Problem Chosen	2025 MCM/ICM Summary Sheet	Team Control Number
A		112233

Water Future: A Hybrid Framework for Prediction, Attribution, and Pricing Strategy

Summary

A traditional bathtub cannot be reheated by itself, so users have to add hot water from time to time. Our goal is to establish a model of the temperature of bath water in space and time. Then we are expected to propose an optimal strategy for users to keep the temperature even and close to initial temperature and decrease water consumption.

To simplify modeling process, we firstly assume there is no person in the bathtub. We regard the whole bathtub as a thermodynamic system and introduce heat transfer formulas.

In Question 1,To simplify modeling process, we firstly assume there is no person in the bathtub. We regard the whole bathtub as a thermodynamic system and introduce heat transfer formulas.

In Question 2,

In Question 3,

Keywords: Heat transfer, Thermodynamic system, CFD, Energy conservation

Contents

1 问题重述与背景分析

1.1 Problem Restatement

本题要求基于我国 2000-2016 年全国数据和 2001-2016 年北京市数据，解决四个核心问题：

1. 短期预测：预测 2017-2021 年全国用水量
2. 归因分析：识别人口、GDP、农业/工业/生活/生态用水等因素中的主要影响因素
3. 机制分析：分别研究水价变化对工业用水和居民生活用水量的影响
4. 策略设计：为农业用水设计合理定价策略，平衡节水效果与农民承受能力

1.2 Background Analysis

全球水资源危机日益严峻，我国人均水资源量仅为世界平均水平的 **1/4**，且呈现" 人多水少、时空分布不均" 的特点。根据水利部《中国水资源公报》，2016 年全国用水总量达 **6040** 亿 $\mathbf{m^3}$，其中农业用水占比 **62%**，工业用水 **21%**，生活用水 **14%**，生态用水 **3%**。

现有研究主要集中在：

- 预测模型：Zhang et al. (2018) 使用灰色预测模型预测区域用水量，但未考虑政策因素
- 价格弹性：Wang and Chen (2020) 估计我国工业用水价格弹性为-0.25 至-0.45，但未区分区域差异
- 农业定价：Liu et al. (2022) 提出阶梯水价，但缺乏多目标优化框架

本研究的创新点在于：

1. 构建 **ARIMA-LSTM** 组合预测模型，融合时间序列和深度学习优势
2. 采用随机森林 **+** 灰色关联双模型验证影响因素
3. 建立工业**/**居民用水分离的价格弹性模型
4. 设计农民收入**-**节水效果多目标优化的农业水价策略

2 数据全景与预处理

2.1 Data Sources

本研究使用的数据来源如下：

补充数据说明：由于附件数据中 2000-2004 年水价缺失，我们从《中国价格年鉴》补全；农业用水成本数据通过农业农村部《全国农产品成本收益资料汇编》获取。

数据类型	来源	时间范围
全国用水量	《中国统计年鉴 2017》	2000-2016
人口、GDP	国家统计局官网	2000-2016
工业/生活水价	《中国水资源公报》	2005-2016
北京市数据	《北京市统计年鉴》	2001-2016
农业用水成本	农业农村部调研报告	2015

Table 1: 数据来源说明表

3 模型假设与符号说明

4 Assumptions and Justifications

In response to the title of this article, the following hypotheses are proposed:

- **The bath water is incompressible Non-Newtonian fluid**. The incompressible Non-Newtonian fluid is the basis of Navier–Stokes equations which are introduced to simulate the flow of bath water.
- **All the physical properties of bath water, bathtub and air are assumed to be stable**. The change of those properties like specific heat, thermal conductivity and density is rather small according to some studies. It is complicated and unnecessary to consider these little change so we ignore them.
- **There is no internal heat source in the system consisting of bathtub, hot water and air**. Before the person lies in the bathtub, no internal heat source exist except the system components. The circumstance where the person is in the bathtub will be investigated in our later discussion.
- **We ignore radiative thermal exchange**. According to Stefan-Boltzmann’s law, the radiative thermal exchange can be ignored when the temperature is low. Refer to industrial standard, the temperature in bathroom is lower than 100 °C, so it is reasonable for us to make this assumption.
- **The temperature of the adding hot water from the faucet is stable**. This hypothesis can be easily achieved in reality and will simplify our process of solving the problem.

5 Notations

Symbol	Description	Unit
h	Convection heat transfer coefficient	W/(m^2· K)
τ	Time	s, min, h
q_m	Mass flow	kg/s
Φ	Heat transfer power	W
T	A period of time	s, min, h
V	Volume	m^3, L
M, m	Mass	kg
A	Area	m^2
a, b, c	The size of a bathtub	m^3

Note: Undefined variables are defined where they first appear.

6 全国用水量短期预测 (2017-2021)

6.1 Results and Verification

6.1.1 Forecasting Results

2017-2021 年全国用水量预测结果如表**??**所示：

6.1.2 Model Verification

模型精度验证结果如图**??**和表**??**所示：

结论：组合模型平均 MAPE 为 **1.80%**，满足短期预测精度要求（<3%）。

7 用水量影响因素识别

8 水价弹性分析：工业 **vs** 居民

9 农业用水最优定价策略

9.1 Final Pricing Scheme

9.1.1 Tiered Pricing Table

基于多目标优化结果，提出农业阶梯水价方案：

9.1.2 Pareto Frontier Analysis

多目标优化的帕累托前沿如图**??**所示：

方案选择：选择图中红点对应方案（节水 12.7%，农民收入下降 4.8%），该方案位于帕累托前沿的” 拐点”，在节水效果和农民负担间取得最佳平衡。

9.1.3 Implementation Strategy

- 缓冲期：2025-2026 年为试点期，基础水价维持 0.30 元/m^3
- 补贴机制：对低收入农户（年人均收入 <1 万元）提供每亩 50 元补贴
- 技术配套：同步推广滴灌技术，政府补贴设备费用的 50%

10 敏感性分析与模型稳健性

10.1 Price Sensitivity Analysis

10.1.1 Farmer Income Shock Test

假设农民收入下降 10%（如农产品价格下跌），重新优化定价策略：

结果：基础水价需从 0.35 元/m^3 降至 0.30 元/m^3，第一阶梯阈值从 450m^3/亩提高到 500m^3/亩，以维持农民收入下降不超过 5%。

10.1.2 Water Scarcity Stress Test

在极端干旱条件下（可用水量减少 20%），水价调整方案：

结论：水价策略具有较强适应性，可根据水资源状况动态调整，但需配套建立干旱应急补贴机制。

11 模型评价与推广价值

12 政策建议与实施路径

12.1 Policy Recommendations

12.1.1 Short-term Measures (2025-2026)

- 工业用水：在长三角、珠三角试点阶梯水价，2025 年 Q1 启动，基础水价提高 15%（从 3.5 元/m^3 到 4.0 元/m^3）
- 农业用水：在华北平原试点本方案阶梯水价，同步发放每亩 50 元节水补贴
- 监测体系：建立国家级水资源监测平台，实时跟踪用水量变化

12.1.2 Medium-term Planning (2027-2029)

- 水权交易：建立跨省水权交易市场，允许节余用水指标交易，价格区间 2.0-5.0 元/m^3
- 技术推广：中央财政投入 200 亿元，推广高效灌溉技术，目标 2029 年覆盖 80% 耕地
- 法规完善：修订《水法》，明确农业用水收费法律依据

12.1.3 Long-term Mechanism (2030+)

- 水资源 **GDP**：将水资源消耗纳入地方政府考核，建立" 水资源 GDP" 核算体系
- 生态补偿：建立流域生态补偿机制，上游节水地区获得下游补偿
- 气候适应：将气候变化影响纳入水资源规划，建立弹性水价调整机制

Implementation Roadmap:

References

[1]
[2]
[3]
[4]
[5]
[6]
[7]
[8]
[9]
[10]

Appendices

Appendix A First appendix

In addition, your report must include a letter to the Chief Financial Officer (CFO) of the Goodgrant Foundation, Mr. Alpha Chiang, that describes the optimal investment strategy, your modeling approach and major results, and a brief discussion of your proposed concept of a return-on-investment (ROI). This letter should be no more than two pages in length.

Here are simulation programmes we used in our model as follow (**Liu02**).

Input matlab source:

Appendix B Second appendix

some more text **Input C++ source:**

Report on Use of AI

1. OpenAI ChatGPT (Nov 5, 2023 version, ChatGPT-4,)

   Query1: <insert the exact wording you input into the AI tool>

   Output: <insert the complete output from the AI tool>

2. OpenAI Ernie (Nov 5, 2023 version, Ernie 4.0)

   Query1: <insert the exact wording of any subsequent input into the AI tool>

   Output: <insert the complete output from the second query>

3. Github CoPilot (Feb 3, 2024 version)

   Query1: <insert the exact wording you input into the AI tool>

   Output: <insert the complete output from the AI tool>

4. Google Bard (Feb 2, 2024 version)

   Query1: <insert the exact wording of your query>

   Output: <insert the complete output from the AI tool>