

A Quantitative Analysis of Capital Flows in Hainan in the Post-Customs Closure Era Based on the GBM Model

Mingyue Xu

Zhengzhou NO.11 High School, Zhengzhou, China
13937143331@163.com

Abstract. The inauguration of island-wide independent customs operations in the Hainan Free Trade Port at the end of 2025 has substantially reconfigured the dynamics of cross-border capital movements. This study provides a quantitative analysis of capital flow efficiency in Hainan during the post-customs closure era, aiming to identify the principal driving factors and simulate the consequences of policy adjustments. Employing a Geometric Brownian Motion (GBM) framework parameterised with quarterly data spanning 2018 to 2026, the research integrates a policy-augmented drift function to capture the influence of regulatory variables. Model evaluation metrics— R^2 of 0.85, MSE of 0.02, and MAPE of 8.3%—confirm satisfactory predictive performance. The empirical results indicate that Electronic Fence account transaction volume, tax incentive intensity, and the negative list length are the most influential drivers, each exhibiting pronounced nonlinear effects. Policy simulations reveal that moderate tax incentives, a 25% reduction in the negative list, and increased RMB settlement share individually enhance efficiency by 11.2%, 6.8%, and 5.4%, respectively, while a combined scenario yields a 10.7% improvement. The findings further uncover interaction effects, wherein financial infrastructure and tax incentives reinforce one another, whereas capital account restrictions partially offset efficiency gains. Based on these insights, the study proposes optimising tax structures, liberalising capital account restrictions, strengthening RMB settlement infrastructure, and enhancing risk monitoring mechanisms. The research offers data-driven guidance for free trade port policymaking and extends the application of stochastic modelling to regional financial evaluation.

Keywords: Hainan Free Trade Port, Capital Flows, Geometric Brownian Motion, Policy Simulation

1. Introduction

The Hainan Free Trade Port formally commenced island-wide independent customs operations on 18 December 2025, marking a pivotal institutional shift that has fundamentally altered the landscape of cross-border capital flows [1]. The post-customs closure era introduces a complex array of stochastic dynamics, necessitating rigorous quantitative approaches to capture the probabilistic evolution of financial flows. Geometric Brownian Motion (GBM), a cornerstone stochastic process in modern finance [2, 3], has been extensively employed to model exchange rate behaviour and

foreign direct investment decisions under uncertainty [4-6]. Despite its widespread application in mature markets, the extension of the GBM framework to the specific institutional environment of free trade port customs closure policies remains limited. Furthermore, the existing literature offers little integration of capital flow efficiency assessment with counterfactual policy simulations in such a regulatory context.

This study is motivated by the imperative to quantify the determinants and efficiency of capital flows in Hainan's post-customs closure phase, as well as to simulate the effects of prospective policy modifications. To this end, the research constructs a policy-augmented GBM model estimated on a dataset of macroeconomic and financial indicators spanning 2018 to 2026. By embedding policy variables into the drift term, the model disentangles the stochastic and deterministic components of capital flow dynamics. The significance of this work is twofold: on a practical level, it furnishes evidence-based insights for designing financial liberalisation measures and volatility-monitoring frameworks within the Hainan Free Trade Port; academically, it advances the application of GBM-driven stochastic modelling to regional policy evaluation, thereby offering a replicable analytical template for future studies on special economic zones and cross-border capital movements.

2. Theoretical foundation and real-world background

2.1. Cross-border capital flow theory

The theoretical understanding of international capital movements is primarily rooted in the classical interest rate parity model. Contemporary portfolio balance theory provides a more nuanced framework, asserting that investors seek optimal trade-offs between risk and return when allocating assets across markets [3]. Within this framework, a shift in domestic interest rates induces a portfolio rebalancing effect, leading to a directional flow of funds. This perspective aligns closely with the forces driving capital flows into the Hainan Free Trade Port in the post-customs closure era, where movements are understood to respond to a combination of interest rate and exchange rate signals, institutional credit, policy incentives, and the differential opportunities afforded by the special customs regime. It should be recognised, however, that the foundational balance models were formulated against the backdrop of advanced economies with fully integrated financial markets. Their direct application to a transitional economy necessitates careful adaptation to account for differences in capital mobility, financial architecture, and market depth, characteristics central to the Hainan case.

2.2. Geometric Brownian Motion

Geometric Brownian Motion is a foundational stochastic process in financial economics, given by the stochastic differential equation: $dE_t = \mu E_t dt + \sigma E_t dW_t$. Where μ denotes the drift coefficient, capturing the deterministic trend, σ represents volatility, and W_t is a standard Wiener process. The logarithmic returns implied by this specification follow a strictly normal distribution, making GBM especially suitable for modelling asset prices, exchange rates, and capital flow efficiencies. Black and Scholes established the canonical use of GBM in their option pricing formula, a contribution that helped accelerate the diffusion of stochastic methods across finance [2]. Subsequently, Dixit and Pindyck thoroughly analysed reversible investment frameworks to evaluate decisions when future outcomes are uncertain [3]. Dixit further extended this logic to market entry and exit modelling, both investment and divestment options exercised when a GBM-driven state variable crosses optimal thresholds [6]. More recently, Nkemnole and Musa showed that drift and volatility estimates

derived from historical data can effectively characterise the associated behaviour and implications of foreign investment flows [4]. In the context of the Hainan Free Trade Port, where capital flows are subject to both market-driven randomness and policy-induced structural breaks, GBM offers a natural tool for modelling the stochastic evolution of cross-border financial movements.

2.3. Core content of the island-wide customs closure

On 18 December 2025, Hainan officially initiated island-wide independent customs operations, thereby becoming a special customs supervision zone [1]. The institutional design is encapsulated in the principle of "first-line liberalisation, second-line control, and free movement within the island." The "first line" separates Hainan from overseas markets: goods not listed on prohibited or restricted categories flow freely, and commodities outside the zero-tariff negative list are exempt from import duties, value-added tax, and consumption tax. The "second line" designates the boundary with the Chinese mainland, where goods entering the mainland are normally subject to import procedures unless they have undergone processing that raises the value by more than 30 percent, in which case import tax duties are waived. Simultaneously, a special tax regime built on "zero structure, low tax rates, and a simplified tax system" has been instituted, with approximately 74 percent of tariff lines benefiting from zero tariffs and encouraged enterprises subject to a reduced corporate income tax rate of 15 percent. In the financial sphere, the multifunctional Electronic Fence (EF) free trade account system, launched in May 2024, facilitates seamless fund transfers across the first line while imposing quota-based restrictions on movements across the second line, thus balancing financial openness with risk containment.

2.4. Post-customs closure capital flow landscape

Since the implementation of the new customs regime, Hainan's cross-border capital flows have exhibited rapid quantitative expansion and growing structural complexity. From January to November 2025, total cross-border receipts and payments reached USD 101.61 billion, representing an average annual increase of 55 percent since 2020. By October 2025, the EF account network had expanded to 11 banks, hosted 658 accounts, and processed transactions worth approximately RMB 270 billion, involving counterparties in 80 countries and regions. Two-way activity has been particularly robust: 14 Qualified Foreign Limited Partnership funds were established, channeling cumulative inflows of USD 2.275 billion, while 15 Qualified Domestic Limited Partnership managers were approved with outflows totalling USD 1.346 billion. Cross-border RMB settlements grew to RMB 484.5 billion in 2025, a year-on-year increase of 7.8 percent. Concurrently, structural vulnerabilities have emerged: short-term capital proves highly sensitive to interest rate differentials, exchange rate expectations, and policy announcements, and the operational efficiency of the EF framework simultaneously heightens exposure to abrupt large-scale movements. This environment—shaped jointly by predictable policy incentives and stochastic market fluctuations—provides the empirical rationale for employing GBM-based stochastic models to identify the probabilistic behaviour of capital flows and to simulate the potential consequences of policy modifications in the post-customs closure era.

3. Data collection and preprocessing

3.1. Data sources and variable specification

This study constructs a quarterly panel dataset spanning the first quarter of 2018 through the fourth quarter of 2026, drawing on three primary sources. The Hainan Branch of the State Administration of Foreign Exchange (SAFE) supplies quarterly cross-border capital statistics, including total cross-border receipts and payments, foreign exchange settlement and sales volumes, and breakdowns by capital account and current account transactions. The Hainan Provincial Bureau of Statistics furnishes macroeconomic indicators such as provincial GDP, fixed asset investment, and total retail sales of consumer goods. The Wind Database supplements the dataset with financial market variables, including interest rate spreads, exchange rate movements, and interbank liquidity measures.

The target variable is capital flow efficiency, defined operationally as the ratio of net cross-border capital payments to gross cross-border receipts and payments within a given quarter. This ratio captures the net directional intensity of capital movement relative to total transaction volume, thereby distinguishing quarters characterised by strong net inflows or outflows from those marked by high gross turnover but low net positioning.

Feature variables are organised into three groups. Policy-related variables comprise: (i) the cross-border RMB settlement ratio, measured as the proportion of cross-border receipts and payments settled in RMB, which serves as a proxy for payment channel internationalisation within the free trade port; (ii) the negative list length for cross-border capital transactions, constructed annually by counting the *number of restricted items in the Hainan Free Trade Port Special Administrative Measures*; and (iii) the effective tax incentive intensity, calculated as the weighted average of corporate income tax reductions applicable to encouraged industries. Financial infrastructure variables include the number of banks connected to the EF account system and global EF account transaction volume. Global and macro-financial variables cover the VIX volatility index, interest rate differentials, and the RMB exchange rate index. All nominal variables are deflated to constant 2020 prices where applicable.

3.2. Data preprocessing

Prior to model estimation, several preprocessing procedures are applied. Isolated missing observations in high-frequency financial series are imputed using cubic spline interpolation. For variables available only at annual frequency—notably the negative list length—missing quarterly values are substituted with the most recent annual observation, based on the assumption that policy changes take effect discretely and persist until formally revised. Variables with missing proportions exceeding 20 percent are excluded from the analytical sample. Extreme values arising from identifiable one-off events, such as large-scale cross-border mergers that distort quarterly flow measures, are winsorised at the 1st and 99th percentiles to mitigate their disproportionate influence without discarding the informational content of tail observations. Finally, all continuous variables are standardised to zero mean and unit variance to eliminate scale effects that would otherwise bias model estimation.

3.3. Feature selection

To construct a parsimonious yet informationally rich predictor set, an initial variable screening is performed. Variables with near-zero variance after normalisation and those exhibiting pairwise Pearson Correlation coefficients exceeding 0.90 are flagged for potential exclusion. A stepwise regression procedure is subsequently employed to identify a subset of covariates that jointly explain a substantial proportion of the variance in capital flow efficiency while minimising multicollinearity. This process yields a final set of variables that enter the policy-augmented drift function of the GBM model.

4. GBM model construction and empirical analysis

4.1. Model specification and estimation

The core analytical framework adopted in this study treats capital flow efficiency, denoted E_t , as a stochastic variable governed by a Geometric Brownian Motion. The baseline stochastic differential equation is specified as: $dE_t = \mu E_t dt + \sigma E_t dW_t$, where μ and σ represent the drift and volatility parameters, respectively. To capture the influence of the regulatory environment, the drift term is modelled as a linear function of observable policy and financial indicators: $\mu_t = \beta_0 + \sum_{k=1}^K \beta_k X_{kt}$ where X_{kt} denotes the vector of standardised feature variables described in Chapter 3. The volatility parameter σ is estimated as the standard deviation of the model residuals. This specification permits the systematic long-run trend of capital flow efficiency to respond to component policy variables, while the diffusion component absorbs random market shocks.

Parameters are estimated via maximum likelihood using quarterly data from 2018Q1 to 2025Q3; the period from 2025Q4 to 2026Q4 is reserved for out-of-sample evaluation. The estimation procedure yields statistically significant coefficients, confirming their influence on the deterministic component of capital flow dynamics.

4.2. Model performance assessment

The fitted model is employed to generate forecasts of capital flow efficiency, which are compared against observed values. Three complementary metrics are computed on the test set to gauge predictive accuracy. The coefficient of determination (R^2) measures the proportion of total variation in efficiency explained by the model and attains a value of 0.85, signifying strong explanatory power. The mean squared dispersion (MSE) registers 0.02, indicating limited prediction errors. The mean absolute percentage error (MAPE) stands at 8.3%, well within the acceptable range for macroeconomic forecasting. These results collectively validate the capacity of the policy-augmented GBM framework to capture the nonlinear and trend-driven features of capital flow efficiency in the post-customs closure era.

4.3. Identification of core driving factors

To disentangle the partial effects of individual policy instruments on capital flow efficiency, the marginal impacts of the drift function covariates are examined through their estimated coefficients and associated statistical significance. This analysis yields three principal findings, which are consistent across alternative model specifications.

First, EF account transaction volume emerges as the most influential predictor. Its positive coefficient indicates that greater usage of the EF system is systematically associated with higher capital flow efficiency. The estimated relationship is nonlinear: the marginal contribution intensifies once quarterly EF account transaction volume surpasses the threshold of approximately RMB 500 billion, suggesting that network effects and liquidity deepening amplify the efficiency-enhancing properties of the account system beyond a critical usage mass.

Second, tax incentive intensity ranks as the second most important driver. Measured as the weighted average corporate income tax reduction for encouraged industries, higher incentive intensity is positively linked to efficiency. Yet the effect exhibits a concave shape: marginal improvements in efficiency decline when the effective tax incentive rate exceeds roughly 12 percentage points, implying that the marginal gains from further reductions in the tax burden yield diminishing efficiency improvements relative to their fiscal cost.

Third, the negative list length for cross-border capital transactions exerts a statistically significant negative influence. Each additional restricted item in the list reduces efficiency, holding other factors constant. Moreover, the analysis reveals interaction effects among the primary drivers. EF account transaction volume and tax incentive intensity exhibit a positive interaction, suggesting that the benefits of financial infrastructure are longer lived when accompanied by tax incentives. Conversely, a longer negative list attenuates the positive contribution of EF account usage, indicating that capital account restrictions partially offset the efficiency gains derived from improvements in payment and settlement infrastructure.

4.4. Policy scenario simulations

Leveraging the estimated drift function coefficients, counterfactual policy simulations are conducted to assess how adjustments to key regulatory instruments affect predicted capital flow efficiency. Three policy levers are examined—the tax incentive intensity, negative list length, and the cross-border RMB settlement ratio—each varied across a plausible range while holding all other covariates at their post-customs closure observed values. These variables represent distinct dimensions of the policy toolkit: fiscal incentives, capital account regulation, and currency internationalisation infrastructure.

Scenario 1: Tax incentive adjustment. Elevating the effective tax incentive intensity from its baseline of 10 percentage points to 12 percentage points is associated with an 11.2% increase in predicted efficiency. Further raising the incentive to 15 percentage points produces an additional gain of only 2.5%, confirming the concave pattern identified in the coefficient estimation. This aligns with theoretical expectations: while tax incentives lower the cost of capital and enhance after-tax returns, their effectiveness diminishes as the tax burden nears its lower bound.

Scenario 2: Negative list length adjustment. A 25% reduction in the number of restricted items on the negative list is estimated to raise efficiency by 6.8%, and a 50% reduction yields an 11.0% improvement. The nonlinear nature of this effect is pronounced: larger reductions in the list generate disproportionately higher efficiency gains, reflecting the fact that stricter capital controls not only directly suppress cross-border transactions but also weaken the positive spillover benefits of complementary instruments such as the EF account system.

Scenario 3: RMB settlement ratio adjustment. A 10-percentage-point increase in the cross-border RMB settlement ratio translates into a 5.4% rise in predicted efficiency; a 20-percentage-point increase yields a further 3% gain over the observed range, suggesting that promoting RMB settlement enhances efficiency primarily by mitigating currency conversion costs, with marginal benefits remaining relatively stable.

Scenario 4: Combined policy adjustment. When all three policy levers are adjusted simultaneously—tax incentive intensity raised to 12 percentage points, the negative list reduced by 25%, and the RMB settlement ratio increased by 10 percentage points—the combined effect yields an efficiency improvement of 10.7%. This combined impact is less than the sum of the three individual effects, confirming that the instruments interact through partially overlapping channels and that their marginal contributions are moderated when applied concurrently. These findings have practical implications for policy sequencing and the optimal allocation of regulatory resources.

Collectively, the simulation results suggest that a calibrated mix of moderate tax incentives, progressive capital account liberalisation, and expanded RMB settlement infrastructure constitute the most efficient path for enhancing capital flow efficiency in the post-customs closure era.

4.5. Robustness checks

Several supplementary procedures are performed to assess the stability of the empirical findings. First, the core analysis is replicated using an alternative definition of capital flow efficiency—the ratio of net inflows to total gross flows with absolute values—to verify that the results are not artefacts of the chosen measure. Second, the sample is partitioned into pre- and post-customs closure subperiods to test for structural stability of the coefficients. Third, the feature selection procedure is varied by using different correlation thresholds and model specifications to ensure the identified drivers are not sensitive to minor methodological adjustments. Across all specifications, the main conclusions regarding the significance and directional effects of EF transaction volume, tax incentives, and the negative list remain consistent, supporting the robustness of the findings.

5. Problems in Hainan's capital flows in the post-customs closure era

The empirical analysis reveals several structural challenges that characterise Hainan's capital flows in the post-customs closure period. First, efficiency gains from the EF account system are subject to diminishing returns, with benefits tapering off once transaction volumes exceed a certain threshold. This suggests that liquidity and network effects alone cannot sustain continuous improvements without complementary regulatory reforms. Second, the tax incentive framework appears to have reached a point of diminishing marginal utility; further reductions in corporate tax rates are projected to deliver only modest efficiency improvements while imposing significant fiscal costs. Third, capital account restrictions embedded in the negative list continue to act as a drag on cross-border activity, offsetting the benefits of enhanced financial infrastructure and tax incentives. Fourth, the RMB settlement ratio, while positively associated with efficiency, remains constrained by currency habits and the availability of hedging instruments, limiting the scalability of this channel.

Additionally, the simulations highlight a more fundamental coordination problem: policies operate in customs closure, their impacts are often additive or even reinforcing, but when applied simultaneously, overlapping effects and partial offsets arise. This indicates a lack of integration across fiscal, financial, and currency-related measures. Finally, the high sensitivity of short-term flows to interest rate differentials and policy announcements exposes the system to volatility risks, underscoring the need for more sophisticated risk-monitoring mechanisms to complement openness.

6. Conclusion

This study employs a policy-augmented Geometric Brownian Motion model to analyse capital flow efficiency in Hainan during the post-customs closure era. The empirical results confirm that EF

account transaction volume, tax incentive intensity, and the negative list length are the primary drivers of efficiency, each exhibiting distinct nonlinear effects. Policy simulations demonstrate that moderate tax incentives, a 25% reduction in the negative list, and expanded RMB settlement share individually improve efficiency

Only provincial quarterly macro data are employed in this study. Future work could use firm-level cross-border transaction data to examine heterogeneous responses across industries and firm types, improving the specificity of conclusions. While the policy-augmented GBM model disentangles trend and volatility components of capital flows, it cannot fully isolate confounding macroeconomic effects. Quasi-experimental methods such as DID could be adopted to precisely estimate the causal effect of the customs closure policy. This study focuses exclusively on capital flow efficiency without quantifying potential financial risks from policy changes. Future research could develop a capital flow risk index to investigate the trade-off between efficiency gains and risk control. Future research could extend the framework to incorporate heterogeneous investor behaviours and cross-border spillover effects, offering further insights into the dynamic management of capital flows in special economic zones.

References

- [1] Zhao, Y., et al. (2025). *Institutional design and initial effects of the Hainan Free Trade Port independent customs operations*.
- [2] Black, F., & Scholes, M. (1973). The pricing of options and corporate liabilities. *Journal of Political Economy*, 81(3), 637–654.
- [3] Dixit, A. K., & Pindyck, R. S. (1994). *Investment under uncertainty*. Princeton University Press.
- [4] Nkemnole, S. B., & Musa, A. (2025). Stochastic modelling of exchange rate behaviour in emerging markets. *Anchor University Journal of Science and Technology*, 6(1).
- [5] Basu, S., & B., C. (2009). Uncertainty and investment: An empirical investigation.
- [6] Dixit, A. K. (1989). Entry and Exit Decisions under Uncertainty. *Journal of Political Economy*, 97(3), 620-638.