Optimal Allocation of Central Bank Assets: A Linear Programming Model

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE

OF

MASTER OF SCIENCE
IN
APPLIED MATHEMATICS

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ACKNOWLEDGEMENT

We take this opportunity to express our sincere gratitude to all those who have extended their support and guidance throughout the course of this project dissertation.
We are deeply grateful to my supervisor, **Prof. Laxmi Narayan Das**, for His constant support, valuable suggestions, and continuous encouragement throughout the dissertation. Their expert guidance and constructive feedback were vital in shaping the direction and outcome of this work.
We would also like to thank the faculty members and staff of the **Department of Applied mathematics**, Delhi Technological University, for providing the necessary resources and environment conducive to research. Last but not least, we thank our family and friends for their unwavering support and motivation during the course of this dissertation.

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CANDIDATE'S DECLARATION

We, **Anamitra Deb (23/MSCMAT/68)** and **Shiksha Devi (23/MSCMAT/66)**, students of M.Sc Applied Mathematics, hereby declare that the Dissertation titled ***"Optimal Allocation of Central Bank Assets: A Linear Programming Model"*** which is submitted by us to the Department of Applied Mathematics, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Science, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition.

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Abstract

This study presents a linear programming model to optimize the virtual allocation of funds by the central bank of a country to various banks and allied sectors, with the objective of maximizing interest revenue while minimizing bad debt. The model assumes a total asset of Rs. 5 trillion, which are allocated to affiliated and registered banks, namely XYZ, ABC, NABARD, BNP, and IBS. These banks further invest the allocated funds in at least five sectors, namely agriculture, power plants, medical research, manufacturing industry, and education. Here, the objective function combines interest revenue and bad debt, with the goal of maximizing interest revenue while keeping bad debt at zero. The model includes eight constraints, such as total allocation limits for each bank, overall bad debt ratio, and sector-specific requirements. The problem is solved using computer software and the optimal allocation of funds is determined. Although the model is hypothetical, it demonstrates the potential of linear programming in optimizing resource allocation in the banking sector. The study highlights the importance of considering multiple factors, such as interest rates and bad debt ratios, in making investment decisions. The findings can improve policy decisions and help banks optimize their investment strategies to maximize returns while minimizing risks. Further research can focus on incorporating real-world data and additional constraints to enhance the model's applicability and effectiveness in the banking industry.

keywords: Bad debt management, Central bank, Financial Optimization, Interest Revenue, Investment, Lpp, Optimization,

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Nomenclature

c_i	Coefficients of objective function
x_i	Decision variable
+	Plus
-	Minus
=	Equal to
[ ]	Matrix
$[\ ]^T$	Matrix transpose
$\geq$	Greater than or equal to
$\in$	Belong to
$\leq$	Less than or equal to
$\sum$	Summation
a_{ij}	Coefficients of constraints

List of Abbreviations

ABC	Sample Bank 1
BNP	Sample Bank 2
IBS	Sample Bank 3
XYZ	Sample Bank 4
NABARD	Sample Bank 5
LP	Linear Programming
OT	Optimization technique
LPP	Linear Programming Problem
ILP	Integer linear programming
MILP	Mixed Integer linear programming
NLP	Non-linear programming
LPM	Linear Programming Model
Rs.	Indian Rupees
i.e.	That is
e.g.	Example
T	Trillion
Max	Maximize
Socio	Social
TORA	Software use to solve LPP
LINGO	Software use to solve LPP
MATLAB	Software use to solve LPP
MODM	Multi-Objective Decision Making
MOLP	Multi-objective linear programming
RHS	Right Hand Side

Terminology

Asset: In this thesis, the term *asset* is used to denote the central bank's pool of *funds* allocated for investment purposes.

Credit risk: Refers to bad debt or expected loss associated with a particular investment option.

CHAPTER 1

1 INTRODUCTION

1.1 Problem Overview

In the field of financial management and economic planning, efficient allocation of funds plays a crucial role in maximizing economic growth. Central banks act as regulatory bodies that oversee the distribution of financial resources to commercial banks, which, in turn, invest these funds in various sectors of the economy.

In this study, a hypothetical model of the central bank of a country has an available amount of Rs. 5 trillion and the Central bank allocates this fund to five different registered commercial banks, each receiving a specific proportion based on certain criteria. 15% of the fund is allocated to XYZ bank, 40% of the fund to ABC bank, 15% of the fund to NABARD bank, 20% of the fund to BNP bank, and 20% of the fund is allocated to IBS. We have assumed an abstract interest rate and a debt rate ratio for each of these commercial banks. These banks further invest their allotted amount in five different sectors of the economy, namely agriculture, power plant, health, industry, and education. Using all the assumed data, we have constructed a linear programming model to manage multiple objectives and constraints, allowing central banks to make more informed and effective investment decisions. The model can take into account a wide range of factors, including budget limitations, risk factors, sectoral investment limits, and regulatory compliance requirements.

1.2 Problem Statement

The investment plan, guided by a linear programming model, seeks to optimize the asset allocation for a hypothetical central bank with Rs. 5 trillion in assets. The model allocates funds to affiliated banks, which then invest in various sectors, including agriculture, power plants, health, industry, and education. The primary objective of the model is to find the optimal allocation of funds in different sectors by affiliated banks maximizing interest revenue while maintaining a zero bad debt threshold, ensuring financial prudence. We have used the TORA Optimization System, Windows version 1.00 to solve the linear programming problem.

1.3 Objective of the Study

The primary objective of this research is to develop a linear programming model that facilitates the optimal allocation of a central bank's asset among its affiliated commercial banks. The study seeks to maximize the interest revenue of banks while minimizing the potential risks associated with bad debt and regulatory constraints. Specifically, the study aims:

1. To formulate a linear programming model that incorporates relevant economic and regulatory constraints faced by central banks in asset allocation.
2. To identify the optimal mix of asset classes that maximizes expected return while satisfying liquidity, safety, and reserve requirements.
3. To perform a sensitivity analysis of the model to assess how changes in interest rates, risk levels, or regulatory policies affect the optimal asset mix.
4. To provide policy implications and recommendations based on the model's output that can assist central banks in strategic investment planning.
5. Compare the LPP model's asset allocation recommendations with traditional allocation methods.

By addressing these objectives, this study aims to provide banks with a robust analytical framework for making informed asset allocation decisions, potentially improving their financial performance and stability in a competitive market environment.

1.4 Limitation of the Study

Despite the rigorous methodology adopted and the insightful outcomes derived from the linear programming model, this study has several limitations that must be acknowledged. These limitations stem from both theoretical constraints and practical considerations, which may affect the generalizability and accuracy of the results.

1.4.1 Simplifying Assumptions in the LPM

Linear programming, by design, requires simplification of real-world complexities into linear relationships. In this study, we have made several simplifying assumptions, including the following.

- Linearity of Constraints and Objective function: Economic relationships, such as risk-return profiles or interest rate responses, are rarely linear in practice. However, for tractability and model solvability, we assumed linearity.

- Additivity and Divisibility: The model assumes that central bank assets can be divided infinitely and combined additively. In reality, many financial instruments come in indivisible units or have constraints such as minimum purchase amounts.

- Certainty and Determinism: Linear programming models operate under deterministic conditions. How ever, real-world financial markets are characterized by uncertainty, including unexpected policy shifts, geopolitical events, and interest rate volatility.

1.4.2 Static Nature of the Model

The LP model used in this study is static, which means that it provides a snapshot optimization for a given period without accounting for dynamic changes over time. However, Central Bank's asset allocation is a dynamic process that must consider:

- Time-based changes in interest rates, inflation, or credit risk.

- Rebalancing requirements due to maturing assets or liquidity needs.

- Adaptive responses to economic shocks or changes in policy priorities.

1.4.3 Data Limitations

The accuracy of any optimization model is dependent on the quality and availability of the input data. In our study:

- We relied on historical or estimated data for variables such as expected returns, credit ratings, risk weights, and policy constraints. These estimates may not reflect future conditions.

- Missing data or inconsistent reporting across asset classes or countries may have introduced biases in parameter values or constraint formulation.

- Some variables, such as risk tolerance or political constraints, are difficult to quantify and were either ignored or qualitatively embedded in the model.

1.4.4 Exclusion of Macroeconomic Feedback Effects

While the LP model optimizes from the central bank's perspective, it does not account for macroeconomic feedback loops, such as:

- How changes in asset allocation influence inflation, exchange rates, or interest rates.
- The potential crowding out of private investment due to government bond purchases.
- Systemic risk implications of investing in specific sectors or instruments.

This partial equilibrium approach may overlook the broader impact of central bank actions on the economy and financial markets.

1.5 Linear Programming

1.5.1 Historical Background

Linear Programming (LP) is one of the most fundamental and widely applied optimization techniques in operations research, management science, economics, industrial engineering, and applied mathematics. It provides a systematic and powerful framework to model decision-making problems involving limited resources, such as labor, materials, capital, and time, in an optimal way. Whether it is maximizing profit, minimizing cost, or achieving the best combination of resources, LP offers a structured approach using mathematical models grounded in linear algebra.

The technique is called "linear" because both the objective function and the constraints are linear equations or inequalities. The term "programming" here does not refer to computer programming but originates from the 1940s, where "programming" referred to planning or scheduling.

The origins of Linear Programming date back to the early 20th century, but it gained formal recognition during World War II. George B. Dantzig, a mathematician working with the U.S. Air Force, developed the Simplex method in 1947, which revolutionized the ability to solve real-world optimization problems. Dantzig's algorithm allowed for efficient computation of optimal solutions in problems involving multiple variables and constraints. Since then, LP has grown into a mature discipline with extensive theoretical development and practical applications.

Definition
Linear programming is defined as a mathematical technique for determining the best allocation of a firm's limited resources to achieve a particular objective (such as profit maximization or cost minimization), assuming the objective function and the constraints can be expressed linearly. Mathematically, a Linear Programming problem is characterized by:

- A linear objective function to be maximized or minimized.
- A set of linear constraints (equalities or inequalities).
- Non-negativity restrictions on variables.

1.5.2 Key Components of a LPP

A Linear Programming (LP) problem consists of several fundamental components that together define the structure and objective of the optimization model. These components are as follows:

Definition

Decision variables are the unknown quantities that the decision makers aim to determine. They represent actions or choices, such as the quantity of products to produce, resources to allocate, or investment proportions. The values assigned to these variables determine the outcome of the optimization.

$$\text{Let } x_1, x_2, \ldots, x_n \text{ be the decision variables.}$$

Definition

Objective function is the function to be optimized (maximized or minimized). It quantifies the goal of the problem in terms of the decision variables. The objective function must be linear.

$$\text{Maximize or Minimize} \quad Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n = \sum_{j=1}^{n} c_jx_j$$

where c_j are known coefficients that represent the contribution of each variable to the objective.

Definition

Constraints are the limitations or requirements that must be satisfied. These can include resource availability, production capacity, demand satisfaction, or policy restrictions. Each constraint is expressed as a linear equation or inequality.

$$a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n \leq (\text{or } =, \geq)\ b_i \quad \text{for } i = 1, 2, \ldots, m$$

Definition

Variables cannot take negative values are known as non-negative constraints. This reflects real-world conditions, as producing negative amounts or allocating negative resources is usually infeasible.

$$x_j \geq 0 \quad \text{for all } j = 1, 2, \ldots, n$$

1.5.3 General Structure of a LPP

A Linear Programming (LP) problem is typically structured as follows:

Objective Function

$$\text{Maximize (or Minimize)} \quad Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n = \sum_{j=1}^{n} c_jx_j \qquad (1)$$

where:

- Z is the value of the objective function to be optimized,
- c_j represents the coefficients of the objective function,
- x_j are the decision variables, for $j = 1, 2, \ldots, n$.

Subject to Constraints

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &\leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &\leq b_2 \\ \vdots \qquad\quad & \quad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &\leq b_m \end{aligned} \qquad (2)$$

or in matrix notation:

$$\text{Subject to} \quad Ax \leq b \tag{3}$$

where:

- $A = [a_{ij}]$ is an $m \times n$ matrix of constraint coefficients,
- $x = [x_1, x_2, \ldots, x_n]^T$ is a column vector of decision variables,
- $b = [b_1, b_2, \ldots, b_m]^T$ is a column vector of resource limits.

Non-Negativity Conditions

$$x_j \geq 0 \quad \text{for all } j = 1, 2, \ldots, n \tag{4}$$

1.5.4 Advantages of LP

- **Precision**: Offers a precise mathematical formulation of complex decision-making problems.
- **Clarity**: Clearly identifies trade-offs among competing objectives or resources.
- **Optimality**: Guarantees an optimal solution if one exists.
- **Versatility**: Applicable to a wide range of fields and problems.
- **Efficiency**: Solved using powerful algorithms even for large-scale problems.

1.5.5 Limitations of LP

- **Linearity Assumption**: Real-world relationships are often non-linear.
- **Certainty Assumption**: The parameters are assumed to be known with certainty.
- **Divisibility**: Fractional values may not be acceptable in real scenarios.
- **Static Nature**: LP does not handle dynamic or time-dependent decisions well.
- **Single Objective**: LP typically handles only one objective. Multi-objective optimization requires extensions like Goal Programming.

1.6 Assumptions of LP

1.6.1 Why Assumptions Matter in LP

Assumptions form the theoretical backbone of Linear Programming. They serve several important functions:

- Define the feasible solution space
- Ensure linearity and thus solvability via LP algorithms
- Allow mathematical modeling of real-life phenomena using simplified abstractions
- Ensure deterministic outcomes, making LP models predictable and reproducible

Violations of these assumptions can render the LP models inaccurate, leading to poor or infeasible decisions. Therefore, understanding and validating these assumptions are crucial steps in any optimization project.

1.6.2 Core Assumptions of LP

Linear Programming is built upon five primary assumptions as follows:

1. Linearity
2. Additivity
3. Divisibility (Continuity)
4. Certainty (Determinism)
5. Non-negativity

1. Linearity

Definition Linearity implies that both the objective function and all constraints are linear in the decision variables. That is, the contribution of each decision variable to the objective function or to a constraint is directly proportional to its magnitude. Objective function:

$$Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n$$

$$a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n \leq b_i$$

There are no powers, roots, trigonometric terms, or products of the decision variables. **Implications**

- No economies of scale or diminishing returns can be represented.
- The marginal impact of a variable is constant.

Limitations:

- Real systems often exhibit non-linear behavior (e.g., bulk discounts, fatigue effects).
- LP may not capture these effects unless linear approximations are used.

2. Additivity

Definition Additivity assumes that the total contribution of all decision variables is the sum of their individual contributions. That is, there are no interaction effects between the variables.
For example: In the context of the objective function:

$$Z = \sum_{j=1}^{n} c_j x_j$$

and for constraints:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i$$

This simplifies the formulation of the model by assuming that combined contributions are additive without synergy or interference between the decision variables.
Implications

- Output and resource usage are additive.
- No synergy or interference between variables.

Limitations:

- Cannot model joint production, learning effects, or inter dependencies.
- More advanced models like non-linear programming (NLP) are required when interactions are significant.

3. Divisibility (Continuity)

Definition Divisibility means that decision variables can take fractional values, i.e. they are continuous and not restricted to integers.This implies that the solution space is continuous and one can divide resources or products into infinitely small parts.

$$x_j \in \mathbb{R}^+ \quad \text{for all } j$$

Implications

- Allows infinite divisibility of resources and products.
- Useful in modeling resources such as time, money, or fuel.

Limitations:

- Not suitable for problems requiring integer decisions (e.g., number of trucks, machines, people).
- Integer Linear Programming (ILP) or Mixed-Integer Linear Programming (MILP) must be used when divisibility is not valid.

4. Certainty (Determinism)

Definition Certainty assumes that all parameters (coefficients in the objective function and constraints) are known with certainty and remain constant during the planning horizon.
That is, coefficients c_i, a_{ij}, b_i, c_i, a_{ij}, b_i are all deterministic.

Implications

- Inputs and outputs do not change unexpectedly.
- Allows deterministic computation of outcomes.

Limitations:

- In real-world scenarios, demand, supply, and costs are often uncertain.
- Stochastic programming or robust optimization is required when dealing with uncertainty.

5. Non-Negativity

Definition All decision variables must be nonnegative, as negative quantities of physical resources typically have no real-world interpretation.

$$x_j \geq 0 \quad \text{for all } j = 1, 2, \ldots, n$$

Implications

- Prevents infeasible or nonsensical solutions.
- Ensures that solutions reflect physical or economic reality.

Limitations:

- Certain economic or financial models may require variables unrestricted in sign.
- These models need special treatment during conversion to standard form.

1.7 The Role of OT in Banking Sector

Optimization techniques provide a systematic and quantitative framework to assist central banks in making these critical asset distribution decisions, taking into account various economic, financial, and institutional constraints. This section explores the role, benefits and challenges of utilizing such techniques—focusing on LP—in achieving optimal allocation among affiliated financial institutions.

1.7.1 The Need for Optimization Model

Mathematical programming offers a structured approach to investment decisions, providing a framework to analyze complex problems and identify optimal solutions. The mathematical programming model then finds the values of the decision variables that optimize the objective function while satisfying all the constraints. For instance, linear programming can be used to optimize asset allocation.

Linear programming can provide optimal solutions for asset allocation, considering various constraints to help the central bank to make the most efficient use of their resources. The solution to the linear programming problem provides the optimal values for the decision variables, which in this case would be the amounts allocated to each asset class [11]. By using optimization models, central banks can identify investment strategies that are more likely to achieve their objectives while staying within their constraints.

1.7.2 Central Bank Asset Allocation: The Strategic Landscape

Central banks hold substantial portfolios that include government securities, foreign exchange reserves, gold, and various forms of loans and advances to affiliated banks. The distribution of these assets is not merely a matter of liquidity management; it is a strategic tool for influencing macroeconomic outcomes such as:

- Interest rates
- Inflation levels
- Credit supply and demand
- Foreign exchange stability
- Systemic financial risks

The allocation decisions must consider multiple objectives: ensuring maximum returns on assets, maintaining minimum risk exposure, ensuring compliance with policy mandates, and sustaining financial market stability. Balancing these objectives under a constrained environment creates a multi-objective optimization problem, for which LP and related techniques are ideally suited.

Table 1: Optimization Brings Structure to Banking Decisions

Banking Problem	Optimization Approach
Loan portfolio selection	LP / Integer Programming
Reserve allocation	LP with liquidity constraints
Credit risk balancing	Multi-objective Optimization
Profitability vs. Risk trade-offs	Goal Programming
Asset-liability matching	Linear/Quadratic Programming

CHAPTER 2

2 LITERATURE REVIEW

2.1 Role of Central Banks in Financial Resource Allocation

The central bank serves as the monetary authority of a country, tasked with controlling inflation, regulating the money supply, stabilizing the currency and ensuring financial system stability. In this context, its role in allocating financial resources is particularly crucial. Traditionally, central banks manage monetary policy tools like the repo rate, reverse repo rate, and statutory liquidity ratio to influence the availability of funds in the economy. However, in several developing and emerging economies, central banks may also intervene more directly in capital allocation to critical sectors to drive socio-economic growth.

The literature emphasizes that financial resource allocation by central banks has broader macroeconomic implications, such as influencing investment trends, sectoral growth, and employment generation. According to Mishkin (2007), central banks use monetary tools to influence the lending behavior of commercial banks, which in turn affects how resources are directed across various sectors. In some hypothetical or special policy cases, a central bank may simulate direct allocation schemes for purposes such as infrastructure development, rural upliftment, or technological advancement.

A hypothetical direct allocation model, like the one proposed in your dissertation, serves as an analytical framework for understanding the effects of capital redistribution when mediated by affiliated banks. By distributing funds to commercial banks, which then invest in various sectors, the central bank indirectly influences sectoral development priorities. This hierarchical allocation model ensures that the funds are channeled through established financial intermediaries, reducing the operational burden on the central bank while leveraging the risk assessment capabilities of commercial banks.

Studies such as Bernanke and Gertler (1989) have shown that central banks indirectly promote economic efficiency and stability by influencing how banks allocate credit. The inclusion of sectoral investment requirements in central bank policy can be particularly effective in addressing sector-specific imbalances. For instance, increased allocations to agriculture or health care can help address rural poverty and public health crises, respectively.

While most real-world central banks operate through policy signaling and indirect mechanisms, simulation studies, like your dissertation, provide valuable insights into the efficiency, effectiveness, and trade-offs involved in more direct intervention strategies. They also underscore the need to account for factors such as risk, debt ratios, and sectoral caps in decision-making models. As such, the proposed linear programming model holds significance in understanding potential outcomes and policy implications of a centrally managed investment plan.

2.2 Application of Linear Programming in Financial Management

Linear programming (LP) is a well-established optimization technique widely used in operations research, economics, and finance for resource allocation problems involving linear relationships. The primary strength of LP lies in its ability to find the most efficient allocation of limited resources given multiple objectives and constraints. Its applications in financial management span from capital budgeting, asset allocation, and portfolio selection to risk management and debt minimization.

According to Taha (2017), LP offers a structured, objective, and transparent decision-making framework that can accommodate multiple quantitative factors, such as returns, risk levels, debt ratios, and investment limits. In finance, LP models have been successfully applied to optimize asset allocations by balancing expected returns against constraints like capital budgets, risk exposure, regulatory caps, and liquidity requirements.

Your dissertation's model fits squarely within this tradition, using a linear programming model to allocate Rs. 5 trillion in hypothetical central bank funds across five banks and five sectors. The use of LP allows decision-makers to determine optimal fund allocations that maximize interest income while keeping bad debts at zero — a dual objective central to responsible financial management. The eight constraints incorporated into your model — covering total allocation limits, bad debt ratios, and sector-specific caps — reflect practical considerations in real-world financial planning.

Recent studies, such as those by Li and Zhang (2018), demonstrate that LP models can significantly improve the efficiency and profitability of investment portfolios when properly calibrated with accurate data. By integrating multiple financial indicators, LP enables central banks and financial institutions to make data-driven, objective decisions rather than relying solely on qualitative judgments.

Moreover, software tools like TORA and LINGO, as mentioned in your dissertation, have made it easier to model, solve, and interpret complex LP problems. These tools allow for sensitivity analysis, scenario simulation, and risk assessment

— capabilities crucial for financial decision-making under uncertainty. The ability to simulate various policy and market scenarios makes LP an invaluable technique for stress-testing investment strategies, evaluating regulatory compliance, and optimizing asset allocation under multiple objectives. Therefore, your dissertation not only applies a proven optimization technique to a hypothetical central bank scenario but also highlights the growing relevance of mathematical programming in modern financial management, policy simulation, and regulatory planning.

2.3 Multi-Objective Decision Making in Financial Planning

Modern financial management increasingly involves multi-objective decision making (MODM), where decision-makers must balance conflicting objectives — such as maximizing returns while minimizing risk, or achieving growth targets while ensuring liquidity. The optimization problem in your dissertation exemplifies this challenge, with the dual objectives of maximizing interest revenue and maintaining zero bad debt.

Literature on MODM highlights that financial decisions cannot be based on a single metric. According to Steuer (1986), real-world financial problems often involve trade-offs between profitability, risk, liquidity, and compliance. A decision model that fails to account for these competing objectives may lead to sub-optimal or even risky outcomes. Multi-objective linear programming (MOLP) methods, such as the one you propose, allow decision-makers to evaluate multiple goals within a coherent, quantitative framework.

In your model, the primary objectives are maximized interest and zero bad debt, but additional implicit goals include sectoral diversification, economic development, and regulatory adherence. Each bank's allocation limit and each sector's investment minimum represent competing demands on scarce resources. By explicitly modeling these constraints, your LP formulation ensures that decisions are made transparently and rationally, even in the face of conflicting priorities.

A practical benefit of MODM models is their capacity to provide decision-makers with a set of feasible alternatives (efficient frontiers) rather than a single point solution. As noted by Zeleny (1973), decision-makers often prefer to evaluate trade-offs among competing outcomes before committing to a final strategy. Although your dissertation seeks an optimal single-point solution, future extensions might use goal programming or weighted multi-objective methods to provide policymakers with flexible, preference-based options.

Recent applications of MODM in central bank policy simulation and sovereign fund management have shown the value of these methods in designing balanced investment portfolios that align with macroeconomic goals. In this sense, your model serves not only as a technical exercise but also as a pedagogical tool for understanding how central banks might navigate complex policy environments using mathematical tools.

2.4 Sectoral Investment Strategies and Their Economic Implications

The choice of investment sectors in your model — agriculture, power plants, medical research, manufacturing, and education — reflects key drivers of long-term economic growth and social welfare. According to endogenous growth theory (Romer, 1990), investments in human capital, infrastructure, and technological innovation have multiplicative effects on economic output and productivity.

Studies have consistently shown that targeted sectoral investments lead to differential economic impacts. For instance, agricultural investments typically enhance food security, rural employment, and income equality, especially in agrarian economies. Power sector investments address energy shortages, increase industrial productivity, and promote environmental sustainability when focused on renewable sources. Similarly, investments in healthcare and education improve human capital, boost labor productivity, and reduce inequality, thereby contributing to long-term macroeconomic stability.

By integrating these sectors into your LP model, you highlight the importance of sector-specific investment strategies in national economic planning. The sectoral constraints in your model ensure that minimum and maximum investment thresholds are met, preventing under- or over-concentration of resources in particular areas. This aligns with empirical findings by Aschauer (1989), who emphasized the role of public infrastructure investments in stimulating private sector productivity and economic growth.

Moreover, your model accounts for sector-specific debt risks, acknowledging that certain sectors — like agriculture and health — may carry higher credit risks but also deliver significant social returns. By balancing these risks through bad debt ratio constraints, the model ensures financial prudence without compromising socio-economic objectives.

Such sectoral prioritization is a key concern in central bank policy planning, especially in countries pursuing inclusive, mission-oriented growth strategies. The World Bank (2019) advocates for evidence-based investment planning, emphasizing the need to align financial flows with national development priorities. Your dissertation's LP model serves as a hypothetical case study demonstrating how mathematical optimization can reconcile financial returns with socio-economic development objectives.

2.5 The Importance of Risk Management in Central Bank Investment Plans

Risk management is an indispensable component of financial decision-making, particularly for central banks, which must preserve economic stability while pursuing growth-oriented objectives. Bad debt, representing credit defaults and non-performing assets, is a significant risk factor in banking and investment activities. Your model incorporates this by maintaining a zero-bad-debt objective, reflecting the central bank's aversion to financial instability.

Literature on financial risk management emphasizes the necessity of integrating risk controls directly into investment models. According to Jorion (2007), financial institutions must actively manage exposure to credit, market, liquidity, and operational risks. While your dissertation focuses primarily on credit risk (bad debt), the framework could be extended to incorporate other risk dimensions using linear or quadratic programming techniques.

The incorporation of bad debt ratios as constraints in your LP model ensures that financial prudence is maintained across different sectoral allocations. This is particularly relevant because different sectors have inherently different credit risk profiles. For example, agricultural loans typically exhibit higher default rates due to factors like weather dependency and price volatility, while investments in education or healthcare may be less financially lucrative but carry lower default risks.

Furthermore, by using LP techniques to identify risk-optimal allocation strategies, central banks can proactively manage systemic risks. Studies such as Saunders and Allen (2010) suggest that financial regulators should employ quantitative tools for portfolio stress-testing and risk forecasting. The LP model in your dissertation represents a simplified yet practical approach to this objective, offering a blueprint for constructing credit-risk-minimized investment plans.

The use of software tools like TORA and LINGO for solving these optimization problems enhances the reliability and replicability of results, enabling decision-makers to assess alternative scenarios and evaluate the sensitivity of optimal solutions to changing economic conditions.

2.6 Simulation and Hypothetical Modeling in Economic Policy Planning

Simulation modeling plays a critical role in modern economic policy planning by enabling policymakers to explore the outcomes of various policy scenarios in a controlled, risk-free environment. Hypothetical models, like the one in your dissertation, are valuable tools for stress-testing financial policies and investment strategies under a range of assumptions.

According to Sterman (2000), simulation models help decision-makers understand the complex, nonlinear interactions within financial and economic systems. In the context of central bank investment planning, simulations allow for the evaluation of multiple allocation strategies, risk scenarios, and policy constraints before actual funds are deployed. This reduces the likelihood of policy missteps and financial instability.

Your dissertation's hypothetical LP model offers a platform for simulating various fund allocation strategies, sectoral priorities, and risk profiles, providing insights into optimal investment distributions under given constraints. While real-world applications would require empirical data, simulations based on plausible assumptions, as you've done, are essential first steps in policy experimentation.

Recent advances in financial modeling and computational tools, such as LINGO, TORA, and MATLAB, have made it easier to construct, solve, and analyze complex optimization problems. These tools facilitate rapid iteration, scenario analysis, and sensitivity testing — features particularly useful in economic planning, where policymakers must account for uncertainties in market behavior, economic growth, and financial risks.

Moreover, by emphasizing the hypothetical nature of your model, you acknowledge its limitations while underscoring its pedagogical and exploratory value. As Sterman (2000) notes, simulation models are not predictive tools but decision aids that improve understanding of dynamic systems and inform policy deliberations. Your model contributes to this tradition by illustrating how central banks might use mathematical optimization to achieve balanced, risk-aware investment strategies in service of broader economic goals.

CHAPTER 3

3 METHODOLOGY

3.1 Assumed data

Central bank has total assets of Rs. 5 trillion. Central bank allocates this fund to five different banks, namely XYZ bank, ABC bank, NABARD, PNB, and IBS bank. The investment decisions are guided by careful analysis, risk assessment, and a commitment to achieving both financial returns and broader social benefits. The following table shows the data about the allocation and their interest rate and bad debt rate.

Here is a summary of fund allocations.

Table 2: Allocation of funds in different banks

Bank	Allocation (in %)	Amount (in trillion)	Interest rate	Bad debt ratio
XYZ	15	0.75	0.140	0.20
ABC	40	2	0.135	0.07
NABARD	15	0.75	0.120	0.03
BNP	20	1	0.125	0.06
IBS	10	0.5	0.110	0.03

Further these banks invest their allocated amount in five different sectors such as agriculture, power plant, health, industry, and education, reflecting the diverse range of economic activities that benefit from central bank funding. The following table shows the amount of investment of the banks in different sectors (in trillion).

Here is a summary of fund allocations.

Table 3: Allocation of funds in different utility sectors

Bank	Agriculture (x_{i1})	Power plants (x_{i2})	Health (x_{i3})	Industry (x_{i4})	Education (x_{i5})
XYZ	0.05	0.15	0.20	0.10	0.25
ABC	0.4	0.35	0.3	0.45	0.5
NABARD	0.45	0.099	0.05	0.075	0.05
BNP	0.25	0.1	0.175	0.175	0.2
IBS	0.15	0.05	0.075	0.075	0.125

3.2 Construction of the model

The situation deals with determining the amount of allocation in each category thus leading to the following definitions of the variables:

x_1 = allocation funds in agriculture,
x_2 = allocation funds in power plant,
x_3 = allocation funds in health,
x_4 = allocation funds in industry,
x_5 = allocation funds in education.

In micro sense sum of the allocations of funds in agriculture invested by XYZ bank, ABC bank, NABARD, BNP and IBS bank should not exceed x_1. Sum of the allocations of funds in power plant invested by XYZ bank, ABC bank, NABARD, BNP and IBS bank should not exceed x_2. Sum of the allocations of funds invested by XYZ bank, ABC bank, NABARD, BNP and IBS bank in health should not exceed x_3. Sum of the allocations of funds invested by XYZ bank, ABC bank, NABARD, BNP and IBS bank in the industry should not exceed x_4 and Sum of the allocations of funds invested by XYZ bank, ABC bank, NABARD, BNP and IBS bank in education should not exceed x_5. Now defining the following variables in the micro sense:

x_{i1}= allocation of funds by the banks in agriculture,
x_{i2}= allocation of funds by the banks in power plant,
x_{i3}= allocation of funds by the banks in health,
x_{i4}= allocation of funds by the banks in industry,
x_{i5}= allocation of funds by the banks in education.
Where, i = 1, 2, 3, 4, 5.

Now we come across following micro constraints:
total allocation in agricultural sector should not exceed x_1 i.e.

$$0.05x_{11} + 0.4x_{21} + 0.45x_{31} + 0.25x_{41} + 0.15x_{51} \leq x_1 \tag{5}$$

total allocation in power plant should not exceed $x2$ i.e.

$$0.15x_{12} + 0.35x_{22} + 0.099x_{32} + 0.1x_{42} + 0.05x_{51} \leq x_2 \tag{6}$$

total allocation in health should not exceed $x3$ i.e.

$$0.20x_{13} + 0.3x_{23} + 0.05x_{33} + 0.175x_{43} + 0.75x_{53} \leq x_3 \tag{7}$$

total allocation in industry should not exceed $x4$ i.e.

$$0.10x_{14} + 0.45x_{23} + 0.075x_{33} + 0.175x_{43} + 0.75x_{54} \leq x_4 \quad (8)$$

and total allocation in education should not exceed $x5$ i.e.

$$0.25x_{13} + 0.5x_{23} + 0.05x_{33} + 0.2x_{43} + 0.125x_{55} \leq x_5 \quad (9)$$

Now the objective of these banks is to minimize bad debt ratio and maximize the interest rate and revenue is accrued in good standing. For example, when bad debt ratio is 0.20, that is, 20% are lost due to bad debt, the bank, XYZ will receive interest on 80% of the allocation, that is, it will receive 14% interest on 0.75-(0.75×20%)x_1 = 0.6x_1 of the agricultural sector x_1. When bad debt ratio is 0.07, that is, 7% is lost to bad debt, the bank, ABC will receive interest on 93% of the allocation, that is, it will receive 13.5% interest on 2-(2×7%)x_2=1.86x_2 of the power plant sector x_2. When bad debt ratio is 0.03 that is 3% is lost to bad debt, NABARD will receive interest on 97% of the allocation, that is, it will receive 12% interest on 0.75-(0.75×3%)x_3 = 0.7275x_3 of the medical research sector x_3. When bad debt ratio is 0.06, that is, 6% is lost to bad debt, the bank, BNP will receive interest on 94% of the allocation, that is, it will receive 12.5% interest on 1-(1×6%)x_4= 0.94x_4 of the manufacturing industry sector x_4. When bad debt ratio is 0.03 that is 3% is lost to bad debt, the bank, IBS will receive interest on 97% of the allocation, that is, it will receive 11% interest on 0.5-(0.5×3%)x_5 = 0.485x_5 of the education sector x_5. Thus, Total interest =
0.140.75-(0.75×20%)x_1 + 0.1352-(2×7%)x_2 + 0.120.75-(0.75×3%)x_3 + 0.1251-(1×6%)x_4 + 0.1100.5-(0.5×3%)x_5
$= (0.14\times0.6)x_1 + (0.135\times1.86)x_2 + (0.12\times0.7275)x_3 + (0.125\times0.94)x_4 + (0.110\times0.485)x_5$

$$= 0.084x_1 + 0.2511x_2 + 0.0873x_3 + 0.1175x_4 + 0.05335x_5. \quad (10)$$

We also have, Bad debt =

$$.2x_1 + .7x_2 + .03x_3 + .06x_4 + 0.03x_5. \quad (11)$$

Here our objective is to minimize bad debt, so the total bad debt ratio is assumed to tend to 0. The objective function combines interest revenue and bad debt as follows:
Maximize z = Total interest - Bad debt
= (0.084x_1 + 0.2511x_2 +0.0873x_3 + 0.1175x_4 + 0.05335x_5)- 0

$$= 0.084x_1 + 0.2511x_2 + 0.0873x_3 + 0.1175x_4 + 0.05335x_5 \quad (12)$$

3.3 Linear programming model

The objective function becomes

$$Max z = 0.084x_1 + 0.2511x_2 + 0.0873x_3 + 0.1175x_4 + 0.05335x_5. \qquad (13)$$

The problem has eight constraints which are discussed as follows:
total allocation of XYZ should not exceed Rs.0.75 trillion:

$$0.05x_1 + 0.15x_2 + 0.20x_3 + 0.10x_4 + 0.25x_5 \leq 0.75 \qquad (14)$$

total allocation of ABC should not exceed Rs.2 trillion:

$$0.4x_1 + 0.35x_2 + 0.30x_3 + 0.45x_4 + 0.5x_5 \leq 2 \qquad (15)$$

total allocation of NABARD should not exceed Rs.0.75 trillion:

$$0.45x_1 + 0.099x_2 + 0.05x_3 + 0.075x_4 + 0.05x_5 \leq 0.75 \qquad (16)$$

total allocation of BNP should not exceed Rs.1 trillion:

$$0.25x_1 + 0.1x_2 + 0.175x_3 + 0.175x_4 + 0.2x_5 \leq 1 \qquad (17)$$

total allocation of IBS should not exceed Rs.0.5 trillion:

$$0.15x_1 + 0.05x_2 + 0.075x_3 + 0.075x_4 + 0.125x_5 \leq 0.5 \qquad (18)$$

total allocation should not exceed 5 trillion:
$0.75(x_1 + x_2 + x_3 + x_4 + x_5) + 2(x_1 + x_2 + x_3 + x_4 + x_5) + 0.75(x_1 + x_2 + x_3 + x_4 + x_5) + 1(x_1 + x_2 + x_3 + x_4 + x_5) + 0.5(x_1 + x_2 + x_3 + x_4 + x_5) \leq 5$
Or,

$$x_1 + x_2 + x_3 + x_4 + x_5 \leq 1 \qquad (19)$$

the bank also has a stated policy of not allowing the overall ratio of bad debts on all loans to exceed 3%:
$0.1x_1 + 0.07x_2 + 0.3x_3 + 0.05x_4 + 0.02x_5 \leq 0.03(x_1 + x_2 + x_3 + x_4 + x_5)$
Or,

$$0.1x_1 + 0.07x_2 + 0.3x_3 + 0.05x_4 + 0.02x_5 \leq 0.03 \qquad (20)$$

and
non-negativity conditions:

$$x_1 \geq 0,\ x_2 \geq 0,\ x_3 \geq 0,\ x_4 \geq 0,\ x_5 \geq 0. \qquad (21)$$

3.4 Solution of the LPP model

Following result is the solution obtained by solving the assumed linear programming mode,

Maximize	x_1	x_2	x_3	x_4	x_5
	0.08	0.25	0.09	0.12	0.05

Subject to:

(1)	0.20	0.15	0.20	0.10	0.25	$\leq$	0.75
(2)	0.40	0.45	0.10	0.45	0.50	$\leq$	2.00
(3)	0.45	0.10	0.05	0.08	0.05	$\leq$	0.70
(4)	0.25	0.20	0.18	0.18	0.20	$\leq$	1.00
(5)	0.15	0.08	0.08	0.08	0.13	$\leq$	0.50
(6)	0.10	0.07	0.30	0.05	0.02	$\leq$	0.30
(7)	1.00	1.00	1.00	1.00	1.00	$\leq$	1.00

Lower bound:

$$x_1, x_2, x_3, x_4, x_5 \geq 0$$

Upper bound:

infinity for all variables

Unrestricted (y/n)?:

$$n, n, n, n, n$$

Iteration 1

Basic	x_1	x_2	x_3	x_4	x_5	sx_6
z (max)	−0.08	−0.25	−0.09	−0.12	−0.05	0.00
sx_6	0.05	0.15	0.20	0.10	0.25	1.00
sx_7	0.40	0.35	0.30	0.45	0.50	0.00
sx_8	0.45	0.10	0.05	0.08	0.05	0.00
sx_9	0.25	0.10	0.18	0.18	0.20	0.00
sx_{10}	0.15	0.05	0.08	0.08	0.13	0.00
sx_{11}	0.10	0.07	0.30	0.05	0.02	0.00
sx_{12}	1.00	1.00	1.00	1.00	1.00	0.00

Lower bound:

0.00, 0.00, 0.00, 0.00, 0.00

Upper bound:

infinity, infinity, infinity, infinity, infinity

Unrestricted (y/n)?:

n, n, n, n, n

Next Table

Basic	sx_7	sx_8	sx_9	sx_{10}	sx_{11}	sx_{12}
z (max)	0.00	0.00	0.00	0.00	0.00	0.00
sx_6	0.00	0.00	0.00	0.00	0.00	0.00
sx_7	1.00	0.00	0.00	0.00	0.00	0.00
sx_8	0.00	1.00	0.00	0.00	0.00	0.00
sx_9	0.00	0.00	1.00	0.00	0.00	0.00
sx_{10}	0.00	0.00	0.00	1.00	0.00	0.00
sx_{11}	0.00	0.00	0.00	0.00	1.00	0.00
sx_{12}	0.00	0.00	0.00	0.00	0.00	1.00

Basic	Solution
z (max)	0.00
sx_6	0.75
sx_7	2.00
sx_8	0.70
sx_9	1.00
sx_{10}	0.50
sx_{11}	0.30
sx_{12}	1.00

Iteration 2

Basic	x_1	x_2	x_3	x_4	x_5	sx_6
z (max)	0.27	0.00	0.99	0.06	0.02	0.00
sx_6	−0.16	0.00	−0.44	−0.01	0.21	1.00
sx_7	−0.10	0.00	−1.20	0.20	0.40	0.00
sx_8	0.31	0.00	−0.37	0.00	0.02	0.00
sx_9	0.11	0.00	−0.25	0.10	0.17	0.00
sx_{10}	0.08	0.00	−0.14	0.04	0.11	0.00
x_2	1.43	1.00	4.29	0.71	0.29	0.00
sx_{12}	−0.43	0.00	−3.29	0.29	0.71	0.00

Lower bound:

$$0.00,\ 0.00,\ 0.00,\ 0.00,\ 0.00$$

Upper bound:

infinity, infinity, infinity, infinity, infinity

Unrestricted (y/n)?:

$$n, n, n, n, n$$

Basic	sx_7	sx_8	sx_9	sx_{10}	sx_{11}	sx_{12}
z (max)	0.00	0.00	0.00	0.00	3.59	0.00
sx_6	0.00	0.00	0.00	0.00	−2.14	0.00
sx_7	1.00	0.00	0.00	0.00	−5.00	0.00
sx_8	0.00	1.00	0.00	0.00	−1.41	0.00
sx_9	0.00	0.00	1.00	0.00	−1.43	0.00
sx_{10}	0.00	0.00	0.00	1.00	−0.71	0.00
x_2	0.00	0.00	0.00	0.00	14.29	0.00
sx_{12}	0.00	0.00	0.00	0.00	−14.29	1.00

Final Solution

Basic	Solution
z (max)	0.11
sx_6	0.69
sx_7	1.85
sx_8	0.66
sx_9	0.96
sx_{10}	0.48
x_2	0.43
sx_{12}	0.57

CHAPTER 4

4 Results and Discussion

This chapter discusses the results obtained from the solution of the Linear Programming Problem (LPP) formulated in the previous chapter. The model aimed to determine the optimal allocation of a central bank's investment assets across five different sectors of economy: agriculture (x_1), power plant (x_2), health (x_3), industry (x_4) and education (x_5). The objective was to maximize interest revenue while minimizing exposure to default risk and adhering to regulatory constraints.

After solving the LP model using the simplex method, the optimal solution yielded the following values for the decision variables: $x_1 = 0$, $x_2 = 0.43$, $x_3 = 0$, $x_4 = 0$ and $x_5 = 0$. This chapter delves into the interpretation of this outcome, evaluates its alignment with the central bank's investment objectives, compares it with findings from similar studies, and outlines the broader implications for monetary policy and financial risk management.

4.1 Presentation of the Optimal Solution

After applying the simplex method to solve the model, the following optimal values were obtained for the decision variables x_1 to x_5, representing investments in agriculture, power, health, industry and education respectively:

Table 4: Optimal Investment Allocation Across Sectors

Sector	**Variable**	**Investment (trillion)**
Agriculture	x_1	0
Power Plant	x_2	0.43
Health	x_3	0
Industry	x_4	0
Education	x_5	0

From this result, it is clear that all the investment has been channeled exclusively into the Power sector. No funds have been allocated to agriculture, health, industry and education.

4.2 Interpretation of Results

The optimal solution obtained is straightforward yet deeply revealing. The entire allocation is shaped primarily by risk aversion and the strict nature of the constraints applied.

- Constraint Dominance: The fact that all other variables are zero strongly implies that the risk and constraints in the model played a decisive role in shaping the solution.
- Absence of Diversification: Another noteworthy observation is the absence of any diversification in the optimal portfolio. Typically, financial portfolios spread investments across multiple assets to balance risk and return. The absence of such diversification here suggests that the central bank's operational constraints (as modeled) discourage even minimal risk in favor of capital preservation.

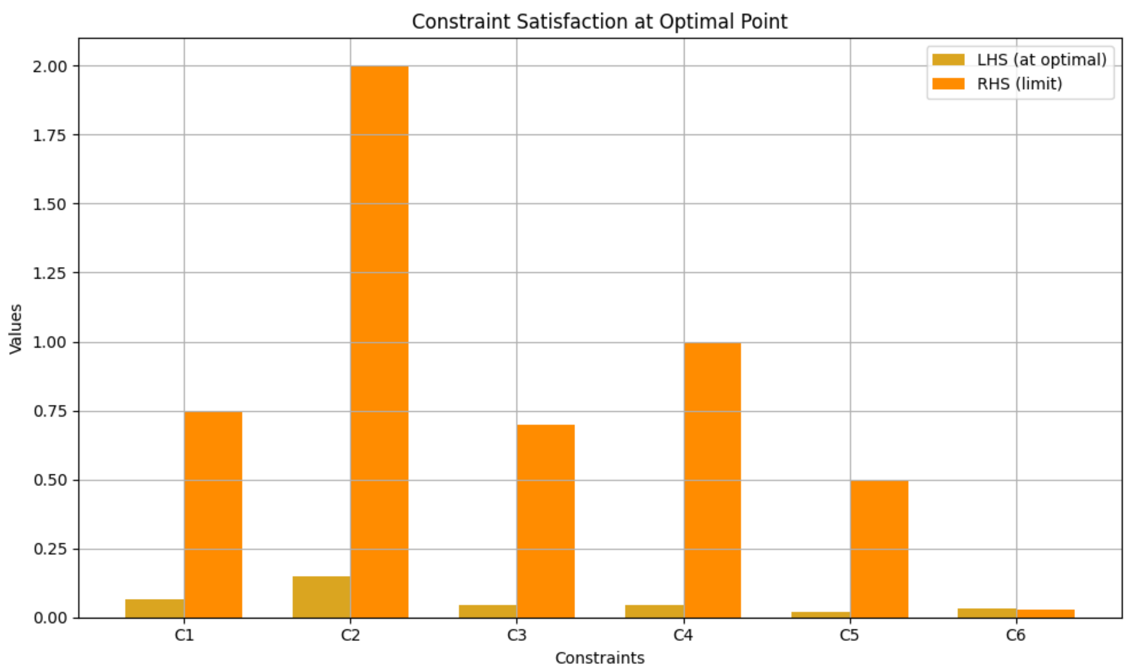

Figure 1: Constraint satisfaction plot

Here's the constraint satisfaction plot at the optimal point $x_1 = 0$, $x_2 = 0.43$, $x_3 = 0$, $x_4 = 0$ and $x_5 = 0$.

Interpretation:

- Yellow bars show how much of each constraint's limit (RHS) is used.
- Orange bars are the total allowable limits.
- The gap between the yellow and orange bars indicates how slack (unused capacity) each constraint has.
- Constraint C6 is nearly tight (used almost all of its capacity), which suggests it could be binding or nearly so.

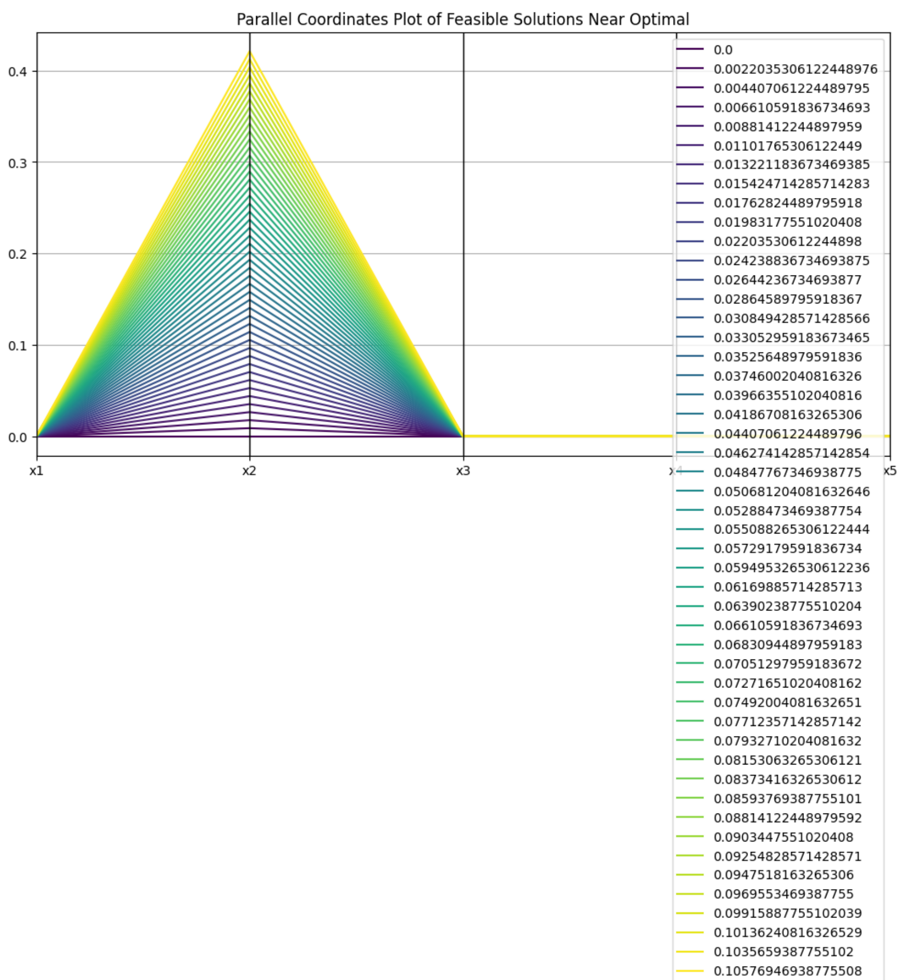

Figure 2: Parallel coordinates plot of feasible solutions

Here is the parallel coordinates plot of feasible solutions near the optimal point.

What This Shows:

- Each line represents one feasible solution.
- Only x_2 varies, since it's the only variable contributing to the optimal solution.
- The color gradient represents the objective value (Z) — it increases as x_2 increases.
- Other variables (x_1, x_3, x_4, x_5) remain at 0, confirming the optimal solution structure.

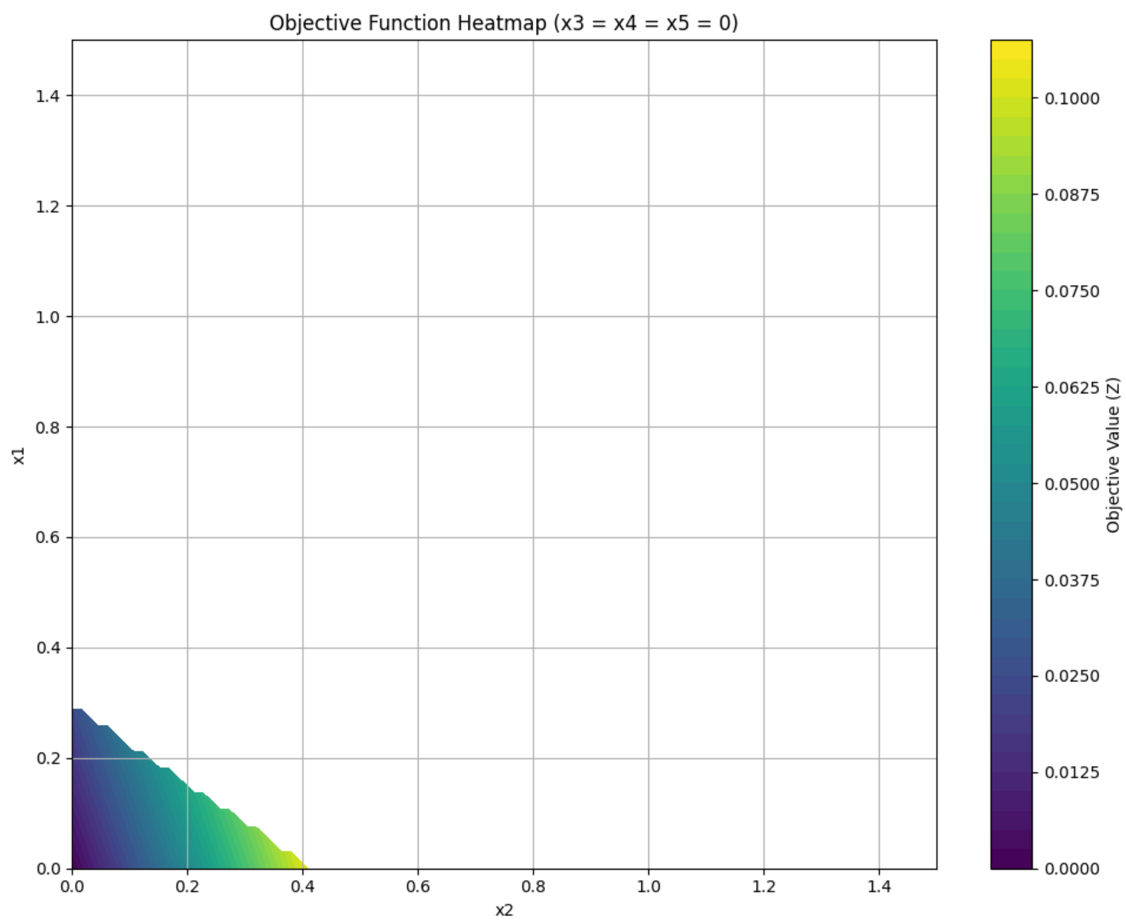

Figure 3: 2D heatmap

Here is the 2D heatmap showing how the objective function Z changes with respect to x_1 & x_2 while fixing $x_3 = x_4 = x_5 = 0$.

Interpretation:

- The colored region shows feasible combinations of x_1 and x_2 where all constraints are satisfied.
- The darker areas represent lower values of Z, while the brighter (yellow-green) areas represent higher Z.
- The maximum value occurs at approximately $x_2 = 0.43$, which matches your provided optimal solution.
- This confirms that x_2 is the dominant decision variable.

4.3 Sensitivity Analysis

Sensitivity Analysis in Linear Programming is the process of studying how changes in input parameters (objective coefficients or constraint values) affect the optimal solution. It is especially useful for decision-makers to understand the robustness of their solution under changing conditions.

4.3.1 Objective Coefficient Sensitivity

Evaluates how changes in the coefficients of the objective function affect the optimal solution.
Insights:

- If the optimal solution remains the same, the current basis is stable.
- If the solution changes, it may trigger a basis change — indicating a shift in which variables are optimal.

We vary one coefficient at a time (e.g., c_2) and check how the optimal value (Z) responds.

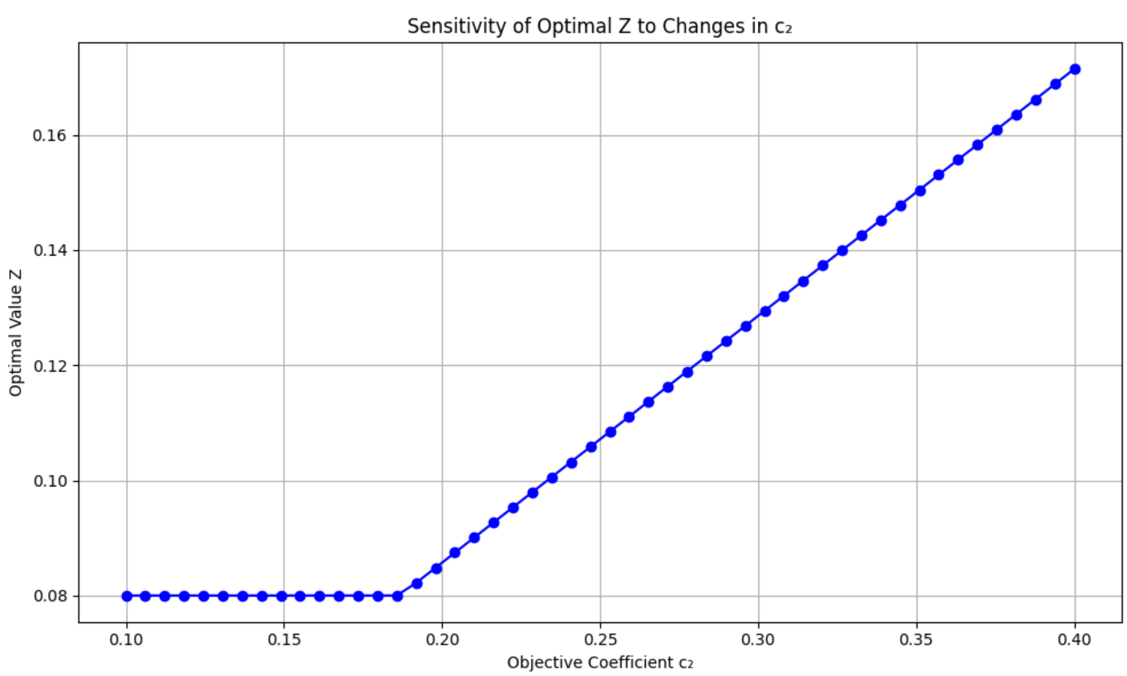

Figure 4: Changes in the coefficients of the objective function

4.3.2 Right-Hand Side (RHS) Sensitivity

Analyzes how changes in the RHS of constraints (available resources, capacities, etc.) impact the solution and the objective value.

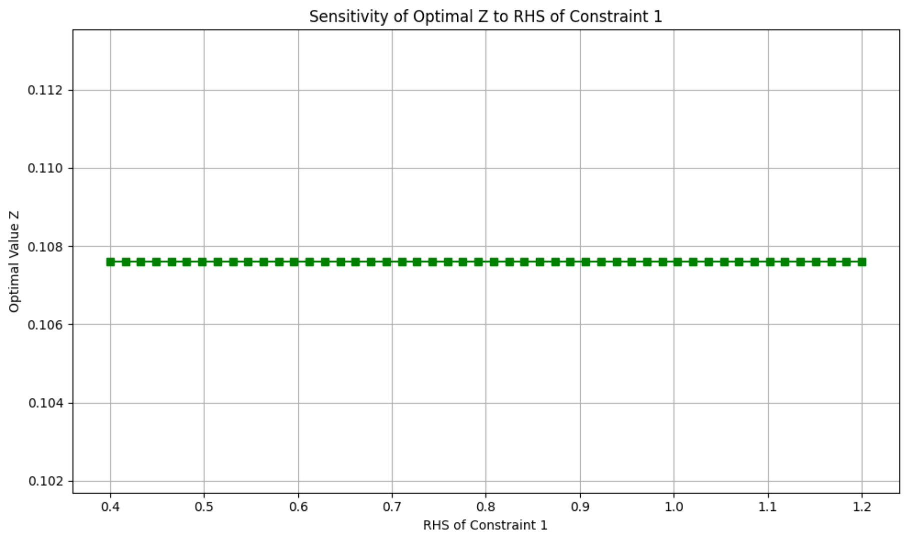

Figure 5: Changes in the RHS of constraints impact the solution

Sensitivity analysis tells us:

- How much the profit per unit of x_2 can change before the optimizer stops choosing x_2.
- Which constraints are limiting, and how easing them would affect profit.
- Whether x_2 remains the only variable in the solution under small data changes.

4.4 Suggestions for Future Research

To enhance the scope and applicability of this research, future studies could explore:

- Multi-Period Investment Models: Modeling investment across a timeline to better capture sectoral dynamics and phased infrastructure development.
- Stochastic Programming: Introducing uncertainty in sectoral returns, political changes, or economic shocks.
- Multi-Objective Optimization: Balancing economic returns with social welfare metrics to ensure holistic development.

CHAPTER 5

5 CONCLUSION

In the above instance, we have formulated a linear programming problem and tried to solve the problem by using TORA Optimization System, Windows version 1.00. From the result obtained, it can be suggested that in the agriculture sector the investment should contain less than Rs. 0.5 trillion. Moreover, the bank should invest in the other sectors such as health care, energy, industrial product, education with considerable quantity of funds.

These values represent the amounts to invest in each sector or the levels to set for other controllable factors. The solution provides optimal values for the decision variables in the sense that it maximizes the objective function while satisfying all the constraints. Optimal solutions indicate the best allocation of resources to achieve the desired objective. However, it is important to recognize that the solution is optimal only in the context of the model and the assumptions that were made. It indicates the optimal allocation of funds across different sectors, specifying the amounts to be invested in each asset class to maximize returns or minimize risk. This allocation takes into account the expected returns, risks, and correlations of the different sectors, as well as the central bank's objectives and constraints. The optimal allocation may vary depending on economic conditions, market conditions, and the central bank's risk tolerance.

Although the model is hypothetical, this article focuses on the broader lessons from mission-oriented programs for innovation policy and referential policies aimed at investment-led growth [12]. The future outlook for central bank investment strategies is likely to involve a greater use of optimization techniques to manage complex portfolios and navigate volatile markets.

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Publications

The following publications submitted during the course of this research work:

1. Anamitra Deb, Shiksha Devi, and Laxmi Narayan Das, *Optimal Allocation of Central Bank Assets: A Linear Programming Model*, Proceedings of the 3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS- 2025), Himachal Pradesh University, Shimla, H. P., India

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

PLAGIARISM VERIFICATION

Title of the Thesis ***"Optimal Allocation of Central Bank Assets: A Linear Programming Model".*** Total Pages 50. Name of the Studesnts **Anamitra Deb (23/MSCMAT/68)** and **Shiksha Devi (23/MSCMAT/66)**.

Supervisor:

1. **Prof. Laxmi Narayan Das**
   Department of applied mathematics

This is to report that the above thesis was scanned for similarity detection. The process and result are given below:

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Candidates' Signature   Signature of Supervisor(s)

Acceptance of Abstract for 3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS-2025)

1 message

ICRTMS2025 <icrtms25hgp@gmail.com> Tue, 29 Apr, 2025 at 1:13 pm
To: Anamitra Deb <anamitradeb23@gmail.com>, shiksha.1809@gmail.com, lndas@dce.ac.in

Dear Sir
I hope you are doing well.

We are pleased to inform you that the Conference Committee reviewed your abstract titled **"Optimal Allocation of Central Bank Assets: A Linear Programming Model"** and has approved for presentation at "**3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS- 2025)"** scheduled to be held on **10th – 11th May, 2025** at **Himachal Pradesh University, Shimla**, H. P., India in Hybrid mode.

We believe that your presentation will make a valuable contribution to the conference. Your Paper ID is **ICRTMS_216**

We request you to **fill the registration form,** if not done already, and mail your f**ull length paper in PDF format** latest by **25th April, 2025.**
Please feel free to contact us for any queries.
To register, please fill out the Google Form available at the link:
https://forms.gle/X1qh8EtQetFBoXLe9

The participants who will not register, will not be allowed to present their paper in the conference.

Lodging Arrangement
The organizing committee of ICRTMS-2025 makes arrangements for the stay of participants in nearby guest houses and hotels. The participants are free to exercise their choice about their stay for which they have to immediately contact the concerned guest house or hotel. **The participants are requested to book their accommodation by the end of March, 2025 as in the months of May and June there is tourist season in Shimla.**

Hotel Green View: Situated at Sangti and is about 1 km from the venue.
Tariff: Rs. 1000/- per person in double or triple sharing room with Balcony and Rs. 750/- per person in double or triple sharing room without Balcony.
Contact Details: **+91-98166-87459, +91-70186-26662, +91-78071-86043**
Hotel Ganga Palace: Situated at Summer Hill, Shimla and is about 100 meters from the venue.
Tariff: Rs. 3200/- per room (2 persons allowed), extra bed available (total 3 persons).
Group booking: Rs 900/- per person (4 persons per room)
Manager: Divesh Rathore
Contact Details: **+91-8262858998**

Thank you for your contribution to the conference.

On behalf of organizing committee

Dr. Neetu Dhiman
Convener
ICRTMS- 2025
Contact-+91-7018451738
Conference Website: https://icrtms25.hgp.org.in

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HIMACHAL GANITA PARISHAD

(REGISTERED UNDER H.P. SOCIETIES REGISTRATION ACT 2006)

3rd INTERNATIONAL CONFERENCE ON RECENT TRENDS IN MATHEMATICAL SCIENCES (ICRTMS-2025)

10th-11th May, 2025

CERTIFICATE OF APPRECIATION

This is to certify that **Mr. Anamitra Deb, UG/PG Student, Department of Applied mathematics, Delhi Technology University** has presented a research paper entitled **Optimal Allocation of Central Bank Assets: A Linear Programming Model** in **3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS-2025)** organized by the **Himachal Ganita Parishad (HGP) at Himachal Pradesh University, Shimla** on **10th-11th May, 2025.**

Dr. Kamalendra Kumar	**Dr. Neetu Dhiman**	**Dr. Shalini Gupta**
Co-Convener	Convener	President (HGP)

HIMACHAL GANITA PARISHAD

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3rd INTERNATIONAL CONFERENCE ON RECENT TRENDS IN MATHEMATICAL SCIENCES (ICRTMS-2025)

10th-11th May, 2025

CERTIFICATE OF APPRECIATION

This is to certify that **Ms. Shiksha devi, UG/PG Student, Dept. Of applied mathematics, Delhi technological university.** has presented a research paper entitled **Optimal Allocation of Central Bank Assets: A Linear Programming Model** in **3rd International Conference on Recent Trends in Mathematical Sciences (ICRTMS-2025)** organized by the **Himachal Ganita Parishad (HGP) at Himachal Pradesh University, Shimla** on **10th-11th May, 2025.**

Dr. Kamalendra Kumar	Dr. Neetu Dhiman	Dr. Shalini Gupta
Co-Convener	Convener	President (HGP)

International Conference on Applied Mathematics and Science (ICAMS-25)

17th May 2025
Chandigarh - India

Acceptance Letter

Date of Issue: 26-04-2025

Paper ID: NIER_87136

Article Title: Optimal Allocation of Central Bank Assets: A Linear Programming Model

Authors: Anamitra Deb, Shiksha Devi, Prof. Laxminarayan Das

We are pleased to inform you that your paper has been accepted by the review committee for Oral Presentation at the **International Conference on Applied Mathematics and Science (ICAMS-25)**

This conference will be held in **Chandigarh - India on 17th May 2025**

Please register as soon as possible in order to secure your participation:

https://nier.in/conf/registration.php?id=3329315

You are requested to release the payment and mail us the screen of successful payment release with your name and title of paper to confirm your registration.

Sincerely,

Dr. Tara Srivastava
Director
National Institute For Engineering And Research (NIER)