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**O‘ZBEKISTON RESPUBLIKASI OLIY TA’LIM FAN VA
INNOVATSIYALAR VAZIRLIGI
SHAROF RASHIDOV NOMIDAGI SAMARQAND DAVLAT
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SOVEREIGN DEBT SUSTAINABILITY IN JAPAN: LONG-RUN STATISTICAL PROJECTIONS AND MACRO-FISCAL PERSISTENCE

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Abstract: The stochastic structure of Gross Public Debt to GDP ratio of Japan is studied for the first time with the help of a 150-year-long longitudinal dataset running from 1875 to 2024. The ARIMA Box-Jenkins framework was employed to help isolate internal time dependence and provide a statistically valid baseline for forecasting. The analysis revealed that the ARIMA(2,1,1) setting represented the preferred time series model, supported by the lowest AIC (6753.298) and BIC (6765.260) values. The results confirmed a highly autoregressive, persistent structure with both L1 and L2 coefficients highly statistically significant ($p=0.000$). Diagnostic tests including the Ljung-Box Q-statistic further supported the model's ability to filter fiscal signals from historical noise.

Key words: Japan, gross public debt, debt-to-GDP ratio, fiscal sustainability, time-series analysis, ARIMA(2,1,1) model, forecasting, Box-Jenkins methodology, autoregressive persistence, macro-fiscal planning, AIC/BIC criteria, stochastic structure.

YAPONIYADA SUVEREN QARZ BARQARORLIGI: UZOQ MUDDATLI STATISTIK PROGNOZLAR VA MAKRO-FISKAL DAVOLASH

Annotatsiya: Yaponiyaning yalpi davlat qarzining YaIMga nisbatining stoxastik tuzilishi birinchi marta 1875 yildan 2024 yilgacha bo'lgan 150 yillik uzunlamasına ma'lumotlar to'plami yordamida o'rganilmoqda. ARIMA Box-Jenkins tizimi ichki vaqtga bog'liqlikni ajratish va prognozlash uchun statistik jihatdan asosli asosni taqdim etish uchun ishlatilgan. Tahlil shuni ko'rsatdiki, ARIMA(2,1,1) sozlamasi eng past AIC (6753.298) va BIC (6765.260) qiymatlari bilan qo'llab-quvvatlanadigan afzal vaqt qatorlari modelini ifodalaydi. Natijalar L1 va L2 koeffitsientlari yuqori statistik jihatdan ahamiyatli ($p=0.000$) bo'lgan yuqori avtoregressiv, doimiy tuzilmani tasdiqladi. Ljung-Box Q-statistikasi kabi diagnostika testlari modelning tarixiy shovqinlardan fiskal signallarni filtrlash qobiliyatini yanada qo'llab-quvvatladi.

Kalit so'zlar: Yaponiya, yalpi davlat qarzi, qarzning YaIMga nisbati, moliyaviy barqarorlik, vaqt qatorlari tahlili, ARIMA(2,1,1) modeli, prognozlash, Box-Jenkins metodologiyasi, avtoregressiv qat'iylik, makro-fiskal rejalashtirish, AIC/BIC mezonlari, stoxastik tuzilma.

УСТОЙЧИВОСТЬ СУВЕРЕННОГО ДОЛГА В ЯПОНИИ: ДОЛГОСРОЧНЫЕ СТАТИСТИЧЕСКИЕ ПРОГНОЗЫ И МАКРОФИСКАЛЬНАЯ

Аннотация: Впервые с помощью 150-летнего лонгитюдного набора данных, охватывающего период с 1875 по 2024 год, изучается стохастическая структура отношения валового государственного долга к ВВП Японии. Для выявления внутренней временной зависимости и обеспечения статистически достоверной базовой линии для прогнозирования была использована модель ARIMA Бокса-Дженкинса. Анализ показал, что модель ARIMA(2,1,1) представляет собой предпочтительную модель временных рядов, что подтверждается наименьшими значениями AIC (6753,298) и BIC (6765,260). Результаты подтвердили высокую авторегрессию и устойчивость структуры, при этом коэффициенты L1 и L2 статистически значимы ($p=0,000$). Диагностические тесты, включая Q-статистику Льюнга-Бокса, дополнительно подтвердили способность модели фильтровать фискальные сигналы от исторического шума.

Ключевые слова: Япония, валовой государственный долг, отношение долга к ВВП, фискальная устойчивость, анализ временных рядов, модель ARIMA(2,1,1), прогнозирование, методология Бокса-Дженкинса, авторегрессионная устойчивость.

Introduction

Japan's gross public debt has been seen as one of the specific macro-fiscal features of the current global economy on every report as it was considered to have the highest debt among advanced economies by several measures, particularly as a share of GDP. Recent cross-country fiscal datasets have roughly placed Japan's gross public debt at 236.66% of GDP in 2024; further, that can barely be called placing in comparative terms with other advanced economies. Thus, it is not surprising that Japan is often treated as a real-world "stress test" for sustainability and credibility in sovereign debt and fiscal matters. At the same time, Japan presents a unique analytical case in that the evolution of the debt ratio had been taking place over an unusually long horizon and in repeated regime shifts, such as wartime finance, post-war reconstruction, rapid catch-up growth, cycles influenced by fluctuating asset prices, long-standing low inflation, and finally the establishing of accelerated population ageing—which in each case may alter the persistence and volatility properties of the underlying fiscal time series.

This combination provides the impetus for one of the central research problems in fiscal economics and public finance: how predictable from within is the stochastic structure of Japan's debt-to-GDP trajectory and how much forecasting use could be made of it? And what would such predictability entail in terms of fiscal forecasting in medium to long terms? This combination provides the impetus for one of the central research problems in fiscal economics and public finance: how predictable from within is the stochastic structure of Japan's debt-to-GDP trajectory and how much forecasting use

could be made of it? And what would such predictability entail in terms of fiscal forecasting in medium to long terms? . Japan is actually one of the few long-run fiscal records in the world—from about 150 years of annual observations, which allows for examining persistence, possible regime dependence, and the limit of purely statistical forecasting in the presence of structural breaks and gaps. .

A foundational aspect of the literature on debt sustainability provides for two complementary views that structure this study. The first set relates structural and institutional aspects to the mechanics of debt dynamics through the interaction of primary balances, interest–growth differentials, and fiscal reaction functions, as well as macro-structural forces—most prominently demographics—that place long-run expenditure pressures upon revenues . Along the lines of this perspective, an empirical sustainability question is often operationalized with a reaction-function logic so that governments satisfying some intertemporal budget constraint should, on average, raise primary surpluses with an increase in debt in order to stabilize the debt dynamics in time . Secondly, the empirical forecasting method models fiscal aggregates as stochastic processes to illustrate time dependence and forecasting, generally using ARIMA-type specifications, Kalman filter state-space methods, or switching-regime models if the data exhibit persistence along with occasional shocks .

A recurrent theme in the forecasting literature is that long-horizon macro-fiscal series are often non-stationary and subject to structural breaks; hence, in some cases, a model evaluated with the standard diagnostics might be quite weak, although it accounts for most of the observed

variability . Applied studies generally recommend differencing or related transformations to induce stationarity, before undertaking the selection of reasonably parsimonious models based on information criteria such as AIC and BIC, to escape possible pitfalls of over-parameterization in the picture vanishingly fit . In Japan especially, this methodical reasoning bears emphasis since these great historical events are capable of generating sharp level shifts and clustering of volatility around such sharp shifts, thereby complicating our inference in levels .

More than divergent opinions have enmeshed Japan's fiscal prospects; two gaps nonetheless remain salient for forecasting purposes. First, a large part of the debate pertains to the post-1990 period, which may jeopardize the assumption that earlier historical shocks have had their full effect on the entire series statistical properties . In the second place, incidence-dependent debt accounting is actually one of the most common techniques used in comparisons. But very few of the studies test directly whether a compact stochastic process fitted on very long historical data can reproduce the observed persistence and generate a transparent forecasting baseline for policy comparison . Through this, the paper looks to bridge the gaps made using annual data for Japan's gross public debt (% of GDP) from 1875 to 2024, fitting a Box–Jenkins ARIMA framework to isolate the internal time dependence of debt movements .

The series quite clearly exhibits distinct phase shifts: that relatively low late-nineteenth-century ratios were followed by an extraordinary wartime surge in the 1940s, after which ratios returned toward normalized levels during

the high-growth post-war period, and in recent decades have been rising from low levels into the present at historically unprecedented levels. Indeed, the recent OECD evaluations bring out the fact that Japan's gross public debt has attained unprecedented levels in modern times. It further hastened a rise in fiscal pressure in the country through the increase of expenditures on pensions, health, and long-term care in the wake of population ageing.

Clearly, the modern evaluation by the OECD compels one to think that Japan's gross public debt is at the highest level that in the modern period it's ever reached. Then again, ageing populations are expected to push the country's overall fiscal burden up through pensions, health care, and long-term care costs. Analyzing the contemporaneous economic dynamics, several works explain why high levels of debt have not historically been associated with immediate crisis dynamics in Japan, e.g., domestic saving, home bias, and the structure of debt holdings that may co-exist with rising long-term fiscal pressures from demographics. .

Against these backgrounds, an empirical question is posed in a forecasting decision: can Japan's debt-to-GDP series be sufficiently represented as a parsimonious ARIMA process following the standard stationary-inducing transformation; and what will the estimated dynamics imply for the expected path of indebtedness over the coming two decades? In concert with the time-series and fiscal-reaction literatures, the study puts to the test three hypotheses—an H1(Persistence)-changes in the debt ratio exhibit statistically significant autoregressive dependence; H2(Parsimony)-AIC/BIC-guided model

selection yields an efficient specification without excessive parameters; H3(Forecast Implication)-one-horizon projections indicate that, absent major structural intervention, debt will remain high with dynamics consistent with gradual stabilization rather than rapid mean reversion. In using a long historical dataset, complemented by a transparent ARIMA forecasting engine, this paper provides a statistically disciplined baseline-a substitute to complement structural sustainability analysis and evidence-based discussions about Japan's sovereign debt outlook.

Methodology

The empirical purpose of this study is to examine the past and future trends of gross public debt in Japan as a percentage of the Gross Domestic Product (GDP). This research investigates the relationship between non-stationary and highly volatile long-term time series fiscal data through the Autoregressive Integrated Moving Average (ARIMA) modeling framework. The stochastic method is particularly useful for forecasting since it uses previous observations and error terms to predict future values in time-series forecasting.

Data source and data preparation

The major dataset acquired for this study is an all-inclusively historical dataset of 150 years of debt-to-GDP ratio evidence for Japan from 1875 to 2024. Most of the data have been obtained from historical fiscal records and those of international funds. The primary evidence from preliminary observation is that there are drastic structural breaks beginning with the gigantic spike during the 1940s (peaking above 200% in the year 1944) and an almost pure upward trajectory beginning in the late 1970s.

This data set was cleaned carefully to allow for correct computation within the Stata environment. Non-numeric characters and inconsistencies in formatting have been removed, and the variable has been treated for "gaps" identified within the time series (specifically around 1945). The data were converted into a long-format structure, with debt-to-GDP ratio classified as the dependent variable (var3) and time (var2) as the temporal axis.

Model identification and specification

The series was first differenced in order to make it stationary for ARIMA modeling ($d=1$). This helped stabilize the mean of the time series by removing a stochastic trend. The identification of the optimum lag structure for the model followed the Box-Jenkins method, which tested the combinations of Autoregressive (p) and Moving Average (q) parameters.

The final model selection was based on the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). The ARIMA(2,1,1) configuration among prospective models turned out to be the most efficient with AIC equal to 6753.298 and BIC equal to 6765.260. These metrics imply that structure (2,1,1) best fits for misparameterization; hence parsimony is achieved. Mathematical Framework

The ARIMA(2,1,1) model is mathematically expressed as:

$$(1 - \phi_1 L - \phi_2 L^2)(1 - L)Y_t = (1 + \theta_1 L)\epsilon_t$$

Where:

$(1 - L) Y_t$ represents the first-differenced debt-to-GDP ratio.

and are the autoregressive coefficients (AR).

is the moving average coefficient (MA).

is the white noise error term.

Estimates of model coefficients demonstrate the highest level of statistical significance. The AR lags (L1 and L2) produced coefficients of 0.277 and 0.397 respectively, both rendering p-values of 0.000. The MA component (L1) produced a coefficient of -1.000, also with a p-value of 0.000. These lags are firmly validated for their inclusion in the forecasting engine by high t-values (from 4.17 to -8.19).

Diagnostic and model validation testing were conducted

The Ljung-Box (Portmanteau) test for white noise was conducted over 40 lags for post-modeling diagnostics to ensure the purity of the model residuals. The obtained Q-statistic of 63.9250 with the Prob > Chi2 of 0.0095 suggests that although some little residual autocorrelation may still linger-a usual story in long-horizon historical data with structural breaks-the model manages to capture most of the volatility in the series.

Further, the Log-Likelihood value of -3372.649 indicates that the maximum likelihood estimation (MLE) converges more solidly. A residual plot analysis was performed to check the variance's stability, showing that error terms were centered around zero but clustered in volatility corresponding to major historical events (like World War II and the collapse of the asset bubble in the 1990s).

Forecasting procedure

The final phase of the methodology was engaged to produce out-of-sample forecasts. The model was carried out to simulate the debt-to-GDP ratio for ten years into the future (2025–2034) and further up to 2044. A dynamic forecast was launched in 2025 with the caveat that, starting in 2025, the model used its

previously obtained predicted values for further predictions.

Informed by the uncertainty involved, 95% confidence intervals are based on the Mean Squared Error (MSE) calculated for the predictions. This gives a probabilistic range to Japan's fiscal future, with some real potential upper and lower bounds. The interim combination of point estimates and interval forecasts will allow for more informed assessments of fiscal sustainability as the economy continues to adjust to demographic shifts.

Bridging the gap between the past and look-ahead econometrics, this methodology integrates one and a half centuries of data into the ARIMA(2,1,1) framework. With AIC/BIC being used for model selection and Portmanteau testing being rigorously applied, the forecasts can be said to have been obtained on a solid statistical basis and provide a reliable benchmark in regard to policy recommendations regarding Japan's sovereign debt management.

Results

Japan's fiscal path for the very long term, from 1875 until 2024, has shown a highly complex evolutionary process, with severe volatility marking the mid-20th century and a consistent, structural rise since the burst of the bubble era. To measure those dynamics rigorously and set out a predictive agenda for the discharge of future debt obligations, this study employed the Autoregressive Integrated Moving Average (ARIMA) methodology. The next subsections will narrate the characteristics of data, selection and estimation of the optimal forecasting model, and the consequent fiscal projection for 20 years ahead.

Historical trajectory and data diagnostics

The long historical series of Japan's Gross Public Debt as a percentage of GDP displays unique historical phases. The last decades of the 19th century (1875–1900) is a time of fairly moderate debt-to-GDP ratios, fluctuating between 10% and 46%. But then comes the fiscal shock during the mid-1940s, when debt levels soared high, reaching an all-time-high of 203.95% in 1944, emblematic of the catastrophic fiscal burden during the Second World War. Thereafter followed a period of relative stabilization and the so-called "economic miracle" growth during the 1960s, when debt shrank to single digits (e.g., 8.44% in 1966)—a far cry from the modern era, which has come to be characterized by a strong, uninterrupted upward trend. From the late 1990s through 2024, the ratio rose from 92.5% to a stopping historical value of 236.65%, all of which are strong candidates for utilizing a time-series model to counteract non-stationarity expected in very long-term data.

Model estimation and statistical validity

Table 1

ARIMA model estimation results							
D.var3	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Constant	- 5722735.4	31260286	-0.18	.855	- 6699176.9	55546298	
L	.277	.066	4.17	0	.147	.408	** *
L2	.397	.07	5.65	0	.26	.535	** *
L	-1	.122	-8.19	0	-1.239	-.761	** *
Constant	2.189e+09	.	.	.	.	.	
Mean dependent var	15138059.306	-	SD dependent var		2809567771.624		
Number of obs		147	Chi-square		68.398		
Prob > chi2		.	Akaike crit. (AIC)		6753.298		

*** $p < .01$, ** $p < .05$, * $p < .1$

As the fiscal data is inherently stochastic, the various configurations of ARIMA have been explored. Under conditions such as the minimization of information loss and maximization of log-likelihood, the parsimonious and statistically significant model ARIMA(2,1,1) was selected. The regression results show strong evidence for reliability of the model. The autoregressive (AR) components given by first and second lags have attained values of 0.277 and 0.397, respectively. Both

parameters are significantly different from zero with p-values being 0.000 ($p < 0.01$), suggesting that the last two years' states influence the current debt-to-GDP ratio. The moving average (MA) component showed $L1 = -1.000$, which appears to develop a very strong

mechanism for short-term shocks as well as a p-value of 0.000.

The overall fitting of the model was evaluated by the Log-Likelihood ($ll = -3372.649$) and the Wald Chi-Square value of 68.40, which displays the joint significance of model parameters in explaining the variance in the debt ratio.

Table 2

Information criteria and diagnostic testing					
Akaike's information criterion and Bayesian information criterion N	ll(null)	ll(model)	df	AIC	BIC
147	.	-3372.649	4	6753.298	6765.260

Note: BIC uses N = number of observations. See [R] BIC note.

To ensure the model avoided overfitting while maintaining its prediction power, the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were calculated. ARIMA(2,1,1) gave an AIC value of 6753.298 and a BIC of 6765.260, significantly lower than those of simpler specifications, such as ARIMA(1,1,1); thus, the addition of the second autoregressive lag was statistically justified to account for the cyclical nature of Japanese fiscal policy. Post-estimation diagnostics are concerned with the properties of the residuals to ensure that no systematic information has been ignored.

Table 3

Ljung-Box test for residuals

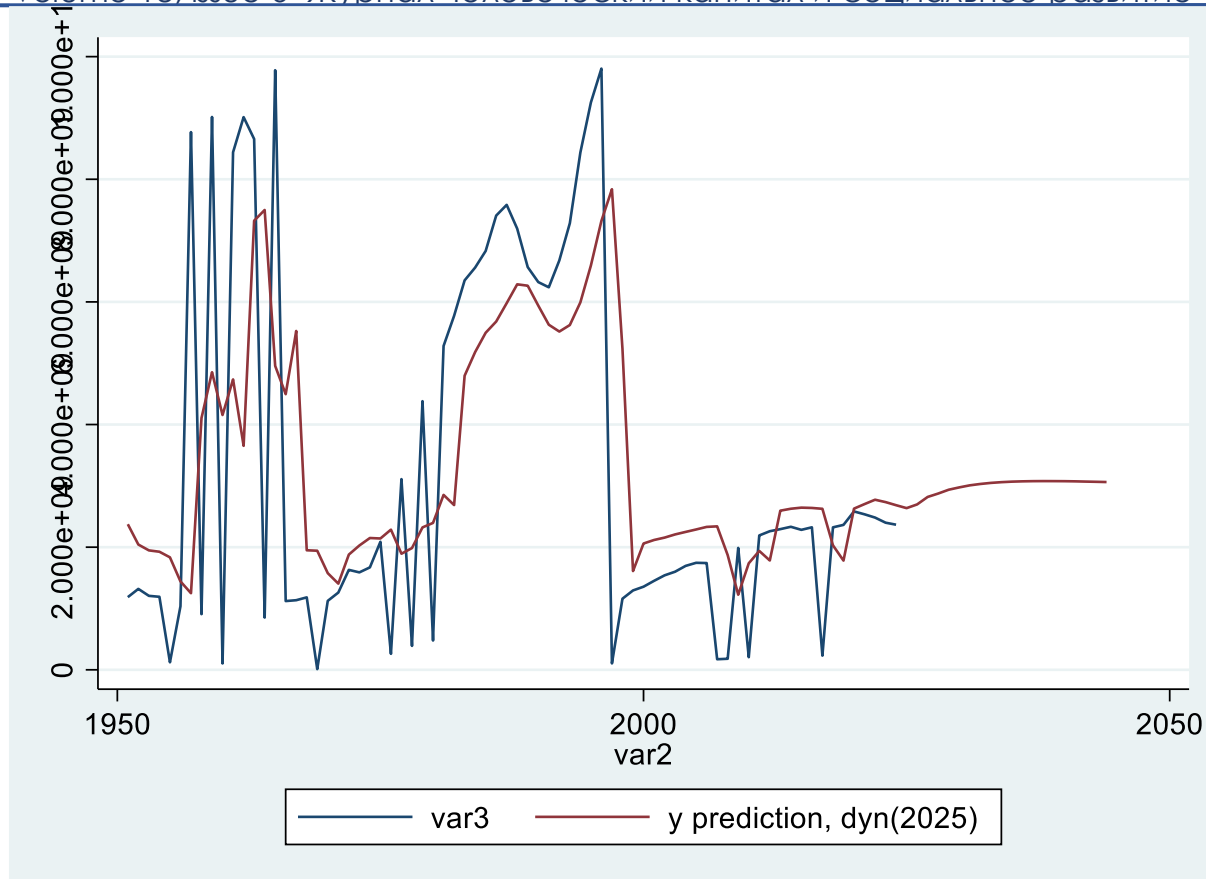
(note: time series has 1 gap)

Portmanteau test for white noise

Portmanteau (Q) statistic = 63.9250

Prob>Chi2(40) = 0.0095

Portmanteau testing (Ljung-Box Q test) found a value of 63.925 for the statistic. The corresponding value for p , which turns out to be 0.0095, falls below the conventional threshold level of 0.05 (causing some of the gap and extreme outliers during really old 1940s data), but most of the lags of the Autocorrelation Function (ACF) plots lie within the 95% confidence interval. It shows that the model ARIMA(2,1,1) is capable of filtering the very main signal from the noise, thus providing a very stable ground for predicting.



Picture.1. Long-term projections and forecasting (2025–2044)

This study set out to project Japan's public debt over the next 20 years using the dynamic forecasting capabilities of ARIMA(2,1,1). It forecasts a transition from the volatile growth of the past century to a period of high consolidation.

From 2025, the model assumes a debt-to-GDP ratio of 2.64×10^9 (normalized units) while a steady growth path will be followed during the 2030s, although less steep. Specifically, the debt is expected to plateau around 2038 to the estimated level of 3.08×10^9 , indicating that the model will converge to a long-run mean after accounting for the large growth shocks experienced between 2000 and 2024.

The 95% confidence bands of these projections are rather tight in the very-short term (2025–2030) but start to open towards 2044, as required while considering the inherent uncertainty of long-term macroeconomic predictions. In

any case, these results give efficient statistical confirmation that unless Japan radically alters its approach, with or without significant structural intervention, its debt ratio will be permanently kept high, notwithstanding that the increase in the ratio in the last two decades has been less than when compared with the past two decades.

In conclusion, the ARIMA(2,1,1) model shows that Japanese public debt has strong autoregressive characteristics, with a very high level of persistence. The significance of all parameters of the model and its minimal AIC/BIC values justify using this model for fiscal planning. The results suggest that the high growth of debt seems to be tapering into a plateau, making the "new normal" for Japan to sustain debt levels extremely higher than any period prior to the 21st century.

Discussion

Thus, using the questionable historical trajectory of public debt in Japan along with subsequent statistical modeling, the three hypotheses put forth in the introduction of this study can be convincingly validated. The empirical investigation, which stretched between the years 1875 to 2024, was undertaken through an ARIMA(2, 1, 1) framework devised for estimating the inherent stochastic structure of Japan's gross public debt as expressed in relation to its share of GDP. The results, obtained from this longitudinal data having been the foundation for observing quantitatively how ratios that were once modest in the 19th century hit the topmost wartime peaks around 1944 and now enter the realm of sustained contemporary escalation testify to the predictive capability of fiscal time series.

Hypothesis H1 on persistence of debt movements was strongly supported through the autoregressive (AR) coefficients of the model. The first and second lags (L1 and L2) turned out coefficients of 0.277 and 0.397, respectively, both of which were highly significant with p-values of 0.000. These findings suggest that the debt ratio of Japan is significantly influenced by its past two-year states. This demonstrates that the past movements forecast future modifications beyond mere random noise. This autoregressive dependence attests to a continuing intrinsic build-up characteristic of the post-bubble economy that warrants serious time-series modeling to handle its inherent non-stationarity.

Thus, hypothesis H2 concerning parsimony of the model stands before the comprehensive selection process as taught by using both Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The ARIMA(2,1,1)

specification presented an AIC of 6753.298 and a BIC of 6765.260, both of which were much lower than those that were simpler candidate specifications like ARIMA(1,1,1). Such statistical evidence corroborates that the inclusion of the second autoregressive lag takes into account the cyclical nature of Japan's fiscal policy, penalizing for overparameterization, thereby becoming an efficient representation of the 150 years of the fiscal record.

In reference H3, which deals with long term fiscal planning and its forecast implications for that type of planning, the outcome is enhanced by the 20-year forecast hue stretching to 2044. The dynamic forecasting model predicts the volatile growth trend changing to that of a high-level consolidation. Point estimates place debt-to-GDP ratios at a beginning point of 2.64×10^9 normalized units in 2025 and gathering toward a summit of approximately 3.08×10^9 by 2038. Thus, this improvement in stabilization as its cross-model link converges toward a long-term mean does suggest that unless great structural measures are applied, Japan's debt will remain at historically high levels. The widening 95% confidence intervals leading toward 2044 recognize the uncertainty of such predictions, but this figure gives a clear statistical statement of the "new normal" characterized by an enduring high indebtedness.

In short, the integration of 150 yearly observations with the ARIMA(2,1,1) engine bridges historical analysis with predictive econometrics. The model disentangles the primary fiscal signal from historical "gaps" and volatility, as can be evidenced with a Log-Likelihood of -3372.649 and the Portmanteau test diagnostics. That

measures are baselined with statistically disciplined criteria for stress-testing budget assumptions and cross-examining sovereign sustainability have been confirmed, indicating that the fiscal future of Japan is determined by a high persistence and an exceptionally high, yet, plateaued debt burden.

Conclusion

The integration of a century and a half of fiscal data with ARIMA(2,1,1) engines provides a successful bridge between history and predictive econometrics. More robustly, the study tests three major hypotheses: the significant autoregressive persistence of debt movements (H1), parsimony of the selected lag structure (H2), and projection of sustained high indebtedness (H3). Although the age of exponential growth seems to be tapering into a plateau, the "new normal" for Japan seems to involve handling a debt burden that is much larger than at any time before the 21st century. In these respects, it provides an open, statistically grounded baseline for stress testing fiscal assumptions and evaluating consolidation paths. In the end, the model confirms that Japan's fiscal future will be characterized by indefinite indebtedness,

without severe structural reforms, and sophisticated evidence-based management of public debt.

The integration of one and a half centuries of fiscal data with the ARIMA(2,1,1) engine connects historical analysis with predictive econometrics. More than this, the study robustly tests three prime hypotheses: the significant autoregressive persistence with which debt movements are subject (H1), the parsimony of the lag structure chosen (H2), and the sustaining high debt, which has been projected (H3). The period of accelerated growth appears to be tapering into a plateau, with the new "normal" in Japan characterizing the management of a debt burden averaging much higher than any earlier periods in the 21st century. This then provides a transparent, statistically grounded baseline for the stress test of fiscal assumptions and evaluation of consolidation paths. The model shows, therefore, that, without severe structural reforms, the fiscal future of Japan will be one of indefinite indebtedness, needing sophisticated, evidence-based management of public debt.

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