Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Machine Learning Prediction of Household Out-of-Pocket Health Expenditure in Ghana: A Comparative Model Analysis

Spencer Dawson-Amoah
sdamoah@stu.ucc.edu.gh
University of Cape Coast
Orleans Ekow de-Graft
University of Cape Coast
Grace Agyekum
Yanshan University
Solomon Matey Kpabitey
University of Cape Coast
Joshua Nyatuame
University of Cape Coast

Article

Keywords: Universal Health Coverage, Financial protection, Predictive analytics, Health system equity

Posted Date: April 29th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9509724/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Financial protection is a central goal of universal health coverage, yet many households in Ghana continue to face high out-of-pocket (OOP) health expenditures despite government and donor financing. Understanding how these financing sources influence household financial risk is important for strengthening health system sustainability and equity.

Methods

This study used a longitudinal ecological design with secondary data from the World Health Organization Global Health Expenditure Database for Ghana from 2000 to 2023. Descriptive statistics was conducted to examine trends. Multivariate time-series regression was applied to estimate the linear effects of government health expenditure and external donor financing on household OOP expenditure. A comparative model analysis was conducted to evaluate the predictive performance of multiple machine learning algorithms in estimating household out-of-pocket health expenditure.

Results

Household OOP expenditure averaged 33.1% of total health spending. Both government and external financing significantly reduced OOP expenditure, with government spending showing the strongest effect. The Decision Tree model explained 87.8% of the variation in household OOP expenditure.

Conclusion

Strengthening domestic public health investment, alongside strategic donor support, is essential for reducing household financial burden and advancing universal health coverage in Ghana.

Background

Universal health coverage has become a central goal for countries around the world because it ensures that everyone can access essential health services without facing financial hardship (17, 31). Financial protection is at the heart of this goal because when people have to pay for care out of pocket, it can push families into poverty, limit access to necessary treatment, and worsen social inequalities (16). This challenge is particularly pressing in many low and middle-income countries, including Ghana, where households often face high out-of-pocket health expenditures. These costs can force families to delay care, borrow money, or reduce spending on essentials such as food and education, creating cycles of poverty and poor health outcomes (21, 15). Reducing these financial risks is therefore a key policy priority, as equitable access to health services is critical for both population health and social development (25).

One approach widely used to protect households from financial hardship is the expansion of pooled and prepaid health financing mechanisms (7). By spreading the costs of illness across the population, these mechanisms

reduce the reliance on direct payments and protect individuals from catastrophic expenses (29). Government health expenditure, funded through taxes or social health insurance, is central to this system. External donor financing can complement government spending by supporting targeted health programs such as maternal and child health, immunization, and infectious disease control, which indirectly reduce the financial burden on households (22). Research has shown that higher public spending on health is generally associated with lower out-of-pocket payments and better financial protection for households (23). These findings highlight the importance of health financing policies that prioritize fairness and equity in distributing both contributions and benefits.

Ghana provides an important example of how health financing influences household financial risk. In 2004, the country introduced the National Health Insurance Scheme to reduce reliance on direct payments and improve access to essential health services (1). Since then, insurance coverage has expanded, and more people are accessing both outpatient and inpatient care (7). Despite these improvements, many households still face substantial out-of-pocket expenses, especially for medicines, diagnostic tests, and inpatient services (19). These costs are often heavier for poorer and rural households, highlighting ongoing inequalities in financial protection.

While previous studies have examined how health financing affects household spending, several important questions remain. Many analyses consider government and donor funding separately, without exploring how these sources might interact over time to influence household financial risk (14, 32). Nonlinear effects are also underexplored, such as the possibility that government spending only significantly reduces out-of-pocket costs once it reaches a certain level (12). Understanding these complex dynamics is critical for designing policies that truly protect households from financial hardship (3). Without this understanding, reforms may fail to meaningfully reduce household spending or improve equity across different population groups. Unlike previous studies that rely primarily on econometric models, this research integrates traditional time-series regression with machine learning techniques to capture both linear and nonlinear relationships between health financing and household financial risk. This combined approach provides deeper insights into threshold effects in public health financing.

This study aims to address these gaps by examining the roles of government health expenditure and external donor financing in shaping household out-of-pocket spending in Ghana from 2000 to 2023. The research investigates whether increases in these funding sources are associated with reduced financial burden for households. To achieve this, the study combines traditional time-series regression with a Decision Tree data mining approach, allowing for the identification of both linear and nonlinear patterns in the data, as well as thresholds where changes in financing have the greatest effect (30, 18). This integrated approach provides a more comprehensive understanding of how different financing mechanisms influence household financial risk and helps identify which interventions may be most effective in reducing out-of-pocket costs.

This study addresses a critical public health and policy question: how to reduce the financial burden of illness on households while improving equitable access to essential health services. By examining both government and donor contributions, identifying nonlinear effects, and highlighting the key drivers of out-of-pocket spending, the research offers insights that can inform policy decisions, strengthen financial protection, and support Ghana’s progress toward universal health coverage.

Literature Review

This study is guided by two key theoretical perspectives that explain how health financing systems influence household out of pocket health expenditure. These are the theory of risk pooling and prepayment and the public health financing theory. The theory of risk pooling and prepayment explains that health care costs should be shared across a population rather than paid directly by individuals at the time they need care. When health systems rely heavily on out of pocket payments, households bear the full financial risk of illness, which can lead to financial hardship, delayed treatment, and reduced access to necessary health services. Risk pooling mechanisms such as taxation and social health insurance collect funds in advance and distribute the costs of care across the population, thereby protecting households from catastrophic health spending (23, 29). In this system, healthy individuals contribute to a common pool that supports those who require care, creating a more balanced and equitable approach to financing health services. Research shows that countries with stronger pooled financing systems tend to experience lower levels of household out of pocket expenditure and improved financial protection (2, 27). For countries pursuing universal health coverage, strengthening risk pooling mechanisms is therefore essential for ensuring that individuals can seek care without fear of financial hardship (15).

Public health financing theory complements this perspective by emphasizing the role of government in ensuring equitable access to health services. Because health care is widely regarded as a social good, governments are expected to invest public resources in the health sector to reduce inequalities and protect vulnerable populations from financial hardship. Public financing allows governments to redistribute resources across different income groups and regions, ensuring that essential services remain accessible to the entire population (25). Increased government health expenditure can expand service coverage, improve health infrastructure, and subsidize essential treatments that might otherwise require direct payments by households. Evidence from many countries suggests that stronger public investment in health is associated with better financial protection and lower rates of catastrophic health expenditure (23, 27). External health financing can further support these efforts by funding specific programs such as immunization, maternal and child health services, and infectious disease control initiatives (22). However, donor funding often focuses on targeted interventions and may not provide the same system wide financial protection that sustained domestic public investment can achieve (4). Together, these theories provide a strong conceptual foundation for examining how government and external health financing influence household out of pocket expenditure in Ghana.

Methodology

Methodology

This study used a longitudinal ecological design to examine how health financing influences household financial risk. By combining national-level data over a 24-year period with both traditional statistical and machine learning approaches, the methodology provides a comprehensive framework to capture linear trends, nonlinear patterns, and key thresholds in health financing. This approach is consistent with prior studies that integrate econometric and data-driven techniques to better understand complex financial and health system dynamics (30, 18). The approach allows for a clear assessment of how changes in government and donor contributions affect household financial risk, while maintaining transparency, reproducibility, and methodological rigor.

Data Source

Data was obtained from the World Health Organization Global Health Expenditure Database, covering the years 2000 to 2023. This source provides nationally aggregated and standardized health expenditure data, allowing for consistent comparisons over time and across financing categories (31). The dataset includes government health expenditure, external donor financing, and household out-of-pocket (OOP) health spending, all expressed as percentages of total current health expenditure. The longitudinal design was particularly suitable for capturing long-term trends and gradual changes in financial protection, which cannot be effectively observed in cross-sectional studies (23). Ethical considerations were addressed by using publicly available aggregate data, ensuring no individual-level or identifiable information was involved and maintaining transparency and responsible research practices.

Variables and Measurements

The primary outcome of interest was household out-of-pocket health expenditure, measured as the share of total health spending paid directly by households. This variable reflects the level of financial risk that households face, with higher values indicating weaker financial protection and greater vulnerability to catastrophic health expenditures (23, 27). The key explanatory variables were government health expenditure and external donor financing. Government health expenditure was measured as the proportion of pooled and prepaid domestic resources allocated to health, representing the capacity of public financing mechanisms to reduce reliance on direct household payments (7, 29). External donor financing represented international contributions directed toward health, typically supporting targeted programs such as maternal and child health, immunization, and infectious disease control (22). The year of observation was included to account for temporal trends. Together, these variables capture both domestic and external health financing efforts that may influence household financial protection, consistent with existing empirical and policy-oriented literature on health financing systems (23, 29).

Research Design and Analytical Approach

All statistical and machine learning analyses were conducted using R statistical software (version 4.5.2). Descriptive analysis was performed using the dplyr and tidyr packages, while ggplot2 was used for visualization. Time-series regression was implemented using stats and lmtest. Machine learning models were developed using rpart (Decision Tree), randomForest (Random Forest), and e1071 (Support Vector Regression). Model performance was evaluated using RMSE and R^2 with functions from the Metrics and caret packages, while pdp and vip were used to generate partial dependence plots and feature importance measures.

A longitudinal ecological design was selected to analyze trends and systemic relationships over time, providing insights into the impact of health financing policies on household financial risk (28). The study combined traditional statistical regression with machine learning techniques to assess both linear and nonlinear patterns, consistent with emerging approaches in health and financial data analytics (30, 18). Descriptive statistics was first conducted to summarize trends in government and donor financing and household OOP expenditures. Next, multivariate time-series regression was applied to estimate the linear association between health financing and household OOP expenditure.

The dataset was divided into training and testing sets to evaluate model performance. Approximately 80 percent of the observations were used to train the models, while the remaining observations were used for validation. The training dataset contained 20 observations, while the testing dataset contained 4 observations. Given the relatively small sample size, model complexity was controlled to avoid overfitting and maintain interpretability, in line with standard practices in predictive modeling (33). Model accuracy was assessed using root mean squared error (RMSE) and the coefficient of determination (R^2). This approach helps ensure that the predictive performance of the models generalizes beyond the observed data.

To capture potential nonlinear relationships and identify key thresholds where financing significantly influences household OOP expenditure, a Decision Tree data mining model was implemented. The model included government health expenditure, external donor financing, and year as input variables, with household OOP expenditure as the outcome. Feature importance scores were calculated to determine which predictors had the greatest influence, while the tree structure revealed critical splits and thresholds (20). To enhance robustness, Random Forest and Support Vector Regression models were also evaluated, as these techniques are widely used for improving predictive accuracy and capturing complex patterns in data (33, 18). Predictive performance for all models was assessed using the coefficient of determination and root mean squared error. This multi-method approach allowed for both precise estimation of linear effects and detection of complex nonlinear dynamics.

Validity, Reliability, and Ethical Considerations

Several steps were taken to ensure validity and reliability. Using standardized, nationally aggregated data minimized measurement error, while combining regression with data mining techniques provided cross-validation and enhanced interpretability. Inclusion of both linear and nonlinear models ensured that complex patterns in the relationships between health financing and household OOP expenditure were captured. Because the study relied exclusively on publicly available aggregate data, formal ethical approval was not required. Nevertheless, all analyses adhered to research ethics and data handling best practices to ensure transparency, accuracy, and responsible use of data.

Results

This section presents the findings on the relationship between health financing sources and household financial risk in Ghana. The results are organized into descriptive statistics, analysis, time-series regression, and machine learning technique. Together, these analyses provide an overview of trends in government and external health financing and examine how changes in these sources are associated with household out-of-pocket (OOP) health expenditure over the study period. Table 1 shows the descriptive statistics for government health expenditure and household out-of- pocket payments in Ghana.

Table 1 Descriptive statistics of health expenditure in Ghana from 2000 to 2023

Variables	Mean	Standard deviation	Minimum	Maximum
Household Out-of-Pocket Expenditure	33.13	5.99	22.65	45.05
Government Health	48.00	8.61	33.40	63.23
Expenditure				
External Health	14.12	5.27	2.54	24.93
Expenditure				

Source: *Author's computation based on data from the World Health Organization Global Health Expenditure Database (2000–2023).*

Table 1 summarized descriptive statistics for key health expenditure variables in Ghana over the study period. Household out-of-pocket (OOP) expenditure averaged 33.13% of current health spending, indicating substantial and persistent financial risk, with values ranging from 22.65% to 45.05%. Government health expenditure averaged 48.00% (range: 33.40%–63.23%), reflecting its
central role in public financing and potential for enhancing financial protection. External health expenditure averaged 14.12% (range: 2.54%–24.93%), showing notable variability due to the program-specific and volatile nature of donor funding. Overall, these results highlighted sustained household financial exposure and considerable variation in both government and external health financing, providing context for the subsequent regression analyses.

Figure 2 shows a gradual decline in household out-of-pocket expenditure over time, particularly after periods of increased government health expenditure. This trend suggests that stronger public financing mechanisms may contribute to improved financial protection for households.

Figure 2: Trends in household out-of-pocket expenditure, government health expenditure, and external health financing in Ghana

Figure 2 illustrates the bivariate relationships between government health expenditure, external health financing, and household out-of-pocket health expenditure in Ghana.

Figure 2 Bivariate associations between government health expenditure, external health financing, and household out-of-pocket health expenditur

Figure 2 shows the bivariate associations between government health expenditure, external health financing, and household out-of-pocket health expenditure in Ghana. The figure highlights a strong
negative relationship between government spending and household OOP payments, indicating that higher levels of public financing are associated with lower financial burden for households. In contrast, external health financing exhibits a weaker negative association, suggesting that donor contributions provide limited overall relief from direct household payments.

Time-Series Regression Analysis

Table 2 presents the multivariate time-series regression results showing that both government health expenditure and external health financing are significantly associated with reductions in household out- of-pocket expenditure.

Table 2: Multivariate Time-Series Regression Results for Household Out-of-Pocket Expenditure

Predictor	Coefficient (B)	Standard Error (SE)	T-value (T)	P-value (P)
Government Health Expenditure	−0.65**	0.08	−7.99	< .001
External Health Financing	−0.60**	0.13	−4.49	< .001
Constant	72.89**	5.03	14.50	< .001

Source: *Author's computation based on data from the World Health Organization Global Health Expenditure Database (2000–2023).*

The regression results indicate that both government and external financing were negatively and significantly associated with household OOP expenditure. Government spending had the strongest effect, confirming its central role in reducing household financial burden, while external financing contributed to lowering OOP costs to a smaller but significant extent **(8, 9)**.

Model Comparison

Table 3 summarizes the predictive performance of the four models: Linear Regression, Decision Tree, Support Vector Regression (SVR), and Random Forest in estimating household out-of-pocket (OOP) health expenditure in Ghana. Model performance is evaluated using the root mean squared error (RMSE) and coefficient of determination (R^2), allowing for a comparison of accuracy, explanatory power, and suitability for data mining and predictive analysis.

Table 3: Comparison of Predictive Model Performance for Household Out-of-Pocket Health Expenditure

Models	RMSE	R^2
Linear Regression	3.658	0.652
Decision Tree	2.662	0.878
Support Vector Regression	3.404	0.799
Random Forest	3.145	0.818

Source: *Author's computation based on data from the World Health Organization Global Health Expenditure Database (2000–2023).*

The comparison of predictive models for household out-of-pocket (OOP) health expenditure in Ghana revealed notable differences in performance and explanatory power. Linear Regression, as a traditional statistical approach, produced a root mean squared error (RMSE) of 3.658 and an R^2 value of 0.652. This indicates that while the linear model captured a moderate proportion of the variation in household OOP expenditure, it was less capable of accounting for the complex, potentially nonlinear relationships present in the data **(13, 26)**. Support Vector Regression (SVR) improved predictive accuracy, achieving an RMSE of 3.404 and an R^2 of 0.799. The stronger performance of SVR reflects its ability to capture nonlinear patterns and interactions between government health expenditure, external financing, and household OOP costs, which linear models may fail to detect **(33)**.

The Random Forest model performed slightly less accurately than SVR, with an RMSE of 3.145 and an R^2 of 0.818. Although Random Forest relies on aggregating multiple decision trees, its slightly higher RMSE compared with SVR may reflect the sensitivity of ensemble models to parameter choices and the relatively small dataset. Nevertheless, Random Forest provides robustness and feature importance analysis, allowing researchers to identify which predictors most strongly influence household financial risk **(10)**.

The Decision Tree model demonstrated the best balance of predictive performance and interpretability, with an RMSE of 2.662 and an R^2 of 0.878, explaining nearly 88 percent of the variation in household OOP expenditure while maintaining a highly interpretable structure. Decision Trees allow visualization of thresholds and splits in predictors, making it possible to identify points at which changes in government or donor financing have substantial effects on household spending. This interpretability is especially valuable in policy contexts, where understanding the magnitude and direction of the impact of health financing decisions is critical **(24)**. The results suggest that while more complex models such as SVR and Random Forest are useful for assessing nonlinear relationships and verifying robustness, the Decision Tree model offers both strong predictive performance and clear interpretability. Its ability to reveal actionable insights from the data makes it particularly suitable for examining how government and external health financing influence household financial risk in Ghana **(8, 9, 11)**.

Figure 3 illustrates the comparative performance of four predictive models in estimating household out- of-pocket health expenditure, highlighting differences in accuracy and explanatory power.

Figure 3: Model Performance Comparison

Figure 4 shows the comparison between actual and predicted household out-of-pocket expenditures, demonstrating the accuracy of the predictive model

Figure 4: Actual and Predicted OOPS

Table 4: Decision Tree Split Summary for Household Out-of-Pocket Health Expenditure

Node	Split Condition	Mean OOP (%)	Observations (n)	% of Sample
1	Root	33	20	100
2	gghed_che ≥ 54	27	7	35
3	gghed_che < 54	37	13	65

Source: *Author's analysis based on WHO Global Health Expenditure Database (2000–2023).*

The decision tree for predicting household out-of-pocket (OOP) health expenditure highlights the influence of government health expenditure as a key determinant. The root node represents the full sample, with a mean OOP expenditure of 33 percent. The first and only split occurs at a government health expenditure threshold of 54 percent of current health expenditure. Observations with government spending at or above this level show a reduced predicted OOP expenditure of 27 percent, whereas observations below this threshold have a higher predicted OOP expenditure of 37 percent. This split illustrates a clear pattern: higher government investment in health is associated with lower household financial burden, confirming the protective role of public financing **(27, 2)**. The node sizes indicate that the majority of observations (65 percent) fall below the 54 percent threshold, suggesting that for most years in the study period, government expenditure may not have reached the level needed to substantially reduce household OOP payments. The tree's simplicity enhances interpretability, allowing policymakers to easily identify actionable thresholds for intervention and prioritize increasing government health expenditure to achieve better financial protection for households.

Figure 5 illustrates the Decision Tree split summary, highlighting how government health expenditure influences household out-of-pocket spending.

Figure 5: Decision Tree Split Summary

Table 5: Feature Importance for Predicting Household Out of Pocket Health Expenditure in Ghana

Predictor Variable	Feature Importance Score	Relative Influence
Government Health Expenditure (gghed_che)	0.64	High
External Health Financing (ext_che)	0.04	Low

Source: *Author's analysis based on WHO Global Health Expenditure Database (2000–2023).*

The Decision Tree feature importance results indicate that government health expenditure is the most influential predictor of household out-of-pocket (OOP) health expenditure in Ghana. With a feature importance score of 0.64, government spending contributes the largest share to the model's predictive capacity, suggesting that variations in public health investment strongly influence the level of financial burden faced by households. This finding is consistent with the theory of risk pooling and prepayment, which emphasizes that government-financed health systems reduce reliance on direct household payments and improve financial protection **(2, 30)**.

External health financing shows a much smaller importance score of 0.04, indicating a relatively limited influence on overall household expenditure patterns. This suggests that donor funding contributes to financial

protection primarily through targeted programs rather than through broad system-wide reductions in household spending. Similar findings have been reported in studies of health financing in low- and middle-income countries, where public expenditure plays the dominant role in reducing OOP payments while external resources provide complementary support **(31)**.

Overall, the Decision Tree analysis highlights the central role of government health expenditure in reducing household financial risk and strengthening progress toward universal health coverage in Ghana **(2, 30, 31)**.

Figure 6 shows the feature importance results from the Decision Tree model, indicating the relative influence of government health expenditure and external health financing on household out-of-pocket expenditure.

Figure 6: Feature Importance

Table 6: Partial Dependence of Government and External Health Financing on Predicted Household Out-of-Pocket Expenditure in Ghana

Predictor Variable	Range of Predictor (% CHE)	Pattern of Predicted OOP (%)	Observed Relationship	Interpretation
Government Health Expenditure (GGHE-D)	35-52	Predicted OOP remains high at about 36–37%	Stable but elevated OOP	Lower government spending levels correspond with higher household financial burden
Government Health Expenditure (GGHE-D)	Above 52-54	Predicted OOP drops sharply to about 26–27%	Nonlinear threshold effect	Increased public spending beyond a threshold substantially reduces household OOP payments
External Health Financing (EXT)	2-25	Predicted OOP remains nearly constant around 33%	Minimal variation	Donor financing shows limited marginal influence on overall household OOP expenditure

Source: *Author's analysis based on WHO Global Health Expenditure Database (2000–2023).*

The partial dependence plots provide additional insight into how health financing sources influence household out-of-pocket (OOP) health expenditure in Ghana **(28)**. They illustrate the marginal effect of each predictor on predicted OOP spending while holding other variables constant, helping to identify nonlinear patterns in the data. The first plot shows a nonlinear relationship between government health expenditure and household OOP payments. When government spending is relatively low, predicted OOP expenditure remains high at about 36–37 percent, indicating that households rely heavily on direct payments for health services. However, once government expenditure reaches roughly 52–54 percent of current health expenditure, predicted OOP falls sharply to about 26–27 percent. This suggests the presence of a threshold effect, where higher public investment leads to substantial reductions in household financial burden. This pattern supports the theory of risk pooling and prepayment, which argues that strong publicly financed systems reduce reliance on point-of-service payments **(2, 29)**.

In contrast, the second plot shows that external donor financing has a relatively stable relationship with household OOP expenditure. Across the observed range of approximately 2–25 percent of current health expenditure, predicted OOP remains close to 33 percent, indicating only a limited marginal effect. This likely reflects the targeted nature of donor funding, which often focuses on specific programs rather than system-wide financial protection **(29)**. Overall, the partial dependence analysis confirms that government health expenditure plays the most significant role in reducing household financial risk in Ghana, while external financing provides complementary but more limited support **(2, 28, 29)**.

Figure 7 presents the partial dependence plots from the Decision Tree model, illustrating how changes in government health expenditure and external financing influence predicted household out-of-pocket expenditure.

Discussion

This study examined the relationship between government health expenditure, external health financing, and household out-of-pocket (OOP) health spending in Ghana from 2000 to 2023. The results show that government health expenditure plays a crucial role in reducing the financial burden on households.

Both the time-series regression and machine learning models reveal a strong negative relationship between public health spending and household OOP payments (27, 2, 6). One of the most important findings of this study is the identification of a threshold effect in government health expenditure. The Decision Tree analysis shows that household OOP spending declines substantially when government health spending exceeds approximately 52 to 54 percent of current health expenditure (27, 2). This finding suggests that small increases in public health financing may not be sufficient to significantly reduce household financial risk. Instead, sustained and higher levels of government investment are required to produce meaningful improvements in financial protection. External health financing was also associated with lower household spending, although its influence appears smaller (24, 25, 28). This may be because donor funding often supports specific health programs rather than broader system-wide financial protection.

These findings are consistent with existing research showing that pooled public financing mechanisms are essential for protecting households from catastrophic health expenditures (2, 27, 3). In the case of Ghana, strengthening government financing through taxation and social health insurance systems such as the National Health Insurance Scheme remains critical for improving financial protection and advancing universal health

coverage (1, 2). Despite these contributions, several limitations should be considered. The analysis relies on national-level aggregate data, which may hide regional differences in health financing and household spending. In addition, factors such as the quality of health services, access to health facilities, and informal payments were not included in the analysis but may also influence household expenditure patterns. Future research could explore how government health spending is allocated across different services and examine regional disparities in financial protection and access to care (5, 6).

Overall, the findings highlight that strong government-led financing is the most effective strategy for reducing household OOP health expenditure in Ghana. Policymakers should prioritize increasing and sustaining public health investment beyond the identified spending threshold to strengthen financial protection. While external financing can complement domestic resources, long-term progress toward universal health coverage will depend largely on strong and sustainable domestic public financing systems (2, 24, 25).

Conclusion

This study provides strong evidence that government health expenditure plays the most important role in reducing household OOP health spending in Ghana. Both time-series regression and Decision Tree analyses consistently showed a clear negative relationship between public health financing and the financial burden faced by households (27, 2). One particularly important finding is the nonlinear effect, where reductions in household spending become much more pronounced once government investment exceeds roughly 52 to 54 percent of current health expenditure (27, 2). This illustrates the importance of reaching adequate levels of public funding to make a real difference in protecting households, supporting the idea that spreading health costs across the population reduces the need for direct payments at the point of care (2, 27).

The central message of this research is that strengthening government-led pooled financing mechanisms is crucial for shielding households from catastrophic health expenditures. Although external health financing does help to reduce household costs, its impact is smaller and often limited to specific programs such as immunizations or maternal health services (24, 25, 28). This demonstrates that lasting improvements in financial protection depend largely on domestic public financing rather than external support.

Looking at the broader contributions, this study not only confirms the importance of government expenditure but also provides a more nuanced understanding of how spending thresholds influence household financial risk (27, 2, 3). By combining traditional regression with Decision Tree analysis, the research offers both statistical rigor and practical insights, showing the points at which increased government investment leads to significant reductions in OOP payments. These findings can help policymakers identify where to focus resources to achieve the greatest impact on household financial protection. Future research could explore how different allocations of government health expenditure across areas such as primary care, hospital services, and pharmaceuticals affect household spending. Investigating the role of health system efficiency, coverage, and quality of care could further clarify how financing translates into protection for households (5, 6, 28).

Comparative studies across countries with varying levels of public and external health financing could also reveal whether the threshold effect observed in Ghana applies elsewhere (2, 24, 25). The findings of this study have important implications for policy and practice. For governments, increasing domestic health financing is essential to reduce household financial risk, while external support should be carefully targeted to complement

public spending (1, 2, 24). For the international community, the study reinforces the idea that strong, government-led financing systems form the foundation of universal health coverage. Strategic public investment, guided by an understanding of spending thresholds and allocation priorities, can significantly improve financial protection for households and contribute to a more equitable and accessible health system for all (2, 27, 28).

Declarations

Ethics Approval and Consent to Participate:

Ethics declaration: not applicable. This study utilized publicly available secondary data from the World Health Organization Global Health Expenditure Database. The dataset contains aggregated national-level information and does not involve human participants, personal data, or identifiable information. Therefore, ethical approval and informed consent were not required.

Competing Interests:

The authors declare that they have no competing interests.

Funding:

This research received no external funding. The authors conducted the study independently without financial support from any public, commercial, or not-for-profit funding agencies.

Author Contribution

S.D.A. and O.E.d.G. conceptualized the study and designed the methodology. S.D.A. conducted the data analysis and drafted the manuscript. G.A. contributed to data interpretation and literature review. S.M.K. supported methodology development and validation. J.N. supervised the study and provided critical revisions. All authors reviewed and approved the final manuscript.

Acknowledgement

The authors would like to acknowledge the World Health Organization for providing access to the Global Health Expenditure Database used in this study.

Data Availability

The data used in this study are publicly available from the World Health Organization Global Health Expenditure Database. The dataset can be accessed at https://apps.who.int/nha/database. No new data were generated.

References

1. Afriyie DO, Loo PS, Kuwawenaruwa A, Kassimu T, Fink G, Tediosi F, Mtenga S (2024) Understanding the role of the Tanzania national health insurance fund in improving service coverage and quality of care. Soc Sci Med 347:116714. https://doi.org/10.1016/j.socscimed.2024.116714
2. Anjorin SS, Ayorinde AA, Abba MS, Oyebode OO, Uthman OA (2022) Variation in financial protection and its association with health expenditure indicators: an analysis of low-and middle-income countries. J Public Health 44(2):428–437. https://doi.org/10.1093/pubmed/fdab021
3. Berger LM, Carlson MJ (2020) Family policy and complex contemporary families: A decade in review and implications for the next decade of research and policy practice. J Marriage Family 82(1):478–507. https://doi.org/10.1111/jomf.12650
4. Chandra Y, Jain AK, Sharma AP (2024) External Funding and its Effects on Out-of-Pocket Expenditure in SAARC Nations: Global Health Financing Strategies. *Library of Progress- Library Science, Information Technology & Computer*, *44*(3). https://research.ebsco.com/linkprocessor/plink? id=37545b5d-0812-3a4c 8680-968b62916819
5. Deleidi M, Iafrate F, Levrero ES (2020) Public investment fiscal multipliers: An empirical assessment for European countries. Struct Change Econ Dyn 52:354–365. https://doi.org/10.1016/j.strueco.2019.12.004
6. Ekholuenetale M, Igwegbe Nzoputam C, Joshua E, C., Barrow A (2024) Impact of Socioeconomic Factors and Health Insurance Coverage on Out-of-Pocket Health Expenditure among Ghanaian Women: Implications for Health Financing Policy. Adv Public Health 2024(1):8414003. https://doi.org/10.1155/2024/8414003
7. Fenny AP, Yates R, Thompson R (2021) Strategies for financing social health insurance schemes for providing universal health care: a comparative analysis of five countries. Global Health Action 14(1):1868054. https://doi.org/10.1080/16549716.2020.1868054
8. Fosu P, Ankrah Twumasi M (2021) The effect of government expenditure and free maternal health care policy (FMHC) on household consumption in Ghana. J Econ Dev 23(2):184–202. https://doi.org/10.1108/JED-07-2020-0088
9. Frimpong AO, Amporfu E, Arthur E (2022) Effects of public and external health spending on out-of-pocket payments for healthcare in sub-Saharan Africa. Health Policy Plann 37(9):1129–1137. https://doi.org/10.1093/heapol/czac068
10. Gupta VK, Gupta A, Kumar D, Sardana A (2021) Prediction of COVID-19 confirmed, death, and cured cases in India using random forest model. Big Data Min Analytics 4(2):116–123. https://doi.org/10.26599/BDMA.2020.9020016
11. Hajji, S., Boudhar, A., Elaloui, A., Merghadi, A., Krimissa, S., Namous, M., … El Bouzekraoui, M. (2025). A review of the literature on spatial prediction of floods using machine learningmodels. *Journal of Coastal Conservation*, *29*(6), 85. https://doi.org/10.1007/s11852-025-01158-2
12. Houeninvo HG, Quenum VCC, Senou MM (2023) Out-Of-Pocket health expenditure and household consumption patterns in Benin: Is there a crowding out effect? Health Econ Rev 13(1):19. https://doi.org/10.1186/s13561-023-00429-8
13. Hu M (2022) Multivariate understanding of income and expenditure in United States households with statistical learning. Comput Stat 37(5):2129–2160. https://doi.org/10.1007/s00180-022-01251-2
14. Islam S, Zobair KM, Chu C, Smart JC, Alam MS (2021) Do political economy factors influence funding allocations for disaster risk reduction? J Risk Financial Manage 14(2):85.

https://doi.org/10.3390/jrfm14020085

15. Jalili R, Gilani N, Najafi B, Gordeev VS, Doshmangir L (2025) Health financial resilience in individuals and households: a scoping review of components, strategies and outcomes. BMC Public Health 25(1):3021. https://doi.org/10.1186/s12889-025-24467-5
16. Ketevan G, Mamuka N, Triin H (2021) Can people afford to pay for health care? New evidence on financial protection in Georgia. https://iris.who.int/handle/10665/342815
17. Kodali PB (2023) Achieving universal health coverage in low-and middle-income countries: challenges for policy post-pandemic and beyond. Risk Manage Healthc policy 607–621. https://doi.org/10.2147/RMHP.S366759
18. Liu S, Wu K, Jiang C, Huang B, Ma D (2023) Financial time-series forecasting: Towards synergizing performance and interpretability within a hybrid machine learning approach. *arXiv preprint arXiv:2401.00534*. https://doi.org/10.48550/arXiv.2401.00534
19. Mekuria GA, Ali EE (2023) The financial burden of out of pocket payments on medicines among households in Ethiopia: analysis of trends and contributing factors. BMC Public Health 23(1):808. https://doi.org/10.1186/s12889-023-15751-3
20. Muremyi R, Haughton D, Kabano I, Niragire F (2020) Prediction of out-of-pocket health expenditures in Rwanda using machine learning techniques. Pan Afr Med J 37:357. https://doi.org/10.11604/pamj.2020.37.357.27287
21. Nie P, Li Q (2024) Does energy poverty increase health care expenditures in China? Appl Econ 56(35):4209–4235. https://doi.org/10.1080/00036846.2023.2210823
22. Radu CP, Pana BC, Pele DT, Costea RV (2021) Evolution of public health expenditure financed by the Romanian social health insurance scheme from 1999 to 2019. Front public health 9:795869. https://doi.org/10.3389/fpubh.2021.795869
23. Rahman T, Gasbarro D, Alam K (2022) Financial risk protection from out-of-pocket health spending in low- and middle-income countries: a scoping review of the literature. Health Res Policy Syst 20(1):83. https://doi.org/10.1186/s12961-022-00886-3
24. Reimann C (2024) Predicting financial crises: an evaluation of machine learning algorithms and model explainability for early warning systems. Rev Evolutionary Political Econ 5(1):51–83. https://doi.org/10.1007/s43253-024-00114-4
25. Saadati SM (2025) The future of health equity: policy strategies to reduce disparities in public health. J Foresight Health Gov 2(2):15–32. https://journalfph.com/index.php/jfph/article/view/8
26. Samantaraya A (2024) Diagnostic Tests in Regression Analysis. Basic Econometric Tools Techniques Data Analytics, *50*. https://www.academia.edu/download/120596266/2024_Data_Analytics_Book.pdf#page=58
27. Söyük S (2023) The impact of public health expenditure and gross domestic product per capita on the risk of catastrophic health expenditures for OECD countries. Front Public Health 11:1122424. https://doi.org/10.3389/fpubh.2023.1122424
28. Vărzaru AA (2025), February Assessing the relationships of expenditure and health outcomes in healthcare systems: a system design approach. In *Healthcare* (Vol. 13, No. 4, p. 352). MDPI. https://doi.org/10.3390/healthcare13040352

29. Waitzberg, R., Allin, S., Grignon, M., Ljungvall, Å., Habimana, K., Kantaris, M.,… Rice, T. (2024). Mitigatingthe regressivity of private mechanisms of financing healthcare: An Assessment of 29 countries. *Health policy*, *143*, 105058. https://doi.org/10.1016/j.healthpol.2024.105058
30. Wang F, Li M, Mei Y, Li W (2020) Time series data mining: A case study with big data analytics approach. IEEE Access 8:14322–14328. https://doi.org/10.1109/ACCESS.2020.2966553
31. World Health Organization (2024) *Universal health coverage* (No. WHO: AFRO/ULC: 2024-12). World Health Organization. Regional Office for Africa. https://iris.who.int/bitstreams/82c2df86- 82c7-4d1c-a3c5-b1fd65489802/download
32. Zehra N, Singh UB (2023) Household finance: a systematic literature review and directions for future research. Qualitative Res Financial Markets 15(5):841–887. https://doi.org/10.1108/QRFM-11-2021-0186
33. Zhang F, O'Donnell LJ (2020) Support vector regression. In *Machine learning* (pp. 123–140). Academic Press. https://doi.org/10.1016/B978-0-12-815739-8.00007-9
34. Zhang J (2021) The Impact of Public Pension Deficits on Households' Investment and Economic Activity. *Available at SSRN 3918170*. https://ssrn.com/abstract=3918170

Figures

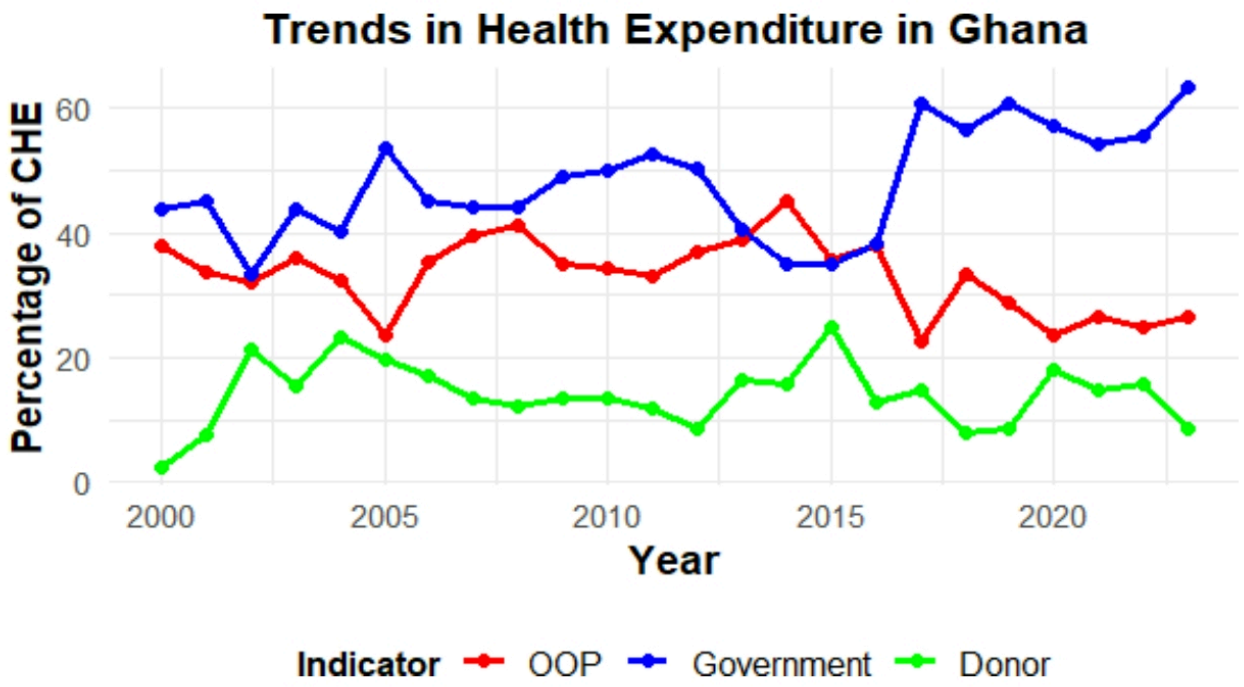


Figure 1

Trends in household out-of-pocket expenditure, government health expenditure, and external health financing in Ghana

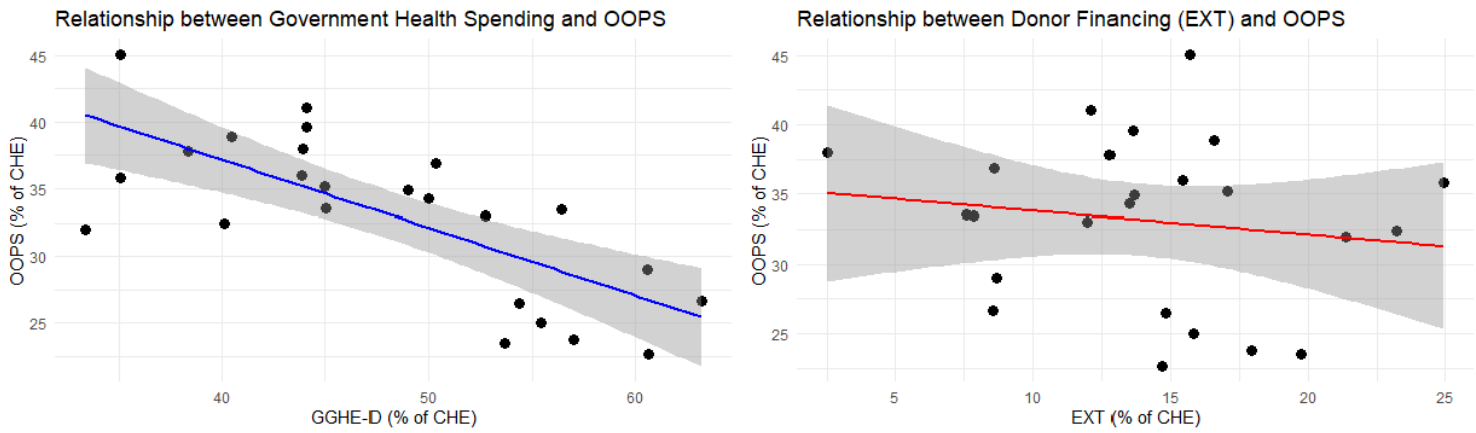


Figure 2

Bivariate associations between government health expenditure, external health financing, and household out-of-pocket health expenditure

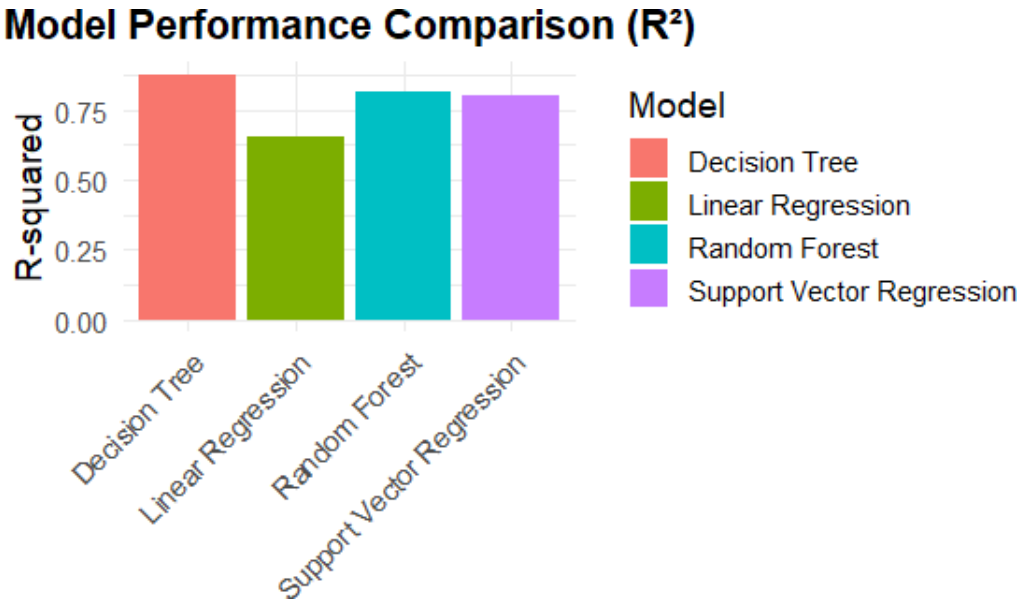


Figure 3

Model Performance Comparison

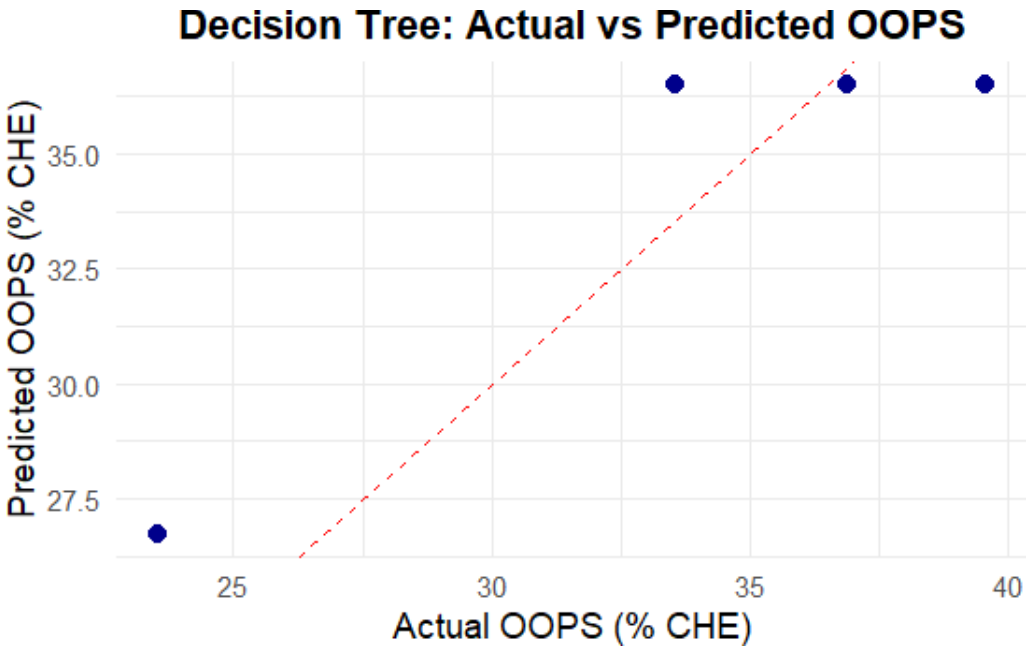


Figure 4

Actual and Predicted OOPS

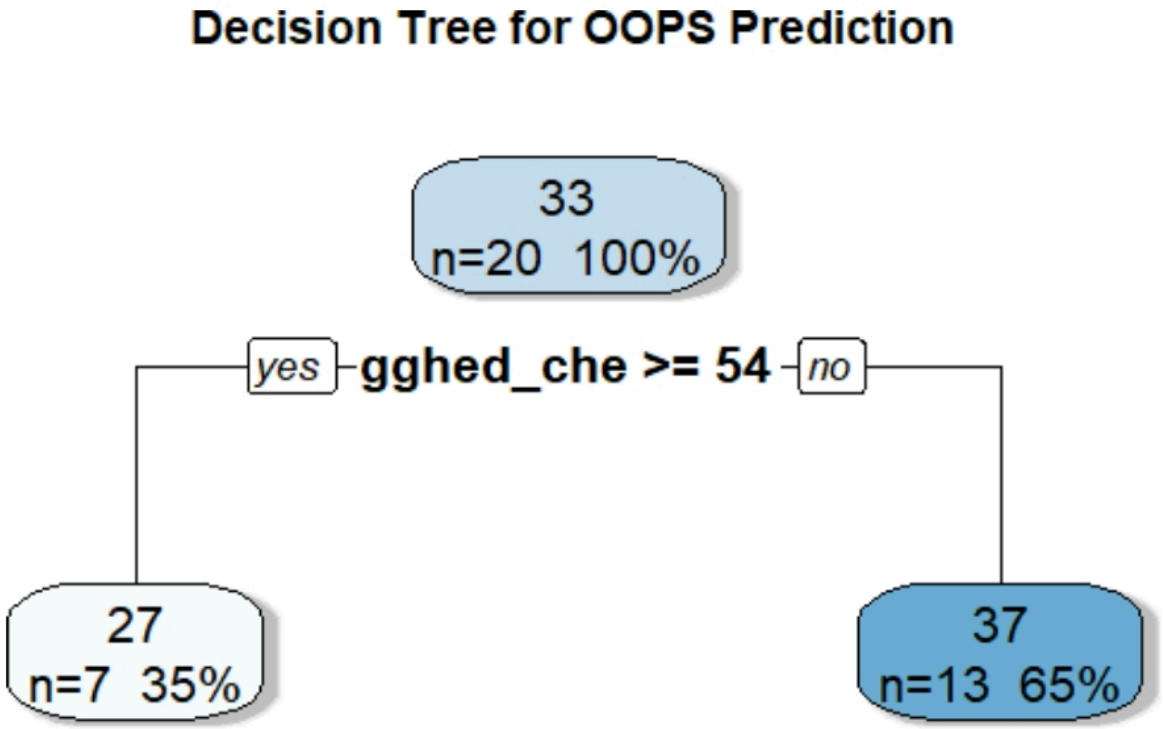


Figure 5

Decision Tree Split Summary

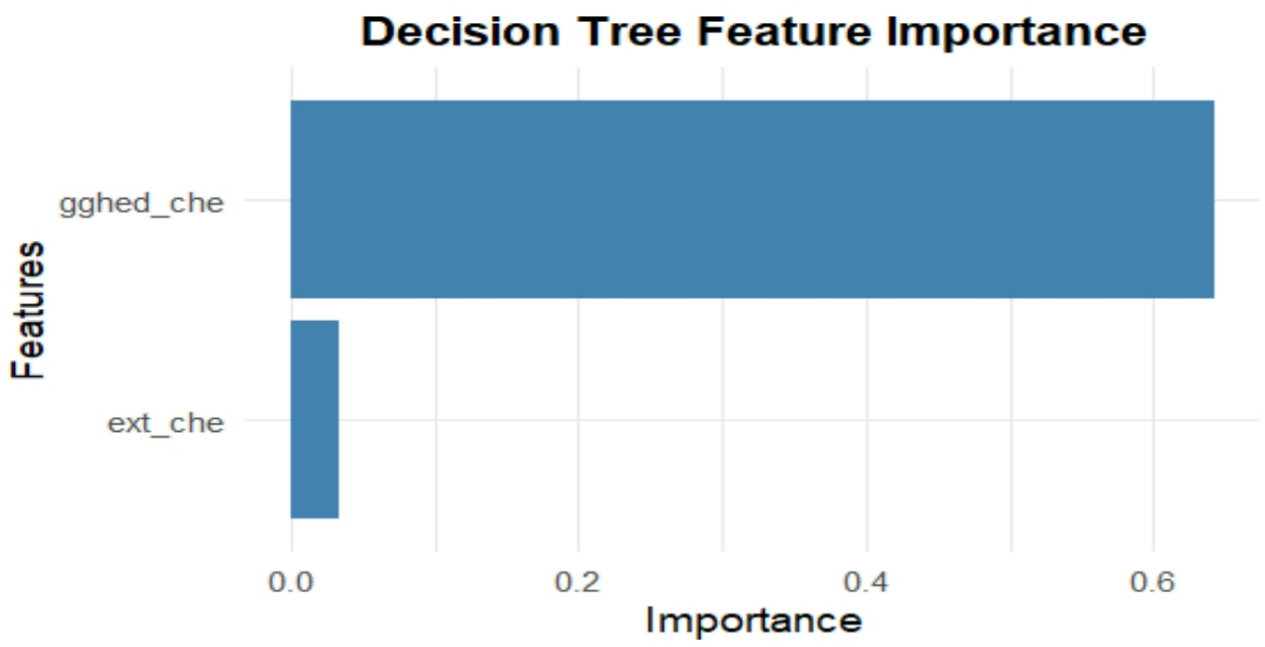


Figure 6

Feature Importance

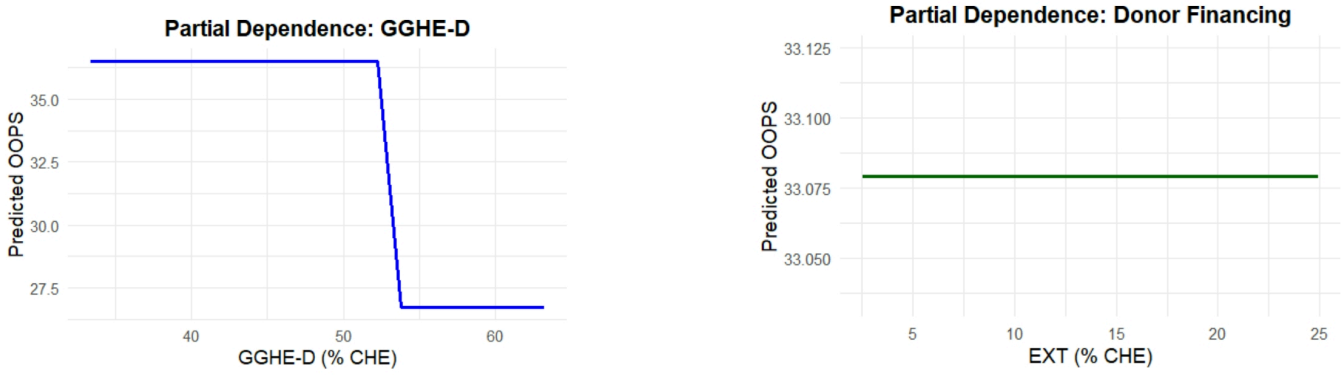


Figure 7

Partial Dependence Plots for Decision TreeModel