.00 | (579,756,503.35) |
| 2016-1 | 2,238,483,371.57 | 459,758,528.97 | 1,265,300,000.00 | 6,157,160,000.00 | (300,506,369.27) |
| 2016-2 | 3,148,448,228.02 | 425,438,304.96 | 1,296,600,000.00 | 6,543,830,000.00 | (566,975,255.39) |
| 2016-3 | 2,715,763,489.70 | 529,807,690.29 | 1,092,400,000.00 | 6,628,810,000.00 | (897,018,274.82) |
| 2016-4 | 2,768,448,960.25 | 733,280,615.22 | 1,296,300,000.00 | 6,659,360,000.00 | (1,470,273,143.93) |
| 2017-1 | 2,312,967,116.44 | 676,814,503.21 | 1,109,234,681.00 | 7,651,410,000.00 | (103,046,908.21) |
| 2017-2 | 3,038,676,011.13 | 578,197,712.29 | 1,319,362,081.00 | 7,892,940,000.00 | (308,490,609.26) |
| 2017-3 | 2,972,862,745.82 | 781,759,966.33 | 1,627,062,650.00 | 8,155,040,000.00 | (302,935,829.54) |
| 2017-4 | 3,166,520,474.05 | 833,727,184.31 | 3,008,069,970.00 | 9,346,060,000.00 | (712,078,831.22) |
| 2018-1 | 2,779,443,719.11 | 861,110,136.62 | 2,983,061,720.00 | 9,379,030,000.00 | (10,702,171.84) |
| 2018-2 | 3,626,770,503.61 | 769,839,302.06 | 2,989,393,370.00 | 8,994,000,000.00 | 5,364,677.67 |
| 2018-3 | 3,338,774,579.89 | 823,066,012.49 | 2,894,009,206.60 | 9,044,480,000.00 | 97,577,864.03 |
| 2018-4 | 3,421,535,489.13 | 926,111,632.88 | 3,549,112,927.29 | 9,214,410,000.00 | 10,738,009.37 |
| 2019-1 | 3,020,984,987.80 | 995,767,858.50 | 3,660,403,981.85 | 9,496,470,000.00 | 73,657,315.46 |
| 2019-2 | 3,769,545,618.84 | 773,167,427.26 | 4,101,355,361.83 | 9,482,180,000.00 | 72,652,702.42 |
| 2019-3 | 3,632,509,189.74 | 962,617,255.54 | 3,985,655,480.24 | 9,377,820,000.00 | 181,931,347.23 |
| 2019-4 | 3,782,294,051.26 | 870,870,502.00 | 4,348,591,730.00 | 9,790,890,000.00 | (279,802,115.75) |
| 2020-1 | 2,705,811,901.99 | 691,481,391.58 | 4,094,192,308.72 | 9,275,190,000.00 | (100,141,400.07) |
| 2020-2 | 3,277,515,655.99 | 513,606,508.01 | 3,555,923,952.53 | 9,980,110,000.00 | (758,225,907.16) |

| | | | | | |
|---|---|---|---|---|---|
| 2020-3 | 3,379,783,703.84 | 803,731,103.51 | 3,697,841,993.05 | 10,214,140,000.00 | (961,529,073.69) |
| 2020-4 | 3,814,060,812.47 | 1,066,122,561.43 | 4,534,233,881.01 | 10,874,830,000.00 | (1,557,468,029.43) |
| 2021-1 | 3,359,025,438.95 | 1,101,908,084.51 | 4,774,664,072.49 | 10,664,490,000.00 | (34,931,985.01) |
| 2021-2 | 3,656,435,635.71 | 676,850,932.60 | 4,731,823,207.43 | 10,709,880,000.00 | (368,925,140.31) |
| 2021-3 | 3,537,117,678.88 | 762,215,937.83 | 4,180,922,468.95 | 10,744,710,000.00 | (448,919,889.27) |
| 2021-4 | 4,780,591,920.20 | 1,257,442,179.40 | 4,366,064,967.19 | 11,064,270,000.00 | (1,023,832,960.37) |
| 2022-1 | 3,379,602,250.53 | 861,334,050.98 | 3,318,668,628.72 | 10,883,790,000.00 | (88,746,712.78) |
| 2022-2 | 4,416,082,011.27 | 937,561,269.35 | 3,097,268,833.19 | 10,363,340,000.00 | (272,941,112.60) |
| 2022-3 | 3,925,511,103.80 | 749,118,428.90 | 2,794,597,067.24 | 9,972,280,000.00 | (300,780,504.72) |
| 2022-4 | 5,273,341,924.96 | 1,362,433,636.73 | 3,399,594,717.46 | 10,191,420,000.00 | (303,518,263.88) |
| 2023-1 | 3,991,558,878.65 | 1,464,306,901.56 | 3,438,460,930.62 | 10,326,400,000.00 | 187,607,997.53 |
| 2023-2 | 4,908,272,377.31 | 1,185,187,687.21 | 3,817,830,920.56 | 9,613,140,000.00 | 446,567,609.53 |
| 2023-3 | 4,743,009,742.38 | 1,001,874,286.10 | 4,124,449,320.30 | 9,441,860,000.00 | 623,759,158.57 |
| 2023-4 | 6,705,319,920.84 | 2,069,701,808.45 | 4,921,470,876.91 | 9,889,880,000.00 | 228,582,087.71 |
| 2024-1 | 4,877,762,329.01 | 1,730,437,679.88 | 5,249,816,500.47 | 9,951,890,000.00 | 479,541,564.08 |
| 2024-2 | 6,054,240,459.70 | 1,562,192,856.57 | 4,838,797,864.43 | 9,124,900,000.00 | 380,952,328.82 |
| 2024-3 | 5,449,065,434.66 | 1,021,721,567.73 | 4,662,733,128.20 | 9,321,050,000.00 | 466,008,139.77 |
| 2024-4 | 7,405,478,483.22 | 2,164,977,471.75 | 5,509,822,497.14 | 9,483,350,000.00 | (270,059,719.92) |
| 2025-1 | 5,035,706,641.43 | 1,544,115,811.93 | 4,995,975,094.75 | 9,832,940,000.00 | (102,147,402.78) |
| 2025-2 | 6,414,619,155.93 | 1,392,666,815.69 | 5,206,074,441.02 | 10,404,000,000.00 | (212,668,929.41) |
| 2025-3 | 5,531,587,680.89 | 791,571,287.72 | 5,874,527,919.11 | 10,192,170,000.00 | (371,802,357.32) |
| 2025-4 | 8,382,098,425.27 | 2,700,694,695.53 | 7,005,270,000.00 | 10,192,170,000.00 | (346,247,958.14) |

| Date | BoP /USD/ | Total Import /USD/ | Total Export /USD/ | Mining export / USD/ | MNT/USD |
|---|---|---|---|---|---|
| 2010-1 | (36,350,000.00) | 568,950,000.00 | 493,260,000.00 | 443,130,000.00 | 1,367.10 |
| 2010-2 | 162,430,000.00 | 755,800,000.00 | 818,700,000.00 | 670,790,000.00 | 1,368.65 |
| 2010-3 | 166,340,000.00 | 882,860,000.00 | 703,130,000.00 | 618,400,000.00 | 1,325.59 |
| 2010-4 | 580,700,000.00 | 992,450,000.00 | 893,420,000.00 | 780,970,000.00 | 1,257.18 |
| 2011-1 | 31,820,000.00 | 1,087,980,000.00 | 741,310,000.00 | 691,030,000.00 | 1,195.27 |
| 2011-2 | 184,940,000.00 | 1,630,580,000.00 | 1,247,320,000.00 | 1,067,050,000.00 | 1,258.64 |
| 2011-3 | (11,140,000.00) | 2,129,430,000.00 | 1,330,500,000.00 | 1,220,580,000.00 | 1,285.64 |
| 2011-4 | (187,850,000.00) | 1,750,370,000.00 | 1,498,370,000.00 | 1,401,480,000.00 | 1,396.37 |
| 2012-1 | 481,580,000.00 | 1,517,110,000.00 | 886,580,000.00 | 838,100,000.00 | 1,318.80 |
| 2012-2 | (13,360,000.00) | 1,826,250,000.00 | 1,382,440,000.00 | 1,249,010,000.00 | 1,342.23 |
| 2012-3 | (77,190,000.00) | 1,903,790,000.00 | 963,060,000.00 | 855,550,000.00 | 1,394.47 |
| 2012-4 | 1,248,070,000.00 | 1,491,230,000.00 | 1,152,580,000.00 | 1,067,710,000.00 | 1,392.10 |
| 2013-1 | (397,760,000.00) | 1,205,540,000.00 | 809,450,000.00 | 748,130,000.00 | 1,410.32 |
| 2013-2 | (585,430,000.00) | 1,865,490,000.00 | 1,205,420,000.00 | 1,006,530,000.00 | 1,446.17 |
| 2013-3 | (435,830,000.00) | 1,755,050,000.00 | 1,082,830,000.00 | 962,610,000.00 | 1,655.44 |
| 2013-4 | (448,290,000.00) | 1,531,740,000.00 | 1,171,360,000.00 | 1,075,640,000.00 | 1,659.34 |
| 2014-1 | (307,830,000.00) | 996,870,000.00 | 976,020,000.00 | 909,740,000.00 | 1,782.01 |
| 2014-2 | (607,320,000.00) | 1,602,630,000.00 | 1,507,210,000.00 | 1,242,490,000.00 | 1,825.74 |
| 2014-3 | 172,040,000.00 | 1,446,010,000.00 | 1,537,840,000.00 | 1,402,710,000.00 | 1,840.91 |
| 2014-4 | 272,030,000.00 | 1,191,160,000.00 | 1,753,250,000.00 | 1,629,330,000.00 | 1,888.44 |

| | | | | | |
|---|---|---|---|---|---|
| 2015-1 | (271,100,000.00) | 702,260,000.00 | 1,074,860,000.00 | 967,410,000.00 | 1,984.69 |
| 2015-2 | 354,310,000.00 | 1,136,800,000.00 | 1,294,580,000.00 | 1,091,560,000.00 | 1,963.56 |
| 2015-3 | (255,650,000.00) | 1,015,980,000.00 | 1,170,720,000.00 | 1,020,090,000.00 | 1,996.83 |
| 2015-4 | (95,640,000.00) | 942,480,000.00 | 1,129,110,000.00 | 1,012,500,000.00 | 1,995.51 |
| 2016-1 | (37,760,000.00) | 594,850,000.00 | 957,900,000.00 | 843,390,000.00 | 2,048.90 |
| 2016-2 | (8,210,000.00) | 900,610,000.00 | 1,240,050,000.00 | 1,036,350,000.00 | 1,982.25 |
| 2016-3 | (186,160,000.00) | 952,820,000.00 | 1,129,660,000.00 | 925,220,000.00 | 2,287.30 |
| 2016-4 | 213,940,000.00 | 909,860,000.00 | 1,588,720,000.00 | 1,431,050,000.00 | 2,489.53 |
| 2017-1 | (163,680,000.00) | 776,230,000.00 | 1,298,140,000.00 | 1,202,380,000.00 | 2,475.41 |
| 2017-2 | 89,670,000.00 | 1,150,920,000.00 | 1,803,280,000.00 | 1,526,310,000.00 | 2,400.95 |
| 2017-3 | 275,920,000.00 | 1,197,110,000.00 | 1,479,950,000.00 | 1,315,710,000.00 | 2,435.70 |
| 2017-4 | 1,258,010,000.00 | 1,213,060,000.00 | 1,619,230,000.00 | 1,478,070,000.00 | 2,447.00 |
| 2018-1 | (42,210,000.00) | 1,130,470,000.00 | 1,482,330,000.00 | 1,373,900,000.00 | 2,408.10 |
| 2018-2 | (129,770,000.00) | 1,585,610,000.00 | 2,099,050,000.00 | 1,790,680,000.00 | 2,410.71 |
| 2018-3 | (303,310,000.00) | 1,633,500,000.00 | 1,701,390,000.00 | 1,507,570,000.00 | 2,476.75 |
| 2018-4 | 333,590,000.00 | 1,525,220,000.00 | 1,728,990,000.00 | 1,527,420,000.00 | 2,594.46 |
| 2019-1 | 219,560,000.00 | 1,285,740,000.00 | 1,771,680,000.00 | 1,662,960,000.00 | 2,638.52 |
| 2019-2 | 236,400,000.00 | 1,608,050,000.00 | 2,167,320,000.00 | 1,820,060,000.00 | 2,644.85 |
| 2019-3 | (191,710,000.00) | 1,705,010,000.00 | 2,007,060,000.00 | 1,793,090,000.00 | 2,663.84 |
| 2019-4 | 188,600,000.00 | 1,528,710,000.00 | 1,673,570,000.00 | 1,474,570,000.00 | 2,702.59 |
| 2020-1 | (350,190,000.00) | 1,161,560,000.00 | 1,035,800,000.00 | 965,110,000.00 | 2,756.01 |
| 2020-2 | (329,010,000.00) | 1,298,580,000.00 | 1,792,360,000.00 | 1,660,180,000.00 | 2,898.89 |
| 2020-3 | 206,700,000.00 | 1,467,980,000.00 | 2,318,870,000.00 | 2,155,650,000.00 | 2,846.56 |
| 2020-4 | 1,259,400,000.00 | 1,370,790,000.00 | 2,429,290,000.00 | 2,258,420,000.00 | 2,851.06 |
| 2021-1 | 170,410,000.00 | 1,523,690,000.00 | 1,982,300,000.00 | 1,793,220,000.00 | 2,756.01 |
| 2021-2 | (224,640,000.00) | 1,737,430,000.00 | 2,086,150,000.00 | 1,805,370,000.00 | 2,898.89 |
| 2021-3 | (526,040,000.00) | 1,865,450,000.00 | 2,313,000,000.00 | 2,233,820,000.00 | 2,846.56 |
| 2021-4 | 358,630,000.00 | 1,718,880,000.00 | 2,859,680,000.00 | 2,687,840,000.00 | 2,851.06 |
| 2022-1 | (953,580,000.00) | 1,690,690,000.00 | 1,920,710,000.00 | 1,819,590,000.00 | 2,869.45 |
| 2022-2 | (104,380,000.00) | 2,257,430,000.00 | 3,387,590,000.00 | 3,131,740,000.00 | 3,092.10 |
| 2022-3 | (300,980,000.00) | 2,408,310,000.00 | 3,611,330,000.00 | 3,401,870,000.00 | 3,198.62 |
| 2022-4 | 631,700,000.00 | 2,347,990,000.00 | 3,618,960,000.00 | 3,309,340,000.00 | 3,402.54 |
| 2023-1 | 79,610,000.00 | 1,939,640,000.00 | 3,764,010,000.00 | 3,483,170,000.00 | 3,500.08 |
| 2023-2 | 394,110,000.00 | 2,334,000,000.00 | 3,800,410,000.00 | 3,437,850,000.00 | 3,465.34 |
| 2023-3 | 317,720,000.00 | 2,481,830,000.00 | 3,731,770,000.00 | 3,361,340,000.00 | 3,459.47 |
| 2023-4 | 665,590,000.00 | 2,494,780,000.00 | 3,890,710,000.00 | 3,590,590,000.00 | 3,438.11 |
| 2024-1 | 373,190,000.00 | 2,414,280,000.00 | 3,658,860,000.00 | 3,464,400,000.00 | 3,391.81 |
| 2024-2 | (430,510,000.00) | 2,964,150,000.00 | 4,227,360,000.00 | 3,902,710,000.00 | 3,379.61 |
| 2024-3 | (193,480,000.00) | 3,229,860,000.00 | 3,896,440,000.00 | 3,594,820,000.00 | 3,380.93 |
| 2024-4 | 873,070,000.00 | 3,006,370,000.00 | 4,000,720,000.00 | 3,691,440,000.00 | 3,407.57 |
| 2025-1 | (602,060,000.00) | 2,547,980,000.00 | 3,013,040,000.00 | 2,855,020,000.00 | 3,455.43 |
| 2025-2 | 151,930,000.00 | 2,980,250,000.00 | 3,568,350,000.00 | 3,374,410,000.00 | 3,564.01 |
| 2025-3 | 503,310,000.00 | 3,005,610,000.00 | 4,127,210,000.00 | 3,766,820,000.00 | 3,590.52 |
| 2025-4 | 981,120,000.00 | 2,778,250,000.00 | 4,992,870,000.00 | 4,560,890,000.00 | 3,556.81 |

## Appendix B. Financial assets monthly return

| Date | 0-5 Year US Treasury | SP500 | Libor | Fed overnight |
|---|---|---|---|---|
| 1/31/2000 | 0.00 | 0.02 | 0.01 | 0.00 |
| 2/29/2000 | 0.01 | (0.02) | 0.01 | 0.00 |
| 3/31/2000 | 0.01 | 0.10 | 0.01 | 0.01 |
| 4/30/2000 | 0.00 | (0.03) | 0.01 | 0.01 |
| 5/31/2000 | 0.00 | (0.02) | 0.01 | 0.01 |
| 6/30/2000 | 0.01 | 0.02 | 0.01 | 0.01 |
| 7/31/2000 | 0.01 | (0.02) | 0.01 | 0.01 |
| 8/31/2000 | 0.01 | 0.06 | 0.01 | 0.01 |
| 9/30/2000 | 0.01 | (0.05) | 0.01 | 0.01 |
| 10/31/2000 | 0.01 | (0.00) | 0.01 | 0.01 |
| 11/30/2000 | 0.01 | (0.08) | 0.01 | 0.01 |
| 12/31/2000 | 0.01 | 0.00 | 0.01 | 0.01 |
| 1/31/2001 | 0.01 | 0.03 | 0.00 | 0.00 |
| 2/28/2001 | 0.01 | (0.09) | 0.00 | 0.00 |
| 3/31/2001 | 0.01 | (0.06) | 0.00 | 0.00 |
| 4/30/2001 | 0.00 | 0.08 | 0.00 | 0.00 |
| 5/31/2001 | 0.00 | 0.01 | 0.00 | 0.00 |
| 6/30/2001 | 0.00 | (0.03) | 0.00 | 0.00 |
| 7/31/2001 | 0.01 | (0.01) | 0.00 | 0.00 |
| 8/31/2001 | 0.01 | (0.06) | 0.00 | 0.00 |
| 9/30/2001 | 0.02 | (0.08) | 0.00 | 0.00 |
| 10/31/2001 | 0.01 | 0.02 | 0.00 | 0.00 |
| 11/30/2001 | (0.00) | 0.08 | 0.00 | 0.00 |
| 12/31/2001 | (0.00) | 0.01 | 0.00 | 0.00 |
| 1/31/2002 | 0.00 | (0.02) | 0.00 | 0.00 |
| 2/28/2002 | 0.01 | (0.02) | 0.00 | 0.00 |
| 3/31/2002 | (0.01) | 0.04 | 0.00 | 0.00 |
| 4/30/2002 | 0.01 | (0.06) | 0.00 | 0.00 |
| 5/31/2002 | 0.00 | (0.01) | 0.00 | 0.00 |
| 6/30/2002 | 0.01 | (0.07) | 0.00 | 0.00 |
| 7/31/2002 | 0.01 | (0.08) | 0.00 | 0.00 |
| 8/31/2002 | 0.01 | 0.00 | 0.00 | 0.00 |
| 9/30/2002 | 0.01 | (0.11) | 0.00 | 0.00 |
| 10/31/2002 | 0.00 | 0.09 | 0.00 | 0.00 |
| 11/30/2002 | (0.00) | 0.06 | 0.00 | 0.00 |
| 12/31/2002 | 0.01 | (0.06) | 0.00 | 0.00 |
| 1/31/2003 | (0.00) | (0.03) | 0.00 | 0.00 |
| 2/28/2003 | 0.01 | (0.02) | 0.00 | 0.00 |
| 3/31/2003 | 0.00 | 0.01 | 0.00 | 0.00 |
| 4/30/2003 | 0.00 | 0.08 | 0.00 | 0.00 |
| 5/31/2003 | 0.01 | 0.05 | 0.00 | 0.00 |
| 6/30/2003 | 0.00 | 0.01 | 0.00 | 0.00 |
| 7/31/2003 | (0.01) | 0.02 | 0.00 | 0.00 |
| 8/31/2003 | 0.00 | 0.02 | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 9/30/2003 | 0.01 | (0.01) | 0.00 | 0.00 |
| 10/31/2003 | (0.00) | 0.05 | 0.00 | 0.00 |
| 11/30/2003 | (0.00) | 0.01 | 0.00 | 0.00 |
| 12/31/2003 | 0.01 | 0.05 | 0.00 | 0.00 |
| 1/31/2004 | 0.00 | 0.02 | 0.00 | 0.00 |
| 2/29/2004 | 0.01 | 0.01 | 0.00 | 0.00 |
| 3/31/2004 | 0.00 | (0.02) | 0.00 | 0.00 |
| 4/30/2004 | (0.01) | (0.02) | 0.00 | 0.00 |
| 5/31/2004 | (0.00) | 0.01 | 0.00 | 0.00 |
| 6/30/2004 | 0.00 | 0.02 | 0.00 | 0.00 |
| 7/31/2004 | 0.00 | (0.03) | 0.00 | 0.00 |
| 8/31/2004 | 0.01 | 0.00 | 0.00 | 0.00 |
| 9/30/2004 | (0.00) | 0.01 | 0.00 | 0.00 |
| 10/31/2004 | 0.00 | 0.01 | 0.00 | 0.00 |
| 11/30/2004 | (0.01) | 0.04 | 0.00 | 0.00 |
| 12/31/2004 | 0.00 | 0.03 | 0.00 | 0.00 |
| 1/31/2005 | 0.00 | (0.03) | 0.00 | 0.00 |
| 2/28/2005 | (0.00) | 0.02 | 0.00 | 0.00 |
| 3/31/2005 | (0.00) | (0.02) | 0.00 | 0.00 |
| 4/30/2005 | 0.01 | (0.02) | 0.00 | 0.00 |
| 5/31/2005 | 0.00 | 0.03 | 0.00 | 0.00 |
| 6/30/2005 | 0.00 | (0.00) | 0.00 | 0.00 |
| 7/31/2005 | (0.00) | 0.04 | 0.00 | 0.00 |
| 8/31/2005 | 0.01 | (0.01) | 0.00 | 0.00 |
| 9/30/2005 | (0.00) | 0.01 | 0.00 | 0.00 |
| 10/31/2005 | (0.00) | (0.02) | 0.00 | 0.00 |
| 11/30/2005 | 0.00 | 0.04 | 0.00 | 0.00 |
| 12/31/2005 | 0.00 | (0.00) | 0.00 | 0.00 |
| 1/31/2006 | 0.00 | 0.03 | 0.00 | 0.00 |
| 2/28/2006 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3/31/2006 | 0.00 | 0.01 | 0.00 | 0.00 |
| 4/30/2006 | 0.00 | 0.01 | 0.00 | 0.00 |
| 5/31/2006 | 0.00 | (0.03) | 0.00 | 0.00 |
| 6/30/2006 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7/31/2006 | 0.01 | 0.01 | 0.00 | 0.00 |
| 8/31/2006 | 0.01 | 0.02 | 0.00 | 0.00 |
| 9/30/2006 | 0.01 | 0.02 | 0.00 | 0.00 |
| 10/31/2006 | 0.00 | 0.03 | 0.00 | 0.00 |
| 11/30/2006 | 0.01 | 0.02 | 0.00 | 0.00 |
| 12/31/2006 | - | 0.01 | 0.00 | 0.00 |
| 1/31/2007 | 0.00 | 0.01 | 0.00 | 0.00 |
| 2/28/2007 | 0.01 | (0.02) | 0.00 | 0.00 |
| 3/31/2007 | 0.00 | 0.01 | 0.00 | 0.00 |
| 4/30/2007 | 0.00 | 0.04 | 0.00 | 0.00 |
| 5/31/2007 | (0.00) | 0.03 | 0.00 | 0.00 |
| 6/30/2007 | 0.00 | (0.02) | 0.00 | 0.00 |

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|---|---|---|---|---|
| 7/31/2007 | 0.01 | (0.03) | 0.00 | 0.00 |
| 8/31/2007 | 0.01 | 0.01 | 0.00 | 0.00 |
| 9/30/2007 | 0.01 | 0.04 | 0.00 | 0.00 |
| 10/31/2007 | 0.00 | 0.01 | 0.00 | 0.00 |
| 11/30/2007 | 0.02 | (0.04) | 0.00 | 0.00 |
| 12/31/2007 | 0.00 | (0.01) | 0.00 | 0.00 |
| 1/31/2008 | 0.02 | (0.06) | 0.00 | 0.00 |
| 2/29/2008 | 0.01 | (0.03) | 0.00 | 0.00 |
| 3/31/2008 | 0.00 | (0.01) | 0.00 | 0.00 |
| 4/30/2008 | (0.01) | 0.05 | 0.00 | 0.00 |
| 5/31/2008 | (0.00) | 0.01 | 0.00 | 0.00 |
| 6/30/2008 | 0.00 | (0.09) | 0.00 | 0.00 |
| 7/31/2008 | 0.00 | (0.01) | 0.00 | 0.00 |
| 8/31/2008 | 0.01 | 0.01 | 0.00 | 0.00 |
| 9/30/2008 | 0.01 | (0.09) | 0.00 | 0.00 |
| 10/31/2008 | 0.01 | (0.17) | 0.00 | 0.00 |
| 11/30/2008 | 0.02 | (0.07) | 0.00 | 0.00 |
| 12/31/2008 | 0.01 | 0.01 | 0.00 | - |
| 1/31/2009 | (0.01) | (0.09) | 0.00 | - |
| 2/28/2009 | (0.00) | (0.11) | 0.00 | - |
| 3/31/2009 | 0.01 | 0.09 | 0.00 | - |
| 4/30/2009 | (0.00) | 0.09 | 0.00 | - |
| 5/31/2009 | (0.00) | 0.05 | 0.00 | - |
| 6/30/2009 | (0.00) | 0.00 | 0.00 | - |
| 7/31/2009 | 0.00 | 0.07 | 0.00 | - |
| 8/31/2009 | 0.00 | 0.03 | 0.00 | - |
| 9/30/2009 | 0.00 | 0.04 | 0.00 | - |
| 10/31/2009 | 0.00 | (0.02) | 0.00 | - |
| 11/30/2009 | 0.01 | 0.06 | 0.00 | - |
| 12/31/2009 | (0.01) | 0.02 | 0.00 | - |
| 1/31/2010 | 0.01 | (0.04) | 0.00 | - |
| 2/28/2010 | 0.00 | 0.03 | 0.00 | - |
| 3/31/2010 | (0.00) | 0.06 | 0.00 | - |
| 4/30/2010 | 0.00 | 0.01 | 0.00 | - |
| 5/31/2010 | 0.01 | (0.08) | 0.00 | - |
| 6/30/2010 | 0.01 | (0.05) | 0.00 | - |
| 7/31/2010 | 0.00 | 0.07 | 0.00 | - |
| 8/31/2010 | 0.00 | (0.05) | 0.00 | - |
| 9/30/2010 | 0.00 | 0.09 | 0.00 | - |
| 10/31/2010 | 0.00 | 0.04 | 0.00 | - |
| 11/30/2010 | (0.00) | (0.00) | 0.00 | - |
| 12/31/2010 | (0.01) | 0.07 | 0.00 | - |
| 1/31/2011 | 0.00 | 0.02 | 0.00 | - |
| 2/28/2011 | (0.00) | 0.03 | 0.00 | - |
| 3/31/2011 | (0.00) | (0.00) | 0.00 | - |
| 4/30/2011 | 0.01 | 0.03 | 0.00 | - |

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|---|---|---|---|---|
| 5/31/2011 | 0.01 | (0.01) | 0.00 | - |
| 6/30/2011 | 0.00 | (0.02) | 0.00 | - |
| 7/31/2011 | 0.01 | (0.02) | 0.00 | - |
| 8/31/2011 | 0.01 | (0.06) | 0.00 | - |
| 9/30/2011 | (0.00) | (0.07) | 0.00 | - |
| 10/31/2011 | 0.00 | 0.11 | 0.00 | - |
| 11/30/2011 | 0.00 | (0.01) | 0.00 | - |
| 12/31/2011 | 0.00 | 0.01 | 0.00 | - |
| 1/31/2012 | 0.00 | 0.04 | 0.00 | - |
| 2/29/2012 | (0.00) | 0.04 | 0.00 | - |
| 3/31/2012 | (0.00) | 0.03 | 0.00 | - |
| 4/30/2012 | 0.00 | (0.01) | 0.00 | - |
| 5/31/2012 | 0.00 | (0.06) | 0.00 | - |
| 6/30/2012 | (0.00) | 0.04 | 0.00 | - |
| 7/31/2012 | 0.00 | 0.01 | 0.00 | - |
| 8/31/2012 | 0.00 | 0.02 | 0.00 | - |
| 9/30/2012 | 0.00 | 0.02 | 0.00 | - |
| 10/31/2012 | (0.00) | (0.02) | 0.00 | - |
| 11/30/2012 | 0.00 | 0.00 | 0.00 | - |
| 12/31/2012 | (0.00) | 0.01 | 0.00 | - |
| 1/31/2013 | (0.00) | 0.05 | 0.00 | - |
| 2/28/2013 | 0.00 | 0.01 | 0.00 | - |
| 3/31/2013 | 0.00 | 0.04 | 0.00 | - |
| 4/30/2013 | 0.00 | 0.02 | 0.00 | - |
| 5/31/2013 | (0.00) | 0.02 | 0.00 | - |
| 6/30/2013 | (0.00) | (0.01) | 0.00 | - |
| 7/31/2013 | 0.00 | 0.05 | 0.00 | - |
| 8/31/2013 | (0.00) | (0.03) | 0.00 | - |
| 9/30/2013 | 0.00 | 0.03 | 0.00 | - |
| 10/31/2013 | 0.00 | 0.04 | 0.00 | - |
| 11/30/2013 | 0.00 | 0.03 | 0.00 | - |
| 12/31/2013 | (0.00) | 0.02 | 0.00 | - |
| 1/31/2014 | 0.00 | (0.04) | 0.00 | - |
| 2/28/2014 | 0.00 | 0.04 | 0.00 | - |
| 3/31/2014 | (0.00) | 0.01 | 0.00 | - |
| 4/30/2014 | 0.00 | 0.01 | 0.00 | - |
| 5/31/2014 | 0.00 | 0.02 | 0.00 | - |
| 6/30/2014 | (0.00) | 0.02 | 0.00 | - |
| 7/31/2014 | (0.00) | (0.02) | 0.00 | - |
| 8/31/2014 | 0.00 | 0.04 | 0.00 | - |
| 9/30/2014 | (0.00) | (0.02) | 0.00 | - |
| 10/31/2014 | 0.00 | 0.02 | 0.00 | - |
| 11/30/2014 | 0.00 | 0.02 | 0.00 | - |
| 12/31/2014 | (0.00) | (0.00) | 0.00 | - |
| 1/31/2015 | 0.01 | (0.03) | 0.00 | - |
| 2/28/2015 | (0.00) | 0.05 | 0.00 | - |

| | | | | |
|---|---|---|---|---|
| 3/31/2015 | 0.00 | (0.02) | 0.00 | - |
| 4/30/2015 | 0.00 | 0.01 | 0.00 | - |
| 5/31/2015 | 0.00 | 0.01 | 0.00 | - |
| 6/30/2015 | (0.00) | (0.02) | 0.00 | - |
| 7/31/2015 | 0.00 | 0.02 | 0.00 | - |
| 8/31/2015 | (0.00) | (0.06) | 0.00 | - |
| 9/30/2015 | 0.00 | (0.03) | 0.00 | - |
| 10/31/2015 | (0.00) | 0.08 | 0.00 | - |
| 11/30/2015 | (0.00) | 0.00 | 0.00 | - |
| 12/31/2015 | (0.00) | (0.02) | 0.00 | 0.00 |
| 1/31/2016 | 0.01 | (0.05) | 0.00 | 0.00 |
| 2/29/2016 | 0.00 | (0.00) | 0.00 | 0.00 |
| 3/31/2016 | 0.00 | 0.07 | 0.00 | 0.00 |
| 4/30/2016 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5/31/2016 | (0.00) | 0.02 | 0.00 | 0.00 |
| 6/30/2016 | 0.01 | 0.00 | 0.00 | 0.00 |
| 7/31/2016 | (0.00) | 0.04 | 0.00 | 0.00 |
| 8/31/2016 | (0.00) | (0.00) | 0.00 | 0.00 |
| 9/30/2016 | 0.00 | (0.00) | 0.00 | 0.00 |
| 10/31/2016 | (0.00) | (0.02) | 0.00 | 0.00 |
| 11/30/2016 | (0.01) | 0.03 | 0.00 | 0.00 |
| 12/31/2016 | 0.00 | 0.02 | 0.00 | 0.00 |
| 1/31/2017 | 0.00 | 0.02 | 0.00 | 0.00 |
| 2/28/2017 | 0.00 | 0.04 | 0.00 | 0.00 |
| 3/31/2017 | 0.00 | (0.00) | 0.00 | 0.00 |
| 4/30/2017 | 0.00 | 0.01 | 0.00 | 0.00 |
| 5/31/2017 | 0.00 | 0.01 | 0.00 | 0.00 |
| 6/30/2017 | (0.00) | 0.00 | 0.00 | 0.00 |
| 7/31/2017 | 0.00 | 0.02 | 0.00 | 0.00 |
| 8/31/2017 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9/30/2017 | (0.00) | 0.02 | 0.00 | 0.00 |
| 10/31/2017 | (0.00) | 0.02 | 0.00 | 0.00 |
| 11/30/2017 | (0.00) | 0.03 | 0.00 | 0.00 |
| 12/31/2017 | 0.00 | 0.01 | 0.00 | 0.00 |
| 1/31/2018 | (0.00) | 0.06 | 0.00 | 0.00 |
| 2/28/2018 | (0.00) | (0.04) | 0.00 | 0.00 |
| 3/31/2018 | 0.00 | (0.03) | 0.00 | 0.00 |
| 4/30/2018 | (0.00) | 0.00 | 0.00 | 0.00 |
| 5/31/2018 | 0.00 | 0.02 | 0.00 | 0.00 |
| 6/30/2018 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7/31/2018 | (0.00) | 0.04 | 0.00 | 0.00 |
| 8/31/2018 | 0.00 | 0.03 | 0.00 | 0.00 |
| 9/30/2018 | (0.00) | 0.00 | 0.00 | 0.00 |
| 10/31/2018 | 0.00 | (0.07) | 0.00 | 0.00 |
| 11/30/2018 | 0.00 | 0.02 | 0.00 | 0.00 |
| 12/31/2018 | 0.01 | (0.09) | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 1/31/2019 | 0.00 | 0.08 | 0.00 | 0.00 |
| 2/28/2019 | 0.00 | 0.03 | 0.00 | 0.00 |
| 3/31/2019 | 0.01 | 0.02 | 0.00 | 0.00 |
| 4/30/2019 | 0.00 | 0.04 | 0.00 | 0.00 |
| 5/31/2019 | 0.01 | (0.07) | 0.00 | 0.00 |
| 6/30/2019 | 0.01 | 0.07 | 0.00 | 0.00 |
| 7/31/2019 | (0.00) | 0.01 | 0.00 | 0.00 |
| 8/31/2019 | 0.01 | (0.02) | 0.00 | 0.00 |
| 9/30/2019 | (0.00) | 0.02 | 0.00 | 0.00 |
| 10/31/2019 | 0.00 | 0.02 | 0.00 | 0.00 |
| 11/30/2019 | (0.00) | 0.03 | 0.00 | 0.00 |
| 12/31/2019 | 0.00 | 0.03 | 0.00 | 0.00 |
| 1/31/2020 | 0.01 | (0.00) | 0.00 | 0.00 |
| 2/29/2020 | 0.01 | (0.08) | 0.00 | 0.00 |
| 3/31/2020 | 0.01 | (0.13) | 0.00 | - |
| 4/30/2020 | 0.00 | 0.13 | 0.00 | - |
| 5/31/2020 | 0.00 | 0.05 | 0.00 | - |
| 6/30/2020 | 0.00 | 0.02 | 0.00 | - |
| 7/31/2020 | 0.00 | 0.06 | 0.00 | - |
| 8/31/2020 | (0.00) | 0.07 | 0.00 | - |
| 9/30/2020 | 0.00 | (0.04) | 0.00 | - |
| 10/31/2020 | (0.00) | (0.03) | 0.00 | - |
| 11/30/2020 | 0.00 | 0.11 | 0.00 | - |
| 12/31/2020 | 0.00 | 0.04 | 0.00 | - |
| 1/31/2021 | (0.00) | (0.01) | 0.00 | - |
| 2/28/2021 | (0.00) | 0.03 | 0.00 | - |
| 3/31/2021 | (0.00) | 0.04 | 0.00 | - |
| 4/30/2021 | 0.00 | 0.05 | 0.00 | - |
| 5/31/2021 | 0.00 | 0.01 | 0.00 | - |
| 6/30/2021 | (0.00) | 0.02 | 0.00 | - |
| 7/31/2021 | 0.00 | 0.02 | 0.00 | - |
| 8/31/2021 | (0.00) | 0.03 | 0.00 | - |
| 9/30/2021 | (0.00) | (0.05) | 0.00 | - |
| 10/31/2021 | (0.00) | 0.07 | 0.00 | - |
| 11/30/2021 | 0.00 | (0.01) | 0.00 | - |
| 12/31/2021 | (0.00) | 0.04 | 0.00 | - |
| 1/31/2022 | (0.01) | (0.05) | 0.00 | - |
| 2/28/2022 | (0.00) | (0.03) | 0.00 | - |
| 3/31/2022 | (0.01) | 0.04 | 0.00 | 0.00 |
| 4/30/2022 | (0.01) | (0.09) | 0.00 | 0.00 |
| 5/31/2022 | 0.01 | 0.00 | 0.00 | 0.00 |
| 6/30/2022 | (0.00) | (0.08) | 0.00 | 0.00 |
| 7/31/2022 | 0.01 | 0.09 | 0.00 | 0.00 |
| 8/31/2022 | (0.01) | (0.04) | 0.00 | 0.00 |
| 9/30/2022 | (0.01) | (0.09) | 0.00 | 0.00 |
| 10/31/2022 | (0.00) | 0.08 | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 11/30/2022 | 0.01 | 0.05 | 0.00 | 0.00 |
| 12/31/2022 | 0.00 | (0.06) | 0.00 | 0.00 |
| 1/31/2023 | 0.01 | 0.06 | 0.00 | 0.00 |
| 2/28/2023 | (0.01) | (0.03) | 0.00 | 0.00 |
| 3/31/2023 | 0.02 | 0.04 | 0.00 | 0.00 |
| 4/30/2023 | 0.00 | 0.01 | 0.00 | 0.00 |
| 5/31/2023 | (0.00) | 0.00 | 0.00 | 0.00 |
| 6/30/2023 | (0.00) | 0.06 | 0.00 | 0.00 |
| 7/31/2023 | 0.00 | 0.03 | 0.00 | 0.00 |
| 8/31/2023 | 0.00 | (0.02) | 0.00 | 0.00 |
| 9/30/2023 | (0.00) | (0.05) | 0.00 | 0.00 |
| 10/31/2023 | 0.00 | (0.02) | 0.00 | 0.00 |
| 11/30/2023 | 0.01 | 0.09 | 0.00 | 0.00 |
| 12/31/2023 | 0.01 | 0.04 | 0.00 | 0.00 |
| 1/31/2024 | 0.00 | 0.02 | 0.00 | 0.00 |
| 2/29/2024 | (0.00) | 0.05 | 0.00 | 0.00 |
| 3/31/2024 | 0.00 | 0.03 | 0.00 | 0.00 |
| 4/30/2024 | (0.00) | (0.04) | 0.00 | 0.00 |
| 5/31/2024 | 0.01 | 0.05 | 0.00 | 0.00 |
| 6/30/2024 | 0.01 | 0.03 | 0.00 | 0.00 |
| 7/31/2024 | 0.01 | 0.01 | 0.00 | 0.00 |
| 8/31/2024 | 0.01 | 0.02 | 0.00 | 0.00 |
| 9/30/2024 | 0.01 | 0.02 | 0.00 | 0.00 |
| 10/31/2024 | (0.01) | (0.01) | 0.00 | 0.00 |
| 11/30/2024 | 0.00 | 0.06 | 0.00 | 0.00 |
| 12/31/2024 | 0.00 | (0.02) | 0.00 | 0.00 |
| 1/31/2025 | 0.00 | 0.03 | 0.00 | 0.00 |
| 2/28/2025 | 0.01 | (0.01) | 0.00 | 0.00 |
| 3/31/2025 | 0.00 | (0.06) | 0.00 | 0.00 |
| 4/30/2025 | - | - | 0.00 | 0.00 |
| 5/31/2025 | 0.01 | (0.01) | 0.00 | 0.00 |
| 6/30/2025 | (0.00) | 0.06 | 0.00 | 0.00 |
| 7/31/2025 | 0.01 | 0.05 | 0.00 | 0.00 |
| 8/31/2025 | (0.00) | 0.02 | 0.00 | 0.00 |
| 9/30/2025 | 0.01 | 0.02 | 0.00 | 0.00 |

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## LIST OF RESEARCH PAPERS

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