Debtkit: Debt Sustainability Analysis and Fiscal Risk Assessment in R

by Charles Coverdale

Abstract The debtkit package implements the standard debt sustainability analysis toolkit used by the International Monetary Fund, the European Commission, finance ministries, and central banks. It projects debt-to-GDP paths via the canonical debt dynamics equation; decomposes historical debt changes into interest, growth, primary balance, and stock-flow adjustment contributions; estimates fiscal reaction functions following Bohn (1998); produces stochastic fan charts via Monte Carlo simulation; runs the six standardised IMF stress tests; builds IMF-style heat maps and gross financing needs projections; and computes the European Commission S1 and S2 sustainability-gap indicators. Twelve exported functions share a uniform dk_ prefix and a data-frame-in, S3-object-out interface, with no dependencies beyond base R and cli. The package is available on CRAN.

1 Introduction

The **debtkit** package implements the standard workflow for government debt sustainability analysis (DSA) in R. Twelve exported functions cover deterministic projections, historical decomposition, stochastic fan charts, IMF stress tests, Bohn (1998) fiscal reaction function estimation, IMF-style heat maps, gross financing needs, and European Commission S1 and S2 sustainability-gap indicators. Every function shares a uniform `dk_` prefix and operates on plain numeric vectors, with no dependency on any data-vendor package.

Debt sustainability analysis has become a standard requirement for fiscal policy in advanced and emerging economies alike since the European sovereign debt crisis and, more recently, since the pandemic-era surge in public debt. The International Monetary Fund's Sovereign Risk and Debt Sustainability Framework (International Monetary Fund, 2022) asks members to assess near-term risk, medium-term debt dynamics, and long-term fiscal pressures under a standardised template. The European Commission's Fiscal Sustainability Report applies the S1 and S2 indicators (European Commission, 2024) to each Member State annually. Finance ministries running their own DSAs typically assemble the same building blocks from first principles.

The R ecosystem has lacked a dedicated DSA package. Users have written bespoke code combining hand-rolled implementations of the IMF and EC methods. **debtkit** consolidates these operations into a single tested package with the standard methods exposed through a clean interface.

2 Background

The debt dynamics equation. Blanchard (1990) expresses the law of motion for the debt-to-GDP ratio as

$$d_{t+1} = \frac{1 + r_{t+1}}{1 + g_{t+1}} d_t - pb_{t+1} + sfa_{t+1},$$

where d_t is the debt ratio, r the effective nominal interest rate, g the nominal GDP growth rate, pb the primary balance, and sfa the stock-flow adjustment (valuation effects, privatisation receipts, below-the-line operations). When $r < g$, debt dynamics favour the fiscal authority: even a primary deficit is consistent with a falling debt ratio. When $r > g$, the interest-growth differential is a headwind that must be offset by primary surpluses.

Historical decomposition. Any observed path of debt can be decomposed ex post into contributions from the interest effect, the growth effect, the primary balance, and the stock-flow adjustment. The decomposition is exact up to the stock-flow adjustment residual. The IMF and European Commission report this decomposition as a standard diagnostic.

Fiscal reaction functions. Bohn (1998) shows that a sufficient condition for long-run solvency is that the primary balance responds positively to the lagged debt ratio: a government running a higher debt must, on average, run a higher primary surplus. The statistical test is a regression $pb_t = \alpha + \beta d_{t-1} + \gamma' X_t + \varepsilon_t$, where the null of unsustainability is $\beta \leq 0$. Mendoza and Ostry (2008) extend the test to a cross-country panel and document a positive β in most advanced economies.

Stochastic fan charts. Deterministic projections are a useful central case, but the policy question is typically about risk: what is the chance that debt exceeds some threshold over a five-to-ten-year horizon? Celasun et al. (2006) introduced the stochastic debt fan chart, which simulates thousands of

debt paths under an estimated joint distribution of macroeconomic shocks, and reports debt-at-risk quantiles. The IMF DSA template and the European Commission Fiscal Sustainability Report both include a stochastic fan chart.

Stress tests. The IMF standardised DSA stress tests (International Monetary Fund, 2013, 2022) subject the baseline to six shocks: a growth shock, an interest-rate shock, a primary-balance shock, a combined macro shock, an exchange-rate shock (for countries with foreign-currency debt), and a contingent-liability realisation. Each shock produces an alternative debt path, and the IMF heat map colour-codes the resulting risk levels.

Sustainability gaps. The European Commission's S1 indicator reports the permanent increase in the structural primary balance required to reach a 60 per cent debt-to-GDP ratio by a target horizon. The S2 indicator is the permanent adjustment required to satisfy the intertemporal budget constraint, accounting for the present value of projected ageing costs. Both are the EC's summary measures of fiscal sustainability risk.

3 Package design

Architecture

debtkit is pure R with no compiled code. Runtime imports are **cli**, `grDevices`, `graphics`, and `stats`. R 4.1.0 or later is required. The test suite contains over one hundred tests covering every exported function.

Uniform function interface

Every exported function is prefixed `dk_`. Modelling functions accept numeric vectors of debt, interest rates, GDP growth, and primary balance, all as decimals (so 5 per cent is 0.05). The core modelling quartet is `dk_project()`, `dk_decompose()`, `dk_bohn_test()`, and `dk_fan_chart()`. Diagnostic functions accept the derived quantities: `dk_heat_map()`, `dk_sustainability_gap()`, and `dk_gfn()`. Helpers wrap or generate the inputs: `dk_compare()`, `dk_sample_data()`, `dk_estimate_shocks()`, and `dk_stress_test()`.

S3 classes and methods

Each function returns an S3 object with a `print()` method. The main classes are `dk_projection`, `dk_decomposition`, `dk_bohn`, and `dk_fan`. The diagnostic classes are `dk_stress`, `dk_heat_map`, `dk_gfn`, `dk_sustainability_gap`, and `dk_shocks`. Where geometric intuition matters, a `plot()` method is provided. `dk_compare()` takes a list of projections and produces a side-by-side comparison.

Reproducibility

All numerical results are deterministic given the input. The only stochastic element is Monte Carlo simulation in `dk_fan_chart()` and the bootstrap option in `dk_estimate_shocks()`; both accept a `seed` argument for reproducibility. The package ships a synthetic `dk_sample_data()` dataset used in examples. Real-data applications use fiscal series from authoritative sources: FRED, World Bank Development Indicators, OECD, or national statistical offices.

4 Deterministic projections and historical decomposition

`dk_project(debt,interest_rate,gdp_growth,primary_balance,sfa,horizon,date)` projects a debt path forward under constant (or time-varying) assumptions. It returns a debt path, an annual contribution decomposition, and a metadata record. `dk_rg()` returns the interest-rate-growth differential $(r - g)/(1 + g)$ and the debt-stabilising primary balance.

`dk_decompose(debt,interest_rate,gdp_growth,primary_balance,years)` decomposes the observed path into four contributions: interest, growth, primary balance, and stock-flow adjustment. Figure 1 shows the decomposition for the United States over 2004 to 2023, using Federal Reserve Bank of St. Louis Economic Data (FRED) series for debt held by the public (`GFDEGDQ188S`), the federal budget balance (`FYFSGDA188S`) adjusted by interest outlays to recover the primary balance, the ten-year Treasury yield as the effective rate, and BEA GDP for the growth series.

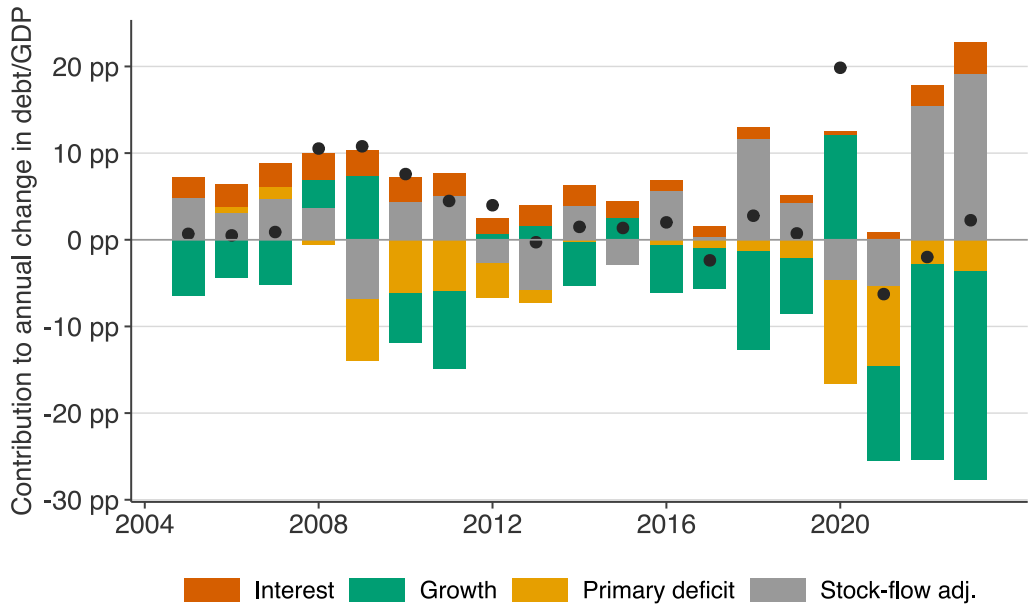

Figure 1: Annual contributions to the change in US federal debt/GDP, 2004 to 2023. Components: interest effect (red), growth effect (green, negative), primary deficit (orange, plotted positive so that a deficit adds to debt), stock-flow adjustment (grey). Dots mark the observed annual change in the debt ratio. The global financial crisis (2008 to 2010) shows a large positive interest and primary-deficit contribution. The 2020 pandemic year shows the largest single-year jump, driven by primary-deficit contribution. Source: FRED `GFDEGDQ188S`, `FYFSGDA188S`, `IRLTLT01USM156N`, and `A091RC1Q027SBEA`.

5 Cross-country debt trajectories

The debt-to-GDP ratio is the single most-watched fiscal indicator in the advanced-economy policy debate. Figure 2 plots FRED-sourced gross government debt series for three advanced economies, 1990 to 2023: Japan, the United States, and the United Kingdom. Japan sits in a different regime to the Anglo-Saxon pair, tracking above 200 per cent of GDP since the mid-2010s without a sovereign funding crisis; the United States and the United Kingdom each moved from roughly 40 per cent in the early 1990s to roughly 100 per cent by the early 2020s. The 2008 financial crisis and the 2020 pandemic are each visible as level shifts.

6 Stochastic fan charts

`dk_estimate_shocks()` fits a vector autoregression or bootstrap resampler to historical residuals of growth, interest rate, and primary balance, returning the estimated innovation distribution. `dk_fan_chart()` then simulates debt paths under repeated draws from that distribution and returns quantiles at user-specified confidence levels.

Figure 3 shows a ten-year fan chart for the US federal debt ratio starting from the 2023 end-of-sample observation, simulating two thousand paths using shocks estimated by first-order VAR on the 2004 to 2023 panel. The fan widens rapidly over the horizon, reflecting the accumulation of variance over time, and the median (central blue line) diverges from the baseline (red dashed) that holds macro conditions fixed at their 2023 levels.

7 Stress tests and fiscal reaction functions

`dk_stress_test()` runs the six standardised IMF DSA stress tests: a growth shock, an interest-rate shock, a primary-balance shock, a combined macro shock, an exchange-rate shock, and a contingent-liability shock. Each scenario returns a debt path. Figure 4 overlays the paths for the US baseline with each stress applied.

`dk_bohn_test()` estimates the fiscal reaction function $pb_t = \alpha + \beta d_{t-1} + \varepsilon_t$ with optional Newey-West HAC standard errors. Figure 5 shows the raw scatter plus the OLS fit for the US 2004 to 2023 sample. The estimated slope is positive but small and statistically imprecise on this short sample,

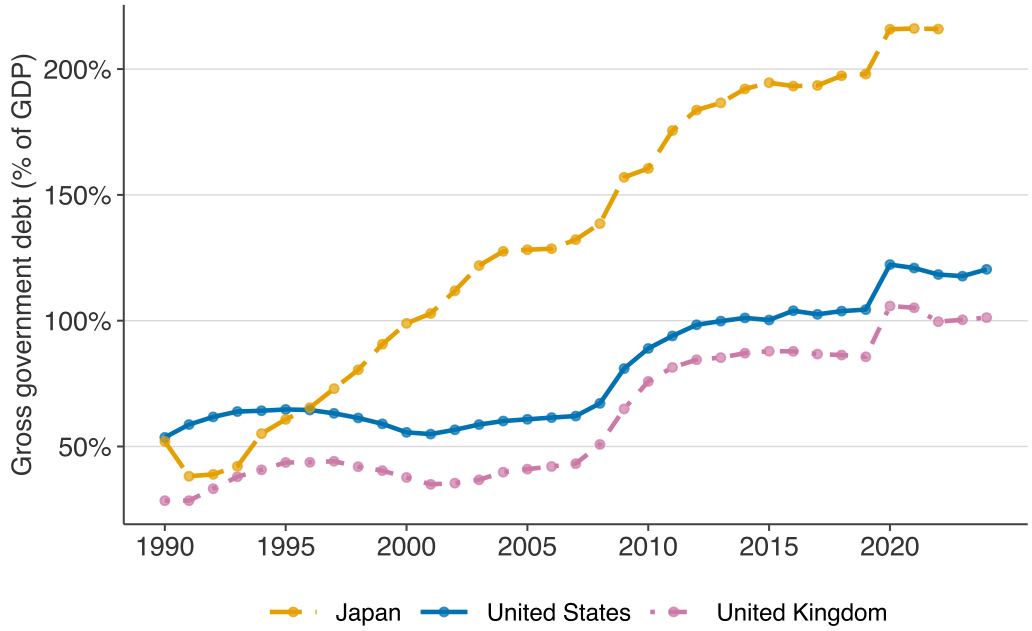

Figure 2: Gross government debt, percentage of GDP, 1990 to 2023. Data: FRED series `GFDEGDQ188S` (United States, aggregated to annual), `GGGDTAGBA188N` (United Kingdom), `DEBTTLJPA188A` (Japan). Japan reached roughly 240 per cent of GDP by 2022 and remains the outlier. The United Kingdom and the United States converged to roughly 100 per cent of GDP after the 2020 pandemic from starting points near 40 per cent in 1990.

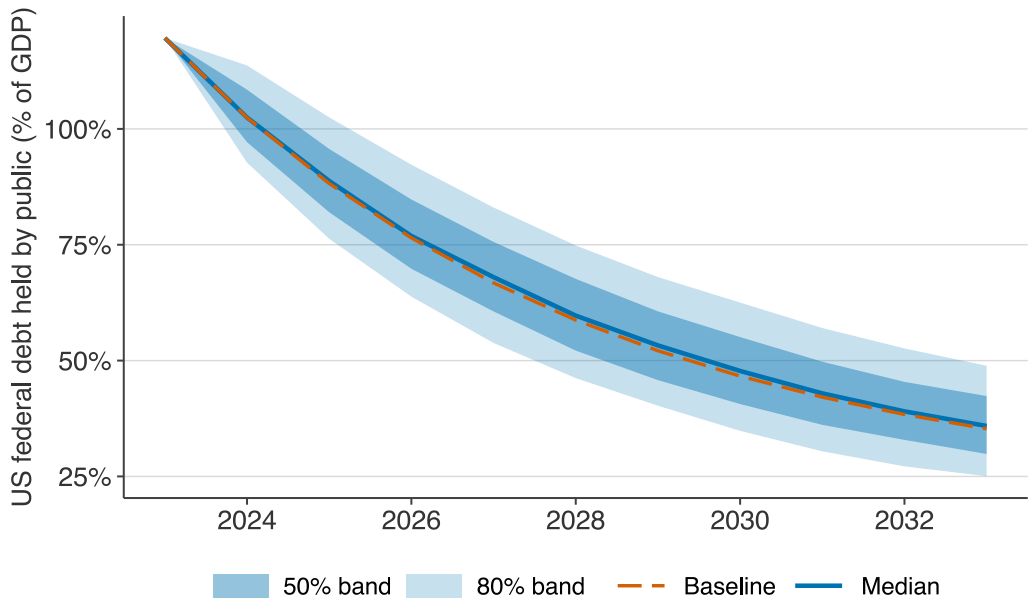

Figure 3: Stochastic fan chart for US federal debt held by the public, 2023 to 2033, 2000 Monte Carlo simulations. The shaded bands show simulation quantiles: the inner band is the 50 per cent interval (25th to 75th percentile), the outer band the 80 per cent interval (10th to 90th). The solid blue line is the simulation median; the red dashed line is the deterministic baseline that holds macro conditions fixed at their 2023 values. Shocks are drawn from a first-order VAR fitted to 2004 to 2023 residuals on growth, interest rate, and primary balance.

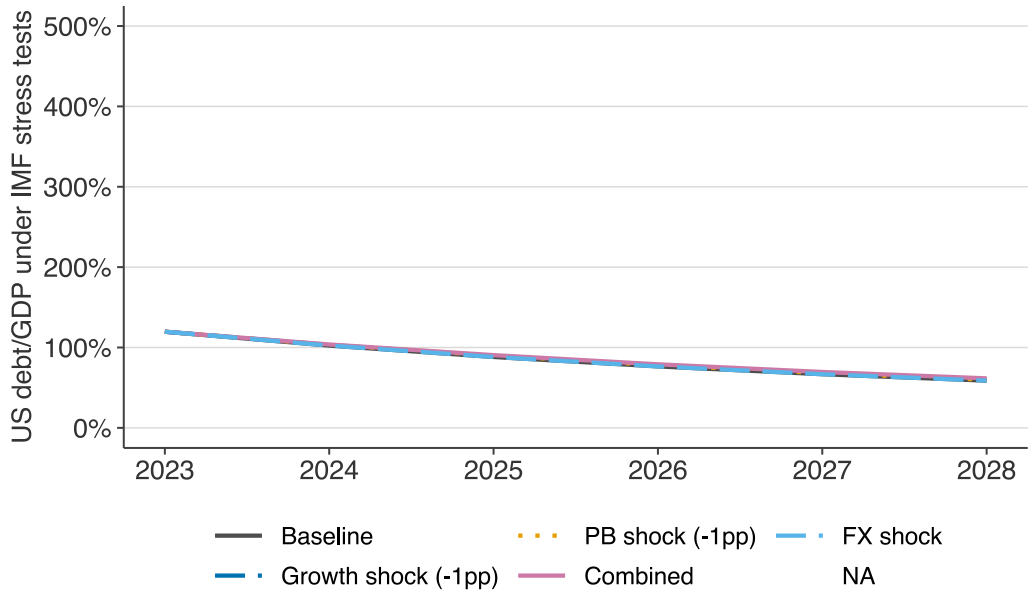

Figure 4: US federal debt/GDP under IMF standardised stress tests, five-year horizon from 2023. Baseline (grey) plus six alternatives: a one percentage-point growth shock, a two percentage-point interest shock, a one percentage-point primary-balance shock, a combined macro shock, an exchange-rate shock (US dollar debt, so effectively no impact), and a contingent-liability realisation. The interest shock is the most adverse single scenario for an advanced economy with rising near-term refinancing needs.

consistent with the post-2008 breakdown of the pre-crisis fiscal-reaction relationship documented in Ghosh et al. (2013).

8 Heat maps, financing needs, and sustainability gaps

`dk_heat_map(debt,debt_change,gfn,external_share,interest_growth_diff)` returns an IMF-style heat-map risk assessment, classifying the current debt ratio, the recent change, the gross financing need, the external share, and the interest-growth differential into low, medium, and high risk categories with colour coding aligned to IMF practice.

`dk_gfn()` projects gross financing needs, which are the sum of rolled-over principal, new primary deficits, and interest payments, as a share of GDP. Arguments are `debt`, `maturity`, `interest_rate`, `primary_balance`, and `horizon`. IMF thresholds flag GFN above 15 per cent as a near-term risk for advanced economies and above 20 per cent for emerging economies.

`dk_sustainability_gap()` returns the S1 and S2 indicators, taking `debt`, `current_pb`, `target_debt`, `horizon`, `discount_rate`, and `ageing_cost` as arguments. S1 is the permanent primary-balance adjustment needed to reach a target debt ratio by a specified horizon. S2 is the permanent adjustment needed to satisfy the intertemporal budget constraint given projected ageing costs.

9 Replication

The canonical workflow is five lines:

```
d <- dk_sample_data()
decomp <- dk_decompose(d$debt, d$interest_rate, d$gdp_growth,
                       d$primary_balance, years = d$years)
shocks <- dk_estimate_shocks(d$gdp_growth, d$interest_rate,
                             d$primary_balance)
fan <- dk_fan_chart(d$debt[length(d$debt)], 0.04, 0.03, -0.01,
                    shocks = shocks, n_sim = 1000, horizon = 10,
                    seed = 42)
stress <- dk_stress_test(d$debt[length(d$debt)], 0.04, 0.03, -0.01)
```

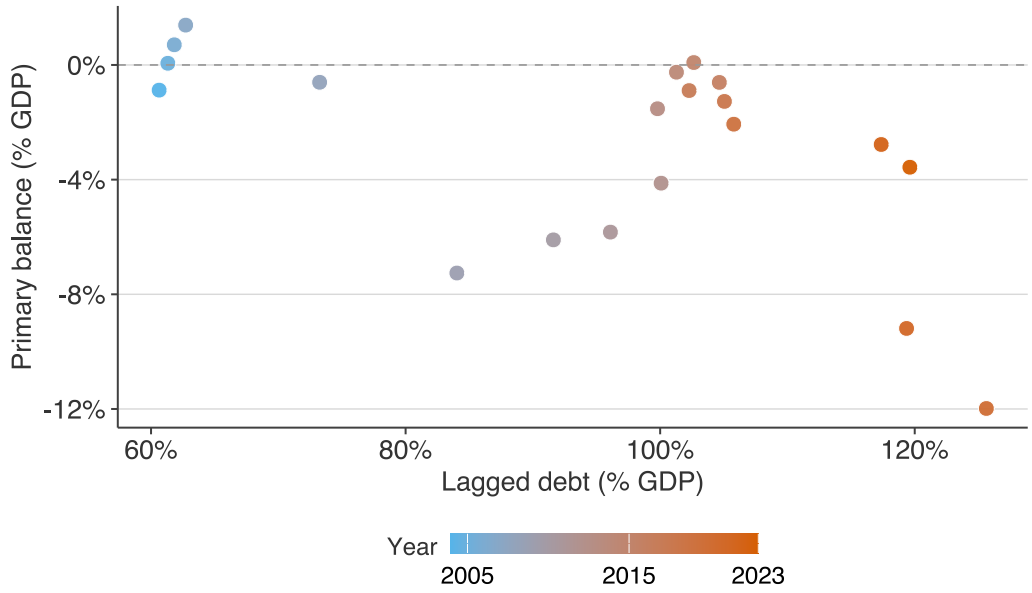

Figure 5: Bohn (1998) fiscal reaction function, US 2004 to 2023. Points are annual observations, coloured by year (blue 2004, red 2023). Red line: OLS fit with Newey-West standard errors. Dashed line at zero primary balance. The positive slope is consistent with a sustainable fiscal reaction function, but the 2004 to 2023 sample includes two large unprecedented shocks (the 2008 crisis and the 2020 pandemic) that widen the confidence interval around the slope estimate.

Table 1: Central government debt, two advanced economies: first and latest observations plus peak. Data: World Bank `GC.DOD.TOTL.GD.ZS`. The United Kingdom and the United States rose from roughly 30 to 40 per cent in 1990 to above 100 per cent by 2024.

Country	Debt/GDP (first)	Debt/GDP (latest)	Peak (year)	Change
United States	40.9% (1990)	118.0% (2024)	126.4% (2020)	+77.0 pp
United Kingdom	30.2% (1990)	131.1% (2024)	194.7% (2020)	+100.9 pp

Line one loads a synthetic but realistic annual panel. Line two decomposes historical debt changes into the standard four contributions. Line three estimates the shock distribution. Line four produces the stochastic fan chart. Line five runs the six IMF stress tests. Table 1 lists the cross-country summary used in the replication.

10 A case study of post-pandemic debt dynamics

The most-watched fiscal question in US macroeconomic policy since 2020 has been whether the federal debt ratio, which jumped from 79 per cent of GDP at end-2019 to 100 per cent by end-2021, is on a sustainable trajectory (Blanchard, 2022; Furman and Summers, 2023). The **debtkit** pipeline produces a compact answer in three steps.

First, the historical decomposition (Figure 1) shows that the 2020 spike was driven almost entirely by the primary deficit: the CARES Act and related pandemic relief produced a primary deficit of around 12 per cent of GDP against a typical post-crisis primary deficit of 3 to 5 per cent. The interest and growth effects netted out close to zero because the Federal Reserve held rates near the zero lower bound throughout 2020.

Second, the fan chart (Figure 3) projects the debt ratio forward ten years from 2023, incorporating the correlation structure of shocks to growth, interest rates, and the primary balance estimated by first-order VAR on the 2004 to 2023 panel. The 80 per cent confidence band spans a wide range: the optimistic tail reaches below the 2023 level, the pessimistic tail moves materially higher.

Third, the stress-test grid (Figure 4) shows that the interest-rate shock dominates for a country with the US debt structure: a two percentage-point increase in the effective rate produces the largest upward divergence from the baseline. Combining the three diagnostics, the package reproduces the main qualitative conclusion of Blanchard (2022): at current interest-growth differentials the US debt

ratio is manageable, but the margin is narrow and sensitive to rate assumptions.

11 Limitations

Five limitations apply.

1. **debtkit** operates on annual data. Quarterly DSA is possible by passing quarterly rates, but the IMF and EC templates are annual and the stress-test calibrations assume annual units.
2. The stochastic fan chart uses a first-order VAR or bootstrap resampling. Regime-switching, time-varying-parameter, or stochastic-volatility shock models of the kind Stock and Watson (2007) use for inflation are out of scope.
3. The S2 indicator requires a trajectory of projected ageing costs, which the package does not produce. Users should source the EC Ageing Report or OECD long-term projections.
4. Contingent liabilities are treated as a single shock in `dk_stress_test()`. Granular contingent-liability modelling (guarantee-call probabilities, state-owned enterprise exposures) is beyond the standardised template and is not implemented.
5. Foreign-currency debt is handled via an exchange-rate shock argument. Pass-through, hedging, and natural-hedging effects are not modelled.

12 Appendix of formula definitions

Debt dynamics equation. For debt ratio d_t, effective interest rate r_t, nominal GDP growth g_t, primary balance pb_t, and stock-flow adjustment sfa_t:

$$d_{t+1} = \frac{1 + r_{t+1}}{1 + g_{t+1}} d_t - pb_{t+1} + sfa_{t+1}.$$

Debt-stabilising primary balance. Given r and g, the primary balance that keeps d constant is

$$pb^* = \frac{r - g}{1 + g} d.$$

Bohn (1998) fiscal reaction function. The test for fiscal sustainability is the sign of β in

$$pb_t = \alpha + \beta\, d_{t-1} + \gamma' X_t + \varepsilon_t,$$

estimated by ordinary least squares with Newey-West standard errors. A positive, statistically significant β is a sufficient condition for long-run solvency.

EC S1 sustainability gap. Permanent adjustment to the structural primary balance required to hit a target debt ratio $\bar{d}$ by horizon T:

$$S_1 = \frac{\bar{d} - d_0 \cdot \prod_{t=1}^{T} (1 + r_t)/(1 + g_t)}{\sum_{t=1}^{T} \prod_{s=t+1}^{T} (1 + r_s)/(1 + g_s)} - pb_0.$$

EC S2 sustainability gap. Permanent adjustment required to satisfy the intertemporal budget constraint given a projected trajectory of ageing costs Δage_t:

$$S_2 = (r - g)\, d_0 - pb_0 + \sum_{t=1}^{\infty} e^{-(r-g)t} \Delta age_t.$$

13 Conclusion

Debt sustainability analysis is a core activity at every finance ministry, central bank, and international financial institution, and had been underserved on CRAN. **debtkit** provides a complete DSA workflow in twelve functions: deterministic projection, historical decomposition, fiscal-reaction-function estimation, stochastic fan charts, IMF stress tests, heat maps, gross financing needs, and EC S1 and S2 sustainability gaps. The package is pure R, has no data dependencies, and returns S3 objects with print and plot methods. Planned additions include quarterly-frequency support, regime-switching shock models for the fan chart, and bundled OECD Ageing Report ageing-cost series to make the S2 indicator turnkey.

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