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Dynamical foresight and optimum development modelling the efficacy of Ghana's rural-community banks (RCB'S) using stochastic differential equations

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Abstract
Using stochastic differential equations, this research examines the performance of RCBs in Ghana. To foretell RCB performance in Ghana, this research employed 4-dimensional stochastic differential equations. With inflation expected to increase, the forecast predicts that the RCB's profitability, liquidity, and solvency will all decline by 2029. The profitability SDE loses the least data and the liquidity SDE is the best predictor of future RCB efficiency. In this way, we assist RCBs in reaching their full financial potential. For RCB, the fifth year is prime time to resolve problems and accomplish objectives. The SDE Model suggests that the ninth year is the optimal time to liquidate RCB assets with minimal impact on their market value. The optimal response to the RCB solvency question indicates that the company has sufficient cash on hand to meet its long-term debt obligations.

Keywords: Efficiency, Ghana, rural and community banks, stochastic differential equations, financial indicators, macroeconomic indicators

Introduction
Banks accept customer deposits and lend them to deficit-spending units in the economy (Afful and Hejkrlik, 2015) [1]. In Ghana, banking remains one of the most lucrative industries despite increasing competition, but banks are exposed to several factors that can affect their profitability (Antwi, 2015) [2].

Rural and Community Banks (RCBs) are key players in Ghana's banking industry to accelerate rural development. They're regulated by the Bank of Ghana and part of Ghana's financial sector. Efficiency in banking is linked to stability and growth. It's hard to choose between profitability, solvency, and liquidity (Setiadi, 2017) [3]. What role do sound financial and economic indicators play in rural bank performance and predictions? (Oteng-abayie, 2017) [4]. Adusei (2015) [5]; Appiah, Narkotey, and Adu (2015) [9]; Nkegbe and Yazidu (2015) [10]; Awoin *et al*. (2020) [11] are some models that have broadened perspectives on performance gaps. Managing and measuring bank performance is a hot topic among academics and non-academics (Titko and Jureviciene, 2014) [12]. No one agrees on what performance measures best reflect a bank's position and growth potential (Adusei, 2016a) [6].

RCBs have grown from a manual to a computerized operation over time. It's believed that this revolution has hampered efficiency and productivity (Antwi, *et al*, 2014a) [14]. Crabbe (2014) [14] noted that not all RCBs are solvent; in 2008, seven were insolvent, and the continued operation of poorly performing RCBs is a key issue for the banking industry in Ghana.

According to a 2012 Bank of Ghana report, 85 RCBs are "satisfactory," 19 are "mediocre," and 31 are "distressed" and need close monitoring to avoid closure. According to ARB Apex (2019), Strong and Satisfactory RCBs fell from 21 to 9 and 76 to 67. Fair and Marginal rose from 20 to 43 and 11 to 12. 9 RCBs were not rated due to operational problems, and 4 were in distress, indicating a decline in performance.

According to Awoin *et al*. (2020) [11], most of these institutions collapsed because they couldn't predict their financial futures. Several studies (Crabbe, 2014; Adusei, 2016a, 2016b; Abdul and Makki, 2013) [14, 6, 7, 20] cited that RCB performance efficiency in Ghana is dipping by profitability indicators, but they failed to identify factors that predict efficiency. Accounting-based financial ratios are used to rank RCB's performance, according to existing studies.

Accounting ratios only measure input or output of financial intermediation. Intermediation doesn't consider input–output combinations. It can't identify inefficiencies and efficiency

changes. This research therefore predicts the efficiency of RCBs in Ghana with real data also determine the best fitting stochastic differential equation model (SDE) for RCB's efficiency and ascertain optimal growth level using financial and macroeconomic KPIs.

Materials and Methods

Developing a prediction methodology for rural bank financial position in Ghana is the primary goal of this research. According to the literature, there are three methods for determining a bank's efficiency: financial ratios; parametric techniques; and non-parametric approaches. Using financial ratios to evaluate a decision-making unit's efficiency has the drawback of creating a false sense of priority for various sorts of input and output. A set of data collected from Bank of Ghana website on RCB's returns namely Profitability, Liquidity, Solvency and Macroeconomic indicators was used to estimate the diffusion drift parameter of stochastic differential equation to meet the study's goals. For this investigation, repeated responses over time are evaluated and assessed using Stochastic Differential Equations algorithm. description of the fundamental statistics of the data, as well as inferences and estimations for the development of stochastic differential equation models, the forecasts accuracy was determined by considering how well a model performs on new data that were not used when fitting the model. When selecting models, we first divide the available data into two distinct categories: training data and test data. The training data is used to determine the parameters of a forecasting method, while the test data is used to determine how accurate the method is. Which is a form of linear stochastic differential equation (SDE) given as?

$$dX(t) = AX(t)dt - \sigma X(t)dB(t)^T \; t \in [0,T], \qquad \text{Eq (1)}$$

Where $AX(t)$ the average is drift term, $\sigma X(t)$ is the diffusion term and $dB(t)$ is the Brownian noise. Consider a multiple 4 -dimensional stochastic differential equation (SDE)

$$\begin{cases} dP^j(t) = \alpha P^j(t)dt + \sigma_1 P^j(t)dB^1(t) \\ dL^j(t) = \beta L^j(t)dt + \sigma_2 L^j(t)dB^2(t) \\ dS^j(t) = \gamma S^j(t)dt + \sigma_3 S^j(t)dB^3(t) \\ dM^j(t) = \delta M^j(t)dt + \sigma_4 M^j(t)dB^4(t) \end{cases} \qquad \text{Eq (2)}$$

$X^j(t)$ = Efficiency of a Bank at time $t \geq 0$
$P^j(t)$ = Profitability of a Bank at time t
$L^j(t)$ = Liquidity of a Bank at time t
$S^j(t)$ = Solvency of a Bank at time t
$M^j(t)$ = Macroeconomic situation at time t
$j =$ Efficiency at a particular state

Thus, the state's parameter can be defined as; $X^j(t) = [P^j(t), L^j(t), S^j(t), M^j(t)]^T$With the solution in Eq (2), we can characterize the qualitative behaviour of the process at $t \to \infty$.

$$\begin{cases} P^j(t) = P_0^j e^{\left(\mu_1 - \frac{\theta_1^2}{2}\right)T + \theta_1 B^1(T)} \\ L^j(t) = L_0^j e^{\left(\mu_2 - \frac{\theta_2^2}{2}\right)T + \theta_2 B^2(T)} \\ S^j(t) = S_0^j e^{\left(\mu_3 - \frac{\theta_3^2}{2}\right)T + \theta_3 B^3(T)} \\ M^j(t) = M_0^j e^{\left(\mu_4 - \frac{\theta_4^2}{2}\right)T + \theta_4 B^4(T)} \end{cases} \qquad \text{Eq (3)}$$

Where
$f: R^4 \times R_+ \to R^4 and\ g: R^4 \times R_+ \to R^{4\times 4}, and\ B(t) = (B_1(t), \ldots \ldots B_m(t))^T$ is a 4-dimensional Brownian motion, with initial $P^j(0) > 0, L^j(0) > 0, L^j(0) > 0, M^j(0) > 0$
The solution is global and positive for initial value. For this, we denote the set $R_+^4 = \{(x_1, x_2, x_3, x_4) \in R^4 | x_1 > 0, i = 1,2,3,4\}$.
Consider a multiple 4 -dimensional stochastic differential equation (SDE) With the solution in Eq (2) and Eq (3) respectively, we can characterize the qualitative behaviour of the process at $t \to \infty$. We observe that profitability, Liquidity, Solvency and Macroeconomic is always positive, assuming the initial $P_0^j, L_0^j, S_0^j\ and\ M_0^j$ is positive. Considering the randomness in formulation of the differential equations provides an attractive description of the phenomena of interest.

Results and Discussion

Model Parameter Estimation

Table 1: Estimated values for the parameters

Parameters	Estimates
α	0.3562
β	0.1958
γ	0.2927
δ	-0.4466
σ_1	1.4509
σ_2	0.5027
σ_3	0.4658
σ_4	0.4219

From table 1, estimated parameters of stochastic differential equation models show that in small time interval of length (σ_1, σ_2, σ_3, σ_4), the stochastic process $P^j(t)$, $L^j(t)$, $S^j(t)$ and $M^j(t)$ changes its value by an amount that is normally distributed with expectation (α, β, γ, δ) and variance (σ_1, σ_2, σ_3, σ_4) which is independent of the past behavior of the process. This is so because the increments of a Wiener process are independent and normally distributed.
Average profitability (ROA) is 35 percent, implying an average rural bank in the sample earned 35 percent on its assets with a 145 percent variance in the time under review. Showing RCBs are chalking up bigger returns, which can undermine rural financial intermediation if the strong returns mean that RCBs charge higher interest rates than other banks on similar loans. If the high returns are due to the market power of RCBs, this implies that rural financial intermediation is inefficient.
However, in table 1, rural banks have met around 20 percent of their financial obligations as due. These assets may be deposited at the Federal Reserve or another large central bank. It usually arises from buying securities that can be sold rapidly for a minor loss, with a 50 percent variance in liquidity throughout the period considered. Moreover, to meet long-term fixed expenses and achieve long-term expansion and growth on its assets, an average rural bank in the sample attained an average capital adequacy ratio (CAR) of 29 percent, showing a range of 47 percent in the CAR return for the period under investigation. The CA Ratio measures a bank's ability to pay liabilities and respond to credit and operational risks. The average inflation growth in the sample is -44 percent, suggesting a 42 percent variance for the analyzed time. This is true when assessing an economy's efficiency, conduct, structure, and decision-making, when an

economy's development and stability are governed by interest rates, taxes, and government spending.

Predicted Efficiency Values for RCBs

Table 2: Predicted Efficiency values of RCB's

Years	$P^j(t)_{n+1}$	$L^j(t)_{n+1}$	$S^j(t)_{n+1}$	$M^j(t)_{n+1}$
2020	3.06	32.15	17.80	11.70
2021	3.03	32.00	17.78	11.61
2022	2.99	34.27	17.74	11.51
2023	3.89	34.76	17.57	11.33
2024	4.14	35.87	17.76	11.36
2025	4.73	35.99	17.73	11.27
2026	4.61	37.59	17.53	11.07
2027	4.86	37.63	17.69	11.09
2028	5.12	40.24	17.81	11.09
2029	5.67	41.44	18.10	11.17

In table 2, Due to Profitable choices, decisions, and strategies analysis show efficiency whiles Liquidity, asset management, and debt affect operating results. RCB's 10-year profitability will fluctuate from 2020 to 2029, with slight growth and inefficiency will set in 2022 and 2026 due to industry competition. In the model, banks' market power maximized profits. Market competition reduces perfect competition profits. Banks make suboptimal output-input choices. Inputs, scale, and combinations may be suboptimal.

Whiles RCBs' liquidity will deteriorate in 2022 with an improved position from 2023, with the current ratio as the main factor. The predicted CAR for RCB's industry is 17.80 percent in 2020 and 18.10 percent by 2029, well above the Basel II/III minimum of 8 percent. Higher capital adequacy ratios above the regulatory threshold show banks' improved ability to expand lending and absorb potential losses.

Macroeconomic variables and long-term growth trends cause the business cycle, Inflation is expected to fluctuate by 11.70 percent from 2020 to 11.17 percent in 2029. The 2008 financial crisis was inspired by Depression-era macroeconomics. Aidoo (2010) [18] found seasonal and no seasonal patterns in Ghana's inflation. Money supply, Treasury bill rates, and exchange rate determine short-run inflation, according to M.K. (2007) [19]. Ghana's inflation is inert.

Confidence interval for predicted efficiency values

Table 3: Confidence interval for predicted values

	$P^j(t)_{n+1}$		$L^j(t)_{n+1}$		$S^j(t)_{n+1}$		$M^j(t)_{n+1}$	
Years	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
2020	3.0600	3.0600	32.1500	32.1500	17.8000	17.8000	11.7000	11.7000
2021	2.5381	3.5215	30.2630	33.9124	16.8563	18.7073	11.0677	12.1533
2022	2.1345	3.8434	28.8179	35.1298	16.1317	19.3544	10.5625	12.4522
2023	1.5440	4.2416	26.4306	36.7839	14.9231	20.2219	9.7704	12.8853
2024	1.1626	4.8122	25.2085	38.6860	14.3060	21.2084	9.3481	13.3814
2025	1.1120	4.7587	25.2495	38.4496	14.3525	21.1128	9.3146	13.2304
2026	0.7532	4.8653	23.8886	38.9461	13.6622	21.3985	8.8539	13.2917
2027	0.5638	5.2146	23.4320	39.9524	13.4398	21.9410	8.6626	13.5192
2028	0.0529	5.9715	21.3203	42.5064	12.3542	23.2633	7.9717	14.1995
2029	-0.055	6.3933	20.9496	43.9361	12.1647	24.0264	7.8140	14.5410

Table 3 presents the degrees of confidence associated with the Efficiency Models' estimate for 2020 through 2029, with a 95% confidence level. This exercise aims to determine both the mean and variation of an estimate, we are 95% confident that RCBs will be contained within the lower or upper limit between 2020 and 2029. This means either the lower limit or the upper limit could be reached.

Efficiency performance of RCB's

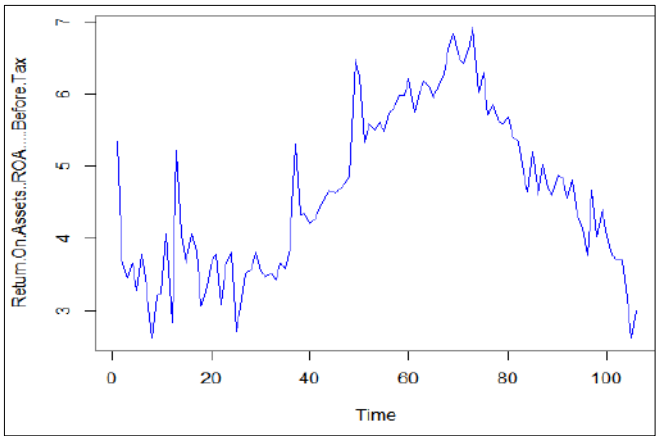

Fig 1: Performance of RCB's Profitability

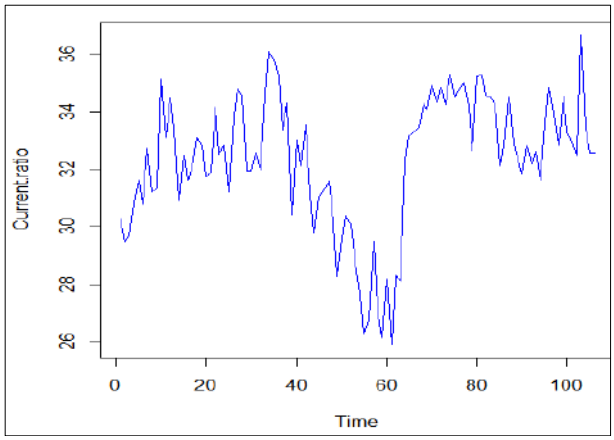

Fig 2: Performance of RCB's liquidity

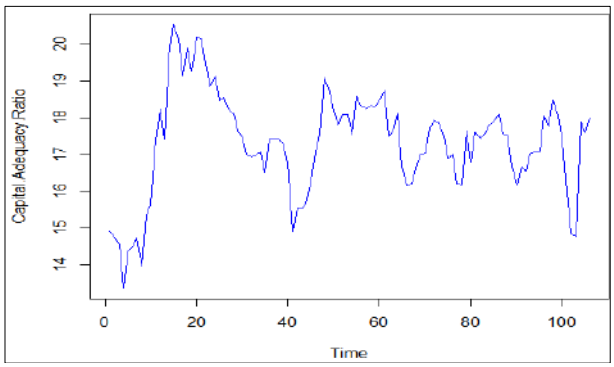

Fig 3: Performance of RCB's solvency

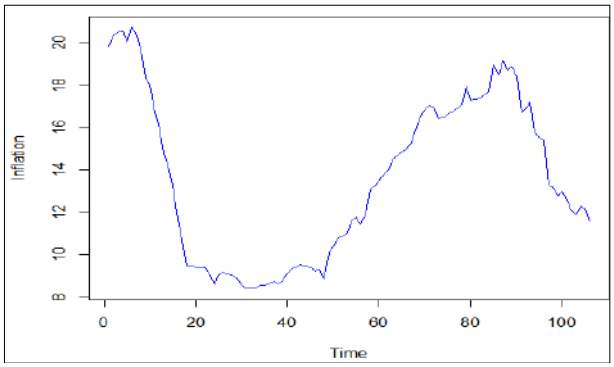

Fig 4: Macroeconomic performance

In figure 1 to 4, we plot trajectories with initial condition $\xi = 0$, the real sector indicators. Figure 1 RCB's profitability examines sales, operations, balance sheet assets, or equity. Data soared and fell but didn't repeat Cycle-long which was driven by Multiple factors.

The real sector performance of RCB's liquidity indicator over time, as shown in Figure 2, can be used to evaluate a company's capacity to satisfy its short-term financial obligations. Despite Basel II/III, Figure 3 illustrates a resilient banking industry. Industry solvency has improved.

Since Basel II/Capital III's Risk Directive (CRD) was introduced in 2019, the industry's CAR has stayed well over the 8 percent buffer threshold, at 19.55 percent. Reforms and recapitalization have improved loss-absorbing capacity.

Forecast value of Efficiency Model

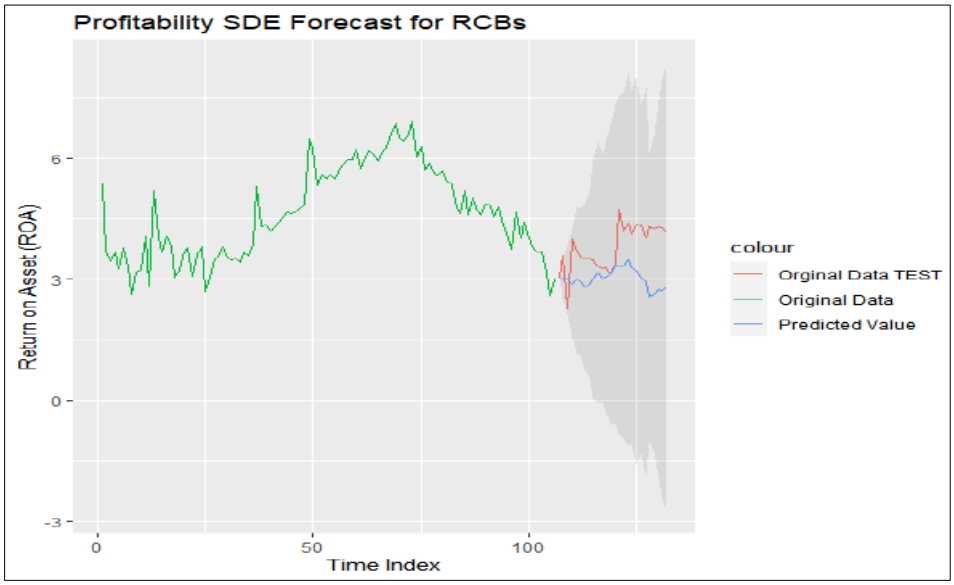

Fig 5: Predictive returns on profitability

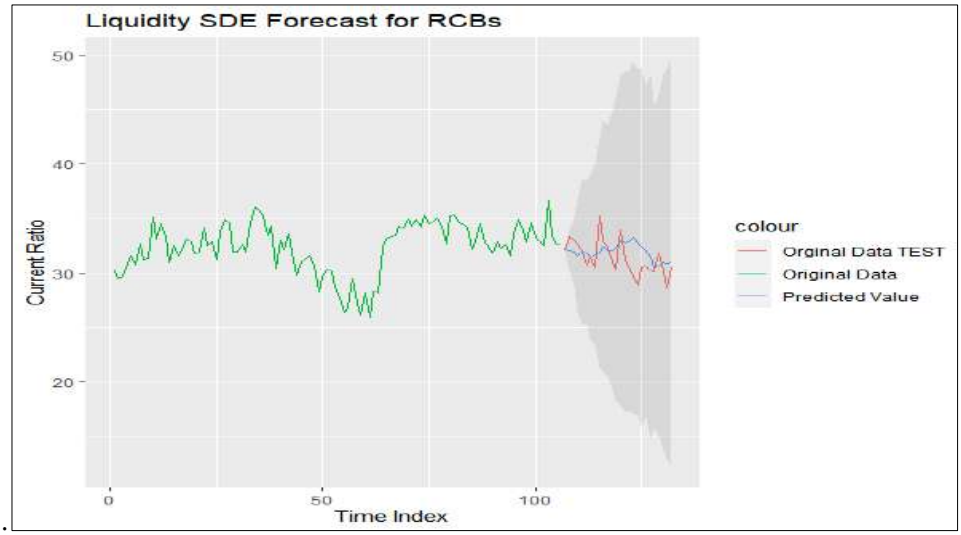

Fig 6: Predictive plot of liquidity

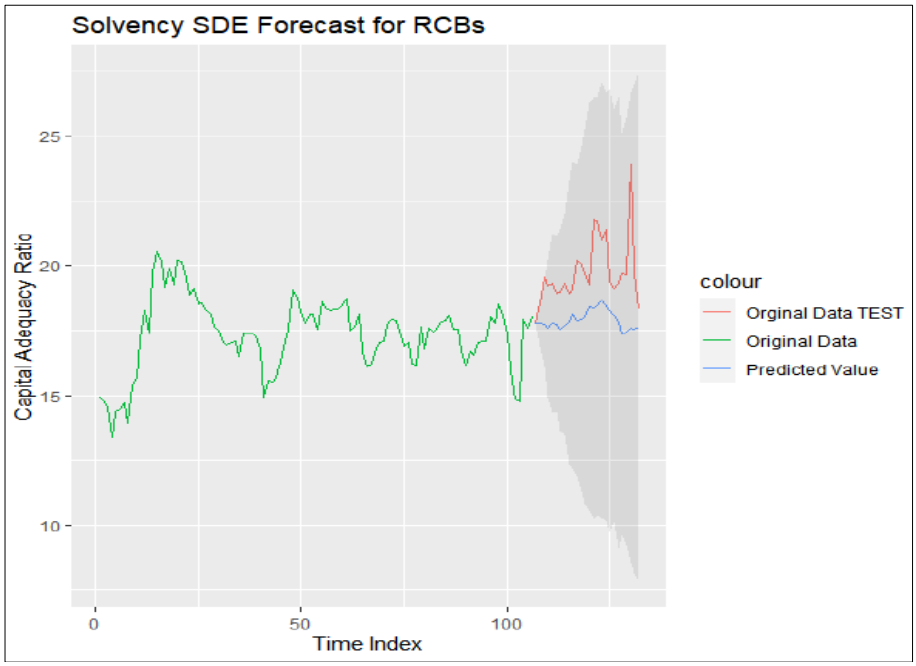

Fig 7: predictive plot of returns on solvency

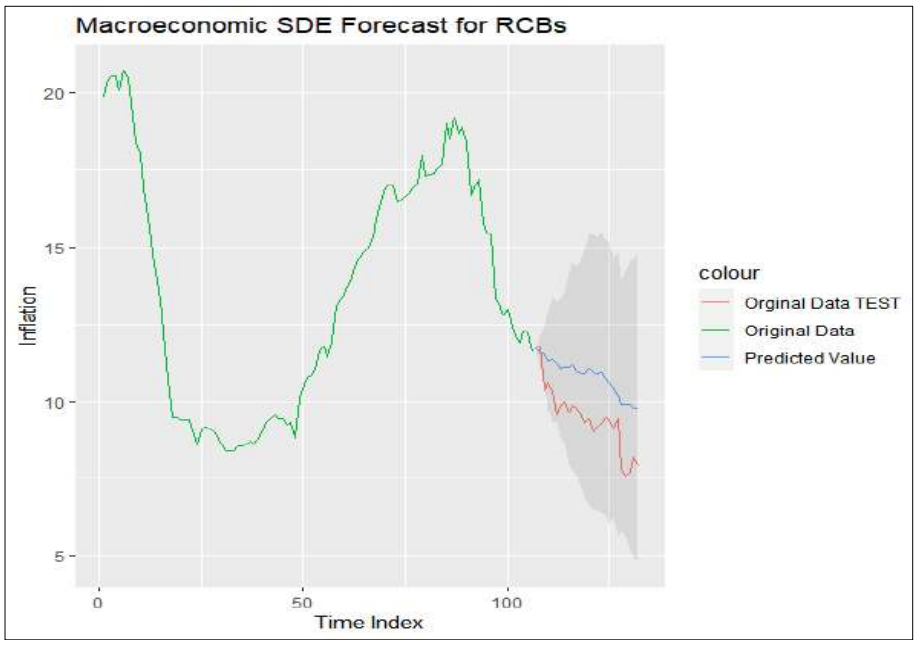

Fig 8: predictive plot of returns on Macro economy

In Figure 5, 6, 7 and 8 shows the observations in the training set form the experience that the algorithm uses for prediction and test set is a set of observations used to evaluate the performance of the model using some performance parameters with predictive returns which shows that all predicted values follow original data set accurately.

Model selection for prediction

Table 4: Best Fitting SDE Model for Prediction

	Profitability Model	Liquidity Model	Solvency Model	Macroeconomic Model
AIC	136.1411	191.9039	171.1685	145.7714
BIC	138.6573	194.4201	173.6847	148.2876
logLik	-66.0705	-93.9520	-83.5842	-70.8857

The quality of a model is proportional to the amount of information it loses; the less information a model loses, the higher its quality. The Profitability model, on the other hand, demonstrates that there is a reduction in information loss with an AIC value of (136.1411), BIC of (138.6573) and logLik of (-66.0705), all of which offer a better fit.

Accuracy Measures for a Forecast Model

Table 5: Mean Absolute Percentage Error (MAPE)

Parameters (SDE Model)	Accuracy Error	Predictive power	Interpretation
Profitability	20.6112	79.3888	Good
Liquidity	4.3472	95.6528	Very Good
Solvency	9.0806	90.9194	Very Good
Macroeconomic	15.4008	84.5992	Very Good

In Table 5, AIC only measures model quality. This indicates that there is still a possibility that none of the tested models will fit properly. We use MAPE and require additional

measures to show that its output meets an acceptable absolute standard. Mean Absolute Percentage Error (MAPE) tells us about the average distance between the model's predicted values and the actual values in the dataset, examine how well the model handles dataset outliers. Therefore, the Liquidity model has the lowest MAPE value (4.3472%), which tells us that it's able to forecast future RCBs efficiency most accurately among the four potential models.

Optimal Solution

We identify the optimal approach for RCB's to take to resolve a problem or accomplish a goal efficiently. In terms of cost and/or profit, the optimal solution is the one that makes the best use of available resources. It's also the most profitable option available given current conditions.

$$\begin{cases} P^j(t) = P_0^j e^{\left(\mu_1 - \frac{{\theta_1}^2}{2}\right)T + \theta_1 B^1(T)} \\ L^j(t) = L_0^j e^{\left(\mu_2 - \frac{{\theta_2}^2}{2}\right)T + \theta_2 B^2(T)} \\ S^j(t) = S_0^j e^{\left(\mu_3 - \frac{{\theta_3}^2}{2}\right)T + \theta_3 B^3(T)} \\ M^j(t) = M_0^j e^{\left(\mu_4 - \frac{{\theta_4}^2}{2}\right)T + \theta_4 B^4(T)} \end{cases} \quad \text{Eq (4)}$$

Table 6: Optimal Estimate

	$P(t)$		$L(t)$		S(t)		M(t)	
	R^2	Norm of Residuals	R^2	Norm of Residuals	R^2	Norm of Residuals	R^2	Norm of Residuals
1	0.1713	67.07	0.9990	24.26	0.9975	23.17	0.9920	19.72
2	0.1757	64.77	0.9993	21.99	0.9969	26.73	0.9930	18.37
3	0.1714	69.21	0.9992	23.36	0.9983	20.83	0.9895	19.83
4	0.2644	70.83	0.9990	25.09	0.9983	20.30	0.9879	21.59
5	0.3298	64.76	0.9990	24.86	0.9984	20.19	0.9880	21.04
6	0.2435	66.22	0.9990	22.77	0.9980	22.17	0.9893	19.92
7	0.2055	67.20	0.9990	24.46	0.9983	20.36	0.9881	19.88
8	0.2484	70.50	0.9986	28.21	0.9985	19.19	0.9899	20.50
9	0.3040	65.49	0.9993	21.97	0.9976	24.02	0.9885	19.97
10	0.1663	73.05	0.9993	21.98	0.9979	22.66	0.9864	21.51

In table 6, The optimal value for RCB's Profitability SDE Model's best solution is the profit level in the fifth year, which yields higher variability of 33 percent observed in the target profitability explained by the model for a company to either resolve a problem or accomplish its goals. Whiles RCB's liquidity year about some criterion for which RCB's asset, or security, can be converted into ready cash without affecting its market price, from among a set of alternatives that are currently available is the liquid level in the ninth year, which yields higher variability of 99 percent observed in the target liquidity explained by the model for a company to solve short term obligation. However, the optimal value for the RCB's solvency SDE Model best solution is level in the eighth year, which yields higher variability of 99 percent observed in measure of a company's financial health. This is because it demonstrates a company's ability to manage operations into the not-too-distant future. Ratios are a useful tool for investors to use when evaluating the financial health of a company and the macroeconomic solution demonstrates how the market systems that are active on a large scale behave. This refers to the overall economy. The SDE Macroeconomics Model investigates phenomena that affect the entire economy, including inflation, price levels, the rate of economic growth, national income, gross domestic product (GDP), and fluctuations in unemployment. The best solution is to wait until the second year for the optimal value level, which will result in higher variability of 98 percent observed.

Conclusion

This study applied the created Stochastic differential equation model to real data to make predictions about the performance of RCBs in Ghana. According to macroeconomic trends, the analysis forecasts a fluctuation in RCB profitability, liquidity, and solvency between 2020 and 2029, alongside a sharp increase in inflation.

For accurate predictions of future RCB efficiency, the best-fit model is the liquidity SDE model, while the profitability SDE model results in the least amount of information loss.

According to the research, best-fit SDE models have a greater impact on liquidity and macroeconomic models. We find the optimal solution for RCBs to implement in any scenario. If you want to maximize efficiency in terms of cost and/or profit, then you need to find the ideal solution.

Indeed, under the current circumstances, it is the most profitable option. The best value for RCB's profit target is the level reached in the fifth year because of the greater variety it provides. Profitability The SDE Model offers the best chance for a business to either resolve an issue or realize its objectives. As a result, using the SDE Model, the ideal year in which an RCB's asset or security can be converted into ready cash without affecting its market price for the company to pay its short-term obligations is the ninth year. The greatest RCB solvency answer, however, demonstrates that the company has sufficient cash on hand to pay its debts in full, including its long-term loans. From a pool of potential best-case scenarios, the SDE Model's optimal solution is flat in year eight if the Reserve Bank of Ghana's financial stability is used as a measure of a company's financial health. This is so because it demonstrates the firm's potential to shortly conduct operations profitably. Investors can get a good idea of a business' financial health by looking at its ratios. The macroeconomic solution serves as an example of how large-scale market systems function. The monetary order is the topic at hand. The SDE Macroeconomics Model investigates a broad range of macroeconomic variables, including but not limited to inflation, price levels, economic growth, national income, GDP, and fluctuations in the unemployment rate. When waiting until the second year to determine the optimal value level, more variation might be seen in the data.

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