WORKING paper

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Projecting the Interests of a Dynamic Debt Portfolio: a Financial Model

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Abstract

This paper presents a financial model developed to project the future interest expenses of a large set of rolling debt instruments. It aims at forecasting the financial consequences, for borrowing entities, of changes in the interest rate environment. Starting from detailed data on the current debt's maturity structure and interest rates, and given a future path for market interest rates, we simulate the progressive repayment of borrowed amounts refinanced by issuing new debt at prevailing conditions, with few structural assumptions. The model simulates the effect of variable-rate interests and inflation indexing. It can handle any joint future trajectory of outstanding amounts and interest rates, as represented by a full yield curve structure. We present two use cases: the French government marketable debt, and the aggregate debt of euro area non-financial corporations (NFC). In the former case, official publications of interest expenses provide a benchmark against which the model performance can be back-tested. The NFC use case provides evidence of a strong dependence of the interest expenses trajectory on debt structure, as the share of fixed-rate long-term debt varies widely across countries. The model quantifies the resulting differences in expense sensitivities to future interest rate changes.

Keywords: Cost of Debt, Nominal Interest Rates, Firm Financial Structure, Sovereign Debt, Financial Forecast.

JEL classification: E43, G32, H63.

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NON-TECHNICAL SUMMARY

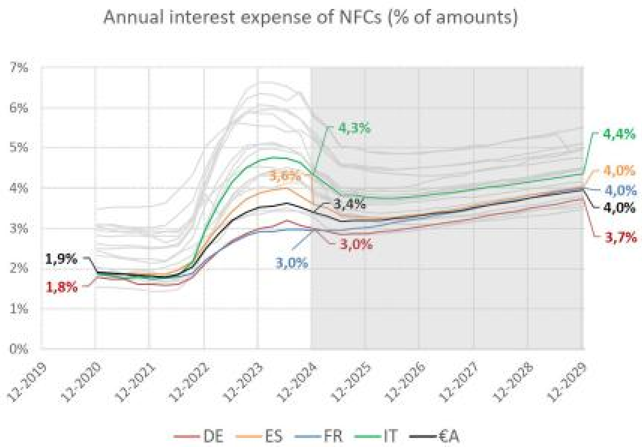
When market interest rates rise, this move translates mechanically into an increase in interest expenses for indebted economic agents. Those indebted at a variable rate see their cost of debt increase with reference rates, and all indebted agents pay an increasing cost when refinancing. The exact timing and magnitude of this rise in interest expenses depend on the structure of their debt portfolio, mainly on the allocation between fixed vs. floating rates, and short vs. long maturities. In this paper, we describe a simple financial model to project the future interest expenses attached to any debt portfolio whose structure is sufficiently well known, under any exogenous scenario prescribing the future evolution of debt amounts and market interest rates. We apply this model to the market debt of the French sovereign state, and to euro area non-financial corporates.

The model simulates the run-off and re-issuance of existing debt, and interest rate adjustment through time. Starting from a summarized but precise description of the debt portfolio of interest, the simulation keeps track of the exact cost of expiring debt throughout the simulation. Taking as given future outstanding debt amounts as well as market interest rates scenarios, the cost of simulated new issuances associated with the cost of non-maturing debt provides the trajectory of the future nominal and average interest expenses on this portfolio. The model can accommodate a wide variety of scenarios of market interest rates and debt amounts.

A first use case is the French sovereign market debt, for which detailed public data are available. Back-testing shows the model's ability to account for the cost of debt of the French central government from December 2019 to December 2024, up to an average relative projection error of 3%, linked to the strongly seasonal nature of the debt issuance schedule. Considering a "risk-neutral" scenario where the 10-year AAA-rated market interest rate rises from 2.8% to 3.5% between August 2025 and December 2029, the average cost of debt of the French sovereign state is projected to grow from 1.7% to 2.9% between end-2024 and end-2029, as cheap debt, contracted when market interest rates were low, is progressively refinanced at higher rates.

The model can also be applied to the debt of euro area non-financial corporates (NFCs), aggregated by country, thanks to detailed Eurosystem data on bank loans and debt securities. The resulting sensitivities of cost of debt to market interest rates turn out to be very different across countries. This heterogeneity originates from differences in the debt structure of non-financial corporates depending on their country of residence: as an example, Italian or Spanish NFCs are more indebted at short term and variable rate than French or German ones. Therefore, a sharp rise in market interest rates would lead to diverging trajectories: the first group of non-financial corporates would experience a quicker increase in their average interest expenses, as witnessed during the 2022-2023 rate hike. In the risk-neutral scenario, the average cost of debt of European NFCs is projected to converge again by 2029.

Figure 1. Projection of the cost of aggregated NFC debt by country



Note: Up to 2024 (white area), the interest expense is obtained from detailed data; 2025–2029 numbers (grey area) are model projections, conditional on an interest rate scenario. The four largest euro area countries are singled out, in addition to the aggregate euro area; the 16 smaller countries are represented by grey curves.

Un modèle financier de projection des intérêts d'un portefeuille dynamique de dette

Résumé

Cet article présente un modèle financier mis au point pour projeter les charges d'intérêt futurs d'un ensemble d'instruments de dette renouvelés périodiquement. Il permet de prévoir les conséquences financières des changements d'environnement de taux d'intérêt pour les émetteurs de cette dette. En partant de données détaillant la structure de la dette actuelle en termes de maturités et de taux d'intérêt, et pour une trajectoire donnée des taux d'intérêt futurs, nous simulons le remboursement progressif des montants empruntés et leur refinancement par la réémission d'instruments de dette aux nouvelles conditions, sous un nombre réduit d'hypothèses. Le modèle simule également les effets particuliers de la dette à taux variable et de la dette indexée sur l'inflation. Il permet d'intégrer toute trajectoire jointe des montants empruntés et de la courbe des taux d'intérêt. Deux cas d'usage sont présentés en détail : celui de la dette négociable de l'État français, et celui de la dette agrégée des sociétés non financières (SNF) de la zone euro. Le premier cas permet de contrôler la performance du modèle par comparaison avec la charge d'intérêt annuelle publiée par l'État dans son compte général. Le cas des SNF, où la part de dette longue à taux fixe varie fortement d'un pays à l'autre, montre à quel point l'évolution des charges d'intérêt dépend de la structure de la dette. Le modèle permet de quantifier les différences qui en découlent en termes de sensibilité aux chocs futurs de taux d'intérêt.

Mots-clés : coût de la dette, taux d'intérêt nominaux, structure financière des entreprises, dette souveraine, projections financières.

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1 Introduction

When market interest rates rise, so does the cost of debt for economic agents. Those indebted at a variable rate see their cost of debt increase with reference rates, and all indebted agents pay an increasing cost when refinancing. The exact timing and magnitude of the rise in interest expense depends on the structure of the "debt portfolio", mainly on the allocation between fixed vs. floating rates and short vs. long maturities. In this paper, we describe a simple yet flexible financial model to project the future interest expense attached to any debt portfolio whose structure is sufficiently well known, under any exogenous scenario prescribing the future evolution of debt amounts and market interest rates. Our definition of the cost of debt covers the cost arising from nominal interest payments, but also the amortization of issuance premia and discounts (if any), as well as the specific costs attached to index debt products (if any). This model is built on a set of simplifying hypotheses, especially regarding the structure of new debt issuance. We apply it to two large and well-documented debt portfolios: the aggreated debt of euro area non-financial corporations (bank loans and securities), and the French central government's tradable debt.

The need for such a financial model stems from the observation that, though market interest rate levels are a good determinant of the *marginal* cost of new debt, the *total* interest cost can feature considerable inertia. Figure 1 illustrates the case of the debt securities issued by the French government: given the prevalence of long-term fixed-rate instruments, the 2022–23 rate hike hardly had any immediate effect on the overall cost of that debt. With expensive new debt progressively replacing cheap expiring debt, it will take a number of years for the interest expense to fully integrate the market shock. Our model aims at providing a precise estimate of this future evolution, conditional on future interest rate levels, as displayed in the right-hand part of the graph.

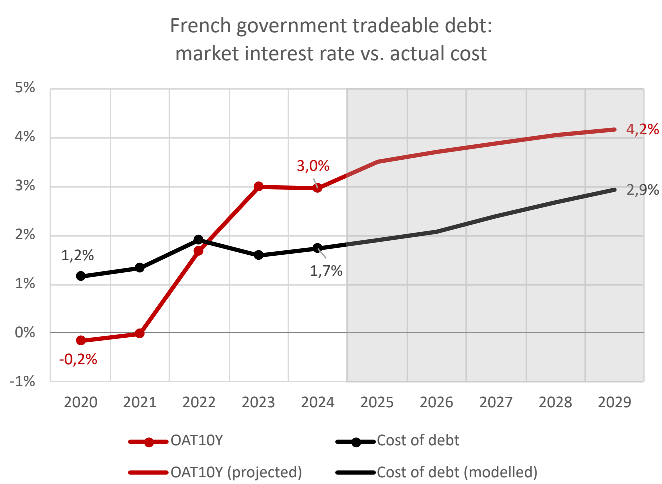


Figure 1: Black: yearly cost of debt, computed as the ratio between interest expense and average outstanding amounts. Red: average yield of French sovereign bonds on the secondary market (benchmark 10-year OAT). 2020–24 points are observations; 2025–29 are projections: given an exogenous scenario for rates (10Y issuance rate displayed), the model determines the future interest expense. Here the cost of debt progressively catches up on market rates. Note the temporary 2022 increase resulting from inflation-indexed instruments: this is accounted for in the model, cf. section 3.

The motivation for quantifying the future evolution of interest expense is twofold. First, large fluctuations of financial costs can be a source of financial instability: in particular, a sudden increase can impair the sustainability of the financial position of heavily indebted institutions. Anticipating such cost increases can help monitor the underlying systemic risk. Second, heterogeneity in debt structures entails differences in financial cost sensitivities to interest rates fluctuations. Such heterogeneity can be large even within a monetary area, as shown on figure 2 for Euro area non-financial corporations (NFCs). Understanding the financial consequences of this situation can help anticipate local variations in the transmission of monetary policy.

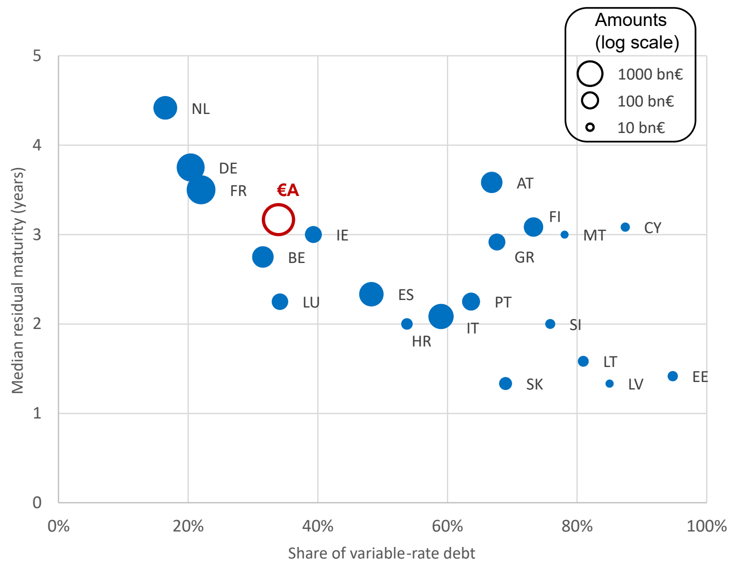


Figure 2: End-2024 structure of aggregated NFC debt by home country (loans from euro area banks + issued debt securities): median residual maturity and share of variable-rate debt. Circle sizes represent the debt amount by country, on a logarithmic scale for readability. The aggregate euro area NFC debt is displayed in red. The data reveal considerable structural differences across countries. The consequences in terms of cost dynamics are discussed in section 4.

The model simulates the run-off and re-issuance of existing debt, and interest rate adjustments through time. The future evolution of outstanding debt amounts is considered as given exogenously, and the associated interest cost is then made to evolve, in a step-by-step approach, as a result of three distinct processes: (1) extinction of maturing debt, (2) automatic adjustment of variable rates, and (3) issuance of new debt at then-prevailing interest rates. The model can also handle two special features: debt issued with a premium or discount, and inflation-indexed debt. It is based only on the present structure of the debt portfolio, namely outstanding amounts and average interest rate by debt type and by residual maturity, obtained by aggregating loan-by-loan information. In particular, the model does *not* rely on econometric estimations based on past behaviour. This forward-looking dimension makes it particularly suited for scenario analysis, including stress-testing. The model can accommodate a wide variety of scenarios in terms of market interest rates and debt amounts, including dynamic scenarios, e.g. timed rise and fall of interest rate levels.

The model focuses on the interest rate risk of a debt portfolio. It can be used to assess the interest rate risk born by an economic agent whose assets or liabilities are mostly made of debts, but does not natively encompasses some strategies such agent can use to mitigate this risk. As an example, the model can make a projection of the future cost of debt of the European non-financial corporates, but does not take into account possible mitigations of this cost, e.g. by derivative positions or remunerated bank deposits on the asset side.

The model fares well in accounting for the cost of debt of the French central government from December 2019 to December 2024, through a volatile market environment. To assess its performance, we perform a back-testing taking as input scenario the *realised* debt amounts, inflation and market interest rates movements over the period, thus isolating the model performance from the deviations resulting from scenario uncertainty. The baseline model correctly captures the effects of the 2022–23 episode (high inflation and rapid interest rate hike) on the overall cost of debt of the French central government, up to numerical errors (7% of the interest cost on average), which can be reduced to less than 3% by running a more computer-intensive version of the model with a finer simulation time step.

Given the good performance of the model on the French government debt portfolio, we turn to the more complex case of the European NFCs debt portfolios. Taking advantage of instrument-level data for both euro area banking loans (*AnaCredit*) and debt securities (*Central Security Database*—CSDB), we exhibit a large geographical heterogeneity in debt structure for non-financial companies when aggregated per country of residence. Focusing on the four largest countries, we show that this heterogeneity translated into a quicker and higher rise in interest rate cost for NFCs in Spain and Italy from 2022 to mid-2024, while the fixed and relatively long maturity of the debt of NFCs in France and Germany acted as a safeguard, containing the rise of the overall cost of debt. In 2025, in a context of lower rate levels, the model projects that NFCs from the former group of countries should see their overall cost of debt decrease, while it should keep increasing in the latter group. Later on, in a scenario of slowly increasing interest rates until 2029, the model projects a progressive convergence of the cost of debt of NFCs from both groups. In case of further fluctuations of interest rate levels, Spanish and Italian NFCs should remain more sensitive than French and German ones.

This paper provides a technical description of the model as well as an analysis of future interest costs of selected sovereign and NFCs debt portfolios. As such, it contributes to three strands of literature.

First, as a tool for portfolio interest expense or income projection, the model is useful for scenario analysis and stress-testing. From a methodological standpoint, it is a refinement of the standard repricing models widely used in the financial industry for interest rate risk management (see Saunders et al. (2024), ch. 8 for a textbook approach). Those financial models, based on decomposing interest rate risk per bucket of maturity, can be used with any interest rate or future debt amounts scenarios, short- or long-term. Such flexible approach can usefully complement existing stress-tests models, such as Correia et al. (2020) for the United

States, Budnik et al. (2023) for the Euro area, or Fique (2017) for Canada, in which the trajectory of interest paid versus interest received by banks need to be simulated in a severe but plausible scenario. While in these models the interest rate income or expense is generally projected using reduced-form econometrics, our forward-looking and more structural approach can offer a different viewpoint. More generally, the model allows for a precise capture of yield curves and debt amounts by maturity; it can therefore be used as a point of comparison with macro-models, which usually adopt a more stylized view of debt maturity structures and yield curves, often distinguishing only short vs long term debts and interest rates (as in Lemoine et al. (2019), for a state-of-the-art semi-structural macro-forecasting model).

Second, the precise projection of the cost of the French sovereign debt portfolio complements existing approaches to debt sustainability analysis, where the sign and magnitude of the difference between the interest cost r and nominal growth g of sovereign debt $(r-g)$, is paramount. In traditional approaches, r is sometimes proxied by a market interest rate, altogether ignoring the inertial effects of long-term fixed-rate issuances, e.g. Blanchard (2019) building on Diamond (1965). More refined models do embed inertial effects, such as in Bouabdallah et al. (2017); this relies however on implicit debt structure assumptions, making it blind to e.g. whether high- of low-cost debt gets extinct first. A further step is taken in Cochrane (2022), which models long-term debt using linearised deviations from an equilibrium maturity structure assumed to be geometric. Our approach altogether dispenses from such structural assumptions, and precisely computes the dynamics of r from empirical debt structure data. As such, it can be used either to check the reliability of existing assumption-based approaches, or directly as input to the wide set of macro-models needing interest cost computations.

Third, by applying the model to the debt of non-financial corporates, our paper contributes to the growing literature on the heterogeneous consequences of market interest rate hikes on NFCs, depending on their debt structure. Since NFCs floating-rate debt influences the transmission of monetary policy (Ippolito et al., 2018) and their overall financial condition has real effects (Dees et al. (2022) for a recent macro approach), the impact of the then-forthcoming rate hikes on NFC cost of debt was an open question in early 2022, as noticed by Kitsul et al. (2023). The rich bank loan data available in the euro area since 2019 through *AnaCredit* allowed to address this question, and also to point out the structural heterogeneity among non-financial corporates and banks, extensively described by Kosekova et al. (2024). In this context, we had studied the heterogeneity of European NFCs debt structure, adding debt securities to banking loans in the analysis, and applied an earlier version of the model to French, Italian, Spanish and German NFCs (Gueuder and Ray, 2022). Later data confirmed that aggregated NFC interest costs in the euro area did follow widely different paths from country to country during and after the 2022–23 rate hike, with a robust link to debt structures (Gueuder and Ray, 2024). Independently, Kerola et al. (2024) came to the same conclusion as to the geographical heterogeneity of NFC debt structures in the euro area and its consequences on interest cost dynamics.
More recently, and from a more causal standpoint, two papers have exploited this heterogeneity to assess the strength of monetary policy pass-through using *AnaCredit*: Schepens et al. (2025) show that, in a restrictive monetary policy context, firms with more variable-rate

loans tend to increase their prices more than firms with fixed-rate loans, as rising market interest rate puts more pressure on their cost structure. Vilerts et al. (2025) assess the cross-country monetary policy pass-through heterogeneity taking both the interest rate type and loan duration characteristics of Euro area NFCs loans into account.

Paper roadmap The paper is organized as follows: section 2 describes the overall principles of the model starting with a simplified example. Section 3 applies the model to the French sovereign market debt. As precise and rigorous yearly accounting of its cost is available, it also stands as the model back-testing. Starting from the December 2024 debt structure, interest expense projections are presented until December 2029. Section 4 shows the different debt structures of European non-financial corporates according to their country of residence, and how it translates into different cost of debt trajectories in a volatile market interest rate environment. The equations and technical implementation details are provided in the Appendix, which is designed to be sufficient to replicate the model.

2 A financial model of debt roll-over and interest expense

Our goal is to simulate the evolution of a debt portfolio as time goes by. Starting from a **debt schedule** representing the initial state of that portfolio, and using a **scenario** describing the subsequent evolution of interest rates and debt amounts (subsection 2.1), the model runs through three steps at each future simulated time period (subsection 2.2):

1. maturing debt goes extinct,
2. variable-rate debt is updated,
3. new debt is issued at prevailing market conditions.

For clarity, we illustrate these steps using simplified fictitious data ; real-life instances involve much more complex debt schedules and market interest rate scenarios, but the principles remain the same.

2.1 Model ingredients: debt schedules and exogenous scenarios

2.1.1 A debt schedule to encode the aggregated structure of the portfolio

Contracting a debt implies incurring an interest cost as time goes by, until it is repaid. In a complex debt portfolio, various types of debt expiring at various maturities coexist. To represent such a structure, we use a **debt schedule**: a decomposition of the portfolio as a sum of atomic debts with homogeneous characteristics, each represented by a line in a table. Table 1 represents the debt schedule in the fictitious 100M€ portfolio we will use as example throughout this section.

A line is characterised by an interest rate type and a residual maturity. For each line, the

Interest type	Residual maturity	Amount (M€)	Amount-weighted interest rate
Fixed	1	40	1.0%
Fixed	2	20	3.0%
Fixed	3	10	4.0%
Variable	1	15	1.0%
Variable	2	10	2.0%
Variable	3	5	1.0%

Table 1: Simplified debt schedule for the example portfolio, using a quarterly time step.
Reading (2nd line): 20 million euros are due be repaid during the second time step (i.e. between 3 and 6 months from the start date); until then they will carry a fixed annualised interest rate of 3% on average.
The total borrowed amount in the portfolio is 100M€, with a current average interest rate of 1.8%. For simplicity no indexed debt is included, and the debt features no issuance premium/discount.

schedule provides the outstanding amount and the prevailing interest rate (annualised convention).

Maturities are rounded up to a given time step. For instance, when using a quarterly time step, any loan due at a date later than 3 months away, and earlier than or equal to 6 months away, falls into the "maturity=2" bucket, i.e. 2nd time step. If several loans share the same interest rate type and are due within the same maturity bucket, they are represented in the schedule by a single line featuring their total amount and their amount-weighted average interest rate, so that their cumulative interest cost is correctly accounted for throughout the simulation.[1]

Maturity rounding allows to dramatically simplify the structure of complex debt portfolios, as millions of individual loans can be represented by a just few hundred lines. However, the consolidation process must carefully take into account the various amortization schemes: it is common, particularly in bank loans, to repay the principal progressively through time instead of at final maturity.[2] In such a case, the model splits each loan into as many sub-loans as there are principal payment dates: each of these sub-loans inherits the interest rate characteristics of the main loan, and is then treated as a standalone paid-at-maturity debt, before being consolidated into the debt schedule. Cf. Appendix A for worked-out examples.

The data structure displayed in table 1 is simplified: in actual fact, debt schedule lines are also characterised by indexation type and by next rate reset period when applicable; it must also include information about any issuance premium or discount. In addition, users are free to add extra columns to further split the debt along any other characteristics they want to

[1] The debt schedule, by default, does not feature information on initial maturities. A 3% fixed-rate 5-year loan contracted in 2023 and a 3% fixed-rate 3-year loan contracted in 2025 are considered equivalent, since their financial costs from 2025 onwards are identical.

[2] Loan amortization can have very material effects: in the case of aggregated French NFC bank loans as of the end of 2024, actual principal payments scheduled in 2025 represented 25% of the total, although only 12% of loans had a final maturity of one year or less: the 13% difference corresponds to the amortisation of longer-maturity loans.

keep track of, such as product type (bonds vs. bank loans). In the following, we will call a **debt set** a set of lines in the schedule sharing the same qualitative characteristics. In the example above, the only qualitative characteristic is Interest type, so there are two debt sets: one with fixed rate (70M€) and one with variable rate (30M€). Other qualitative data may include country of issuer, nature of debt instrument (bank loans vs. bonds) etc. Within each given debt set, the schedule contains one line by maturity bucket. The model treats each debt set independently throughout the simulation.

Consistently with the chosen example, this section does not cover the technicalities that surround indexation and issuance premia/discounts. We refer to appendix B.3 for a summary of how indexed debt (typically to inflation) is taken into account, and to appendix B.2 for the treatment of the premia/discounts that arise when debt securities are not issued at par.

2.1.2 A scenario to prescribe an exogenous evolution of the environment

Taking a debt schedule as starting point, the model projects its future interest cost under future conditions as determined by an exogenous scenario. Such a scenario must specify three key elements:

1. The evolution of prevailing (market) interest rates. This determines, for each future time step within the simulated horizon, the interest rate at which new debt can be contracted, but also the evolution of the interest rate of variable-rate debt.
2. The evolution of the total borrowed amount, by debt set. A constant amount means that any repayment is financed by an equivalent amount of new debt. An increasing amount means that new debt is issued faster than the pace of repayment of existing debt.[3]
3. The evolution of indices for indexed debt. This corresponds to the path of reference consumer price indices in the case of inflation-linked debt. Cf. appendix B.3 for more details on the consequences.

In theory, the future value of market interest rates could be specified for each time step, for each residual maturity and for each debt set. In practice, we choose to simplify the scenario by specifying a single "reference interest rate curve" for each time step and residual maturity: the model then derives the interest rate for each debt set by applying a constant spread over the reference rate. This spread is computed using past debt issuance data, cf. section D for details.

As we deal with euro-denominated debt, the chosen reference curve is the **AAA euro area sovereign spot rate**, computed by the ECB from the observed yields of the sovereign bonds of AAA-rated euro area governments traded on the market at any given date. This curve is publicly available on daily basis for an extensive set of maturities, and embeds little to no specific credit risk, making it suitable as a universal reference rate.

[3] As this scenario is wholly exogenous, it cannot capture "snowball effects" whereby higher interest costs are likely to lead to higher refinancing needs. These effects are by nature second-order, but may not be negligible on the longer term.

Though the model can handle any specification of future interest rate levels, the "default" interest rate scenario is the so-called "risk-neutral" scenario, obtained by computing forward interest rates from standard curve construction techniques applied to the reference curve observed at the starting point at the simulation.[4] It corresponds to the (unique) interest rate evolution consistent with the current state of markets under the assumption of efficient markets and zero uncertainty. To that extent, the "risk-neutral" scenario is considered as agnostic regarding future interest rate evolution, and is commonly used in macroeconomic forecasting (ECB (2016)). This typically results in an interest rate curve that becomes flat on the long term, as the rates of all maturities progressively converge towards a single long-term expected value.

For illustrative purposes we will use below a scenario where reference interest rates follow a risk-neutral path (as displayed in figure 3), and debt amounts remain constant for both of the debt sets of the example portfolio.

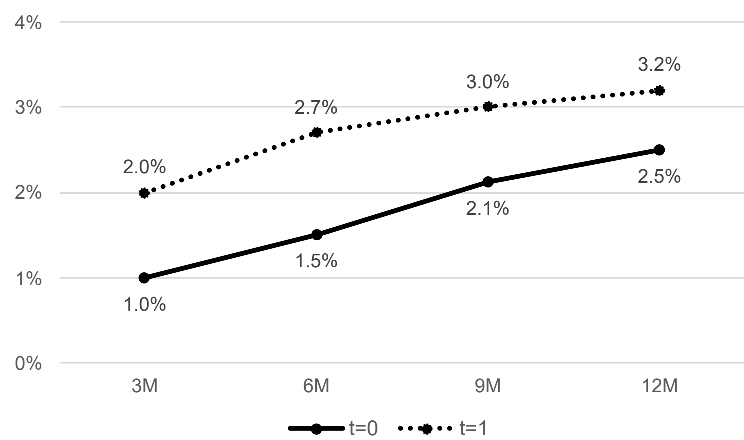


Figure 3: Simplified example of a reference curve as observed at $t = 0$, and its value at $t = 1$ (i.e. 3 months later with quarterly time steps) in the risk-neutral scenario. Interest rates move up, consistently with the upward-sloped shape of the curve.

2.2 The debt life cycle

The successive operations described in this section are illustrated in figure 5, using a graphical representation of the example debt portfolio: the starting point is provided in figure 5(a), equivalent to table 1.

[4]Curve construction, i.e. computation of forward interest rates implied from spot interest rates, follows from a so-called "bootstrap" technique, which is roughly as follows — skipping technical details, for which cf. e.g. Svensson (1994). The current term interest rate at any given maturity is, by no-arbitrage, a weighted average of the forward short-term rates over the whole period. Knowing term interest rates at all maturities, one can therefore infer ("bootstrap") forward short-term rates for all future dates. These are, in turn, averaged starting from future dates to determine the forward value of term rates.

2.2.1 Residual maturities are shortened and maturing debt goes extinct

As one time step passes by, residual maturities shorten: all numbers in the "residual maturity" column of the debt schedule are reduced by 1 (fig. 5(b)). After that operation, lines with zero residual maturity, which correspond to debt repaid during the time step, are simply removed from the schedule since they stop bearing interest.

In the more generic case, this first step also includes applying index evolution to indexed debt, and amortising issuance discounts or premia, cf. appendix B.3. Such operations do not apply in the simple example we use here.

2.2.2 The prevailing interest rate is reset for variable-rate debt

A variable interest rate is a rate that is periodically reset as a function of the evolution of a benchmark interest rate, which is generally a short-term rate (€STR or EURIBOR for euro debt instruments). The model reflects this by assuming the following:

- *Short-term rate adjustment hypothesis: the interest rate of variable-rate debt follows one-for-one the evolution of the shortest-maturity interest rate of the reference curve.*

This means that we neglect basis spread volatility, as well as any contractual cap or floor on the rate. In our example, the shortest term of the reference curve is 3 months; its interest rate moves from 1% to 2% during the first time step. The interest rate for all variable rate debt lines is therefore increased by 1%, cf. figure 5(c).

In this simplified example, variable rates are reset at each time step. Actually, the model tracks the next reset date, and a variable-rate reset is only performed when that date is due — at which point the *cumulative* change in the reference interest rate since the start of the simulation is applied. Absent reliable information on subsequent reset frequency, the model has to make an additional assumption:

- *Frequent readjustment hypothesis: Once the first reset date is passed, variable-rate debt is reset at each time step.*

In practice, this means that the next reset date is reset to 1 by default.

2.2.3 New debt is issued at prevailing market conditions

The last modelled step is the issuance of fresh debt. The amounts to be issued are computed separately for each debt set, as the difference between the debt amount specified by the scenario and the residual debt amount after removal of maturing debt. Before incorporating these new amounts into the schedule, the model has to (1) allocate them across maturities, and (2) determine their respective interest rates.

While, in real life, the decision of issuing debt at short or long maturities can depend on multiple financial and non-financial considerations, the model cuts across the complexity of the topic with a one-size-fits-all hypothesis:

- *Stable debt structure hypothesis: The residual maturity structure of a debt set remains constant.*

In other words, the new debt amount for a given debt set is allocated across maturities in such a way that, after adding the pre-existing debt amounts in the same set, the proportion by residual maturity is the same as observed in the initial debt schedule. In particular, if the scenario specifies a stable amount per debt set, then the amount by maturity must also be constant. This principle was designed in the perspective of a large number of decision-makers converging towards an average behaviour — this is well verified in the case of the aggregate non-financial corporate debt, cf. section 4.2. It can also hold for large debtors with consistent financial targets, such as the French government, cf. section 3.1. Figure 5(d) illustrates this principle applied on the example.

While this simple instance offers no difficulty, the model must sometimes cope with irregular debt schedules where the stability hypothesis would lead to the issuance of *negative* debt amounts for certain maturity plots. Such situations are handled by deviating locally from the assumption. A full description of this problem and its adopted solution is illustrated and detailed in Appendix C.

The model then determines the interest rate for each newly issued amount, using the following assumption:

- *Common reference rate hypothesis: new debt is issued at an interest rate equal to the reference curve at the given maturity, plus a constant spread by debt set.*

Indeed the *general* interest rate level, as represented by the reference curve, is usually more volatile than the spreads, that represent the credit or liquidity risks associated with specific debt types. That assumption allows for simplified scenario specifications, since the reference curve moves are sufficient to determine all relevant future interest rates.
On the flip side, the model ignores spread term structures. In practice this has limited consequences on model performance, cf. in particular section 3.2. Yet, an alternative strategy using an exponentially term-dependent spread is made available to the user. The issuance spread estimation for both methods using recently issued debt is detailed on appendix D.

Reference rate values outside the maturity pillars provided in the scenario are obtained by linear interpolation and constant extrapolation. Note that, when determining the interest rate for newly issued variable-rate debt, the model considers the next *reset date* in lieu of the maturity (in practice the next reset date is assumed to be the next time step). Indeed, longer-term interest rates are *fixed* rates, which reflect market expectations of future rate changes. In the case of variable-rate debt, where such changes are automatically applied, they should not also be factored in the initial price, which therefore depends on the short-term rate only.

Given the market interest rate scenario shown in figure 3), and assuming a 200bp issuance spread for fixed-rate debt and 100bp issuance spread for variable-rate debt, the interest rates for newly issued debt at $t = 1$ are computed from the curves displayed in figure 4, leading to the situation in figure 5(e).

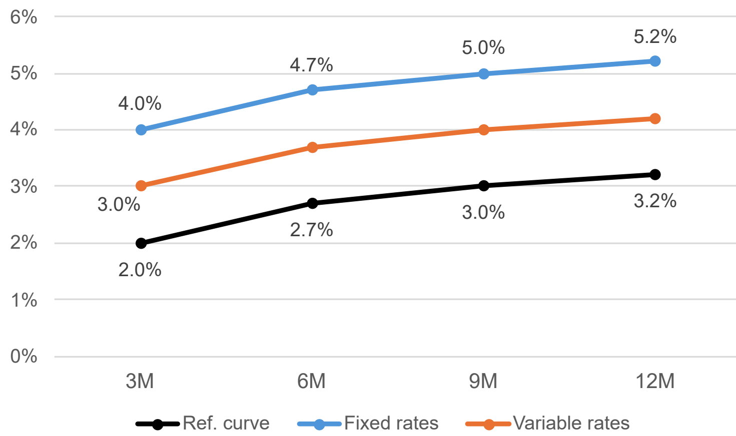


Figure 4: Reference curve at $t = 1$, and issuance curves for fixed- and variable-rate debt, obtained by adding respectively 200bp and 100bp over the reference curve. Since variable rates are assumed to reset every 3 months, only the 3-month plot of the variable-rate issuance curve is actually used.

Finally, the old and new debt that coexist within the same debt set at the same residual maturity are summed together; the interest rate for the sum is computed as the amount-weighted average of the old and new debt rates, which ensures that the interest cost is the sum of the costs from the old and new debt. The resulting debt schedule, displayed in figure 5(f), is used as starting point for the next simulation time step.

2.3 Computing interest costs

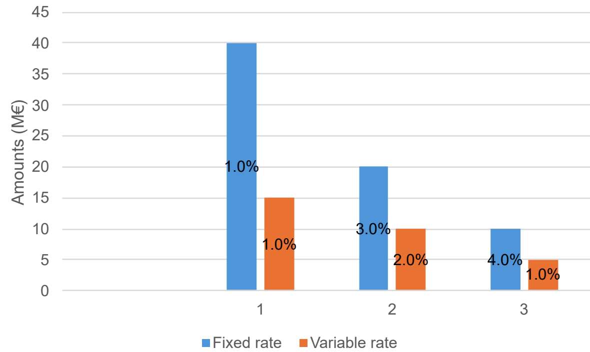
From the evolved debt schedule, the model estimates the interest rate paid on each debt set i during the time step t using the following hypothesis:

- *Time discretisation hypothesis: the repayment of expiring debt and the issuance of new debt all take place at the very beginning of the time step.*

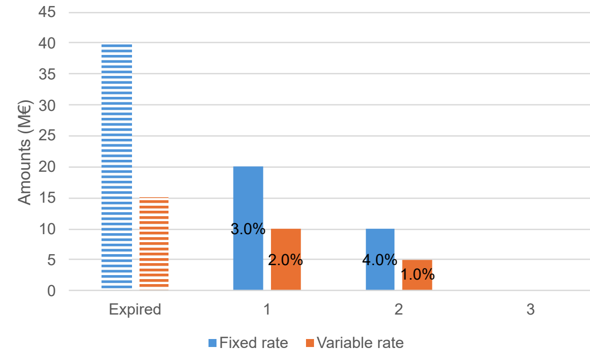
This allows to use a simple interest expense formula, valid at first order:

$$InterestExpense_t(i) = \sum_T N_t(i,T) \times R_t(i,T) \times \Delta,$$

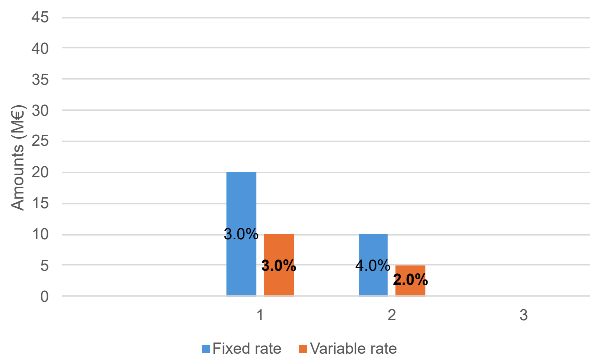
where N_t and R_t are the end-of-step amount and interest rate for the debt set i at maturity T, and Δ is the time step length in years. The timing errors generated by the hypothesis are expected to become negligible when Δ is small enough compared to the speed of interest rate moves. The cost computation applied to the example is displayed in figure 2.



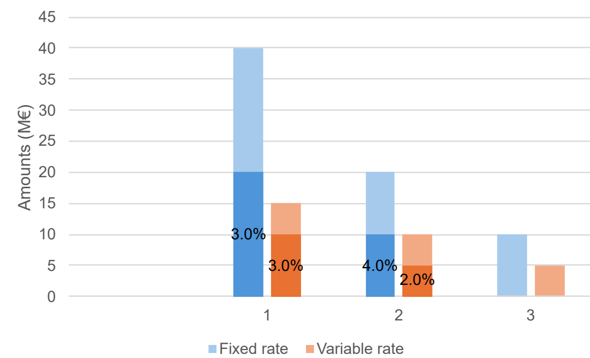
(a) Simplified debt portfolio at $t = 0$, with two debt sets: fixed- and variable-rate debts. The average interest rate of each debt set, by residual maturity bracket, is displayed as a percentage.



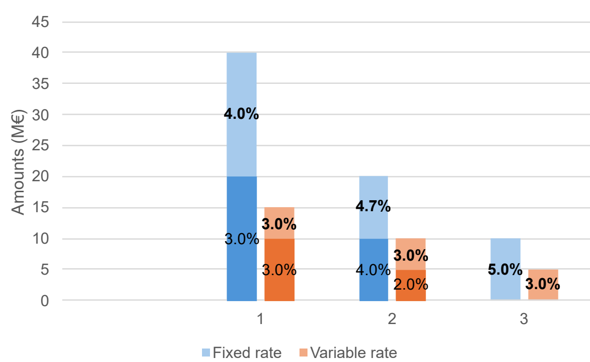
(b) $t = 0$ schedule as seen from $t = 1$. All amounts shift by one maturity bucket; expired amounts are repaid and no longer bear interest.



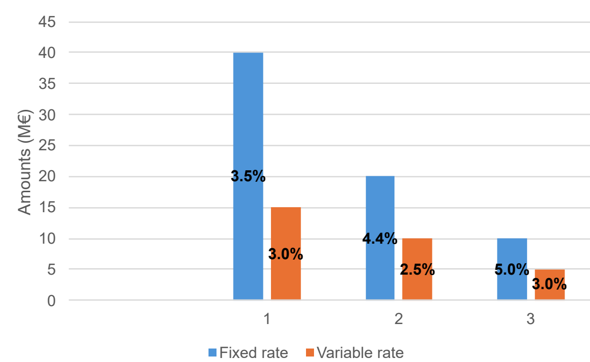
(c) Variable interest rates are shifted up, following a $+100bp$ shock on the shortest-term of the yield curve (Figure 3). By nature, the fixed-rate debt set is not modified in this step.



(d) New debt (here in lighter colors) is issued so as to reach the specified debt amounts: 40M€ at fixed rate (+30M€ residual = 70M€) and 15M€ at variable rate (+15M€ residual = 30M€). By the stable debt structure hypothesis, the maturity profile of each debt set after issuance recovers the shape it had at $t = 0$.



(e) Each new debt issuance is assigned an interest rate read from the issuance curves in figure 4.



(f) Residual debt and newly issued debt are merged and assigned a weighted-average interest rate. This is the final $t = 1$ state: interests are computed and the next step can start—back to (a).

Figure 5: A quarter in the life of the model: simple worked-out example.

Interest type	Residual maturity	Amount (M€)	Amount-weighted interest rate	$t = 1$ cost
Fixed	1	40	3.5%	0.35
Fixed	2	20	4.4%	0.22
Fixed	3	10	5.0%	0.13
Fixed	*Total*	*70*	*4.0%*	*0.69*
Variable	1	15	3.0%	0.11
Variable	2	10	2.5%	0.06
Variable	3	5	3.0%	0.04
Variable	*Total*	*30*	*2.8%*	*0.21*
Total		**100**	**3.6%**	**0.91**

Table 2: The interest expense for each debt set over the time step is computed by summing contributions across residual maturities. Here the fixed-rate debt cost simulated for the first simulated quarter is 0.69M€ and the variable-rate debt cost is 0.21M€. The average interest rate over the whole debt has gone up from 1.8% to 3.6% as a result of (1) expiration of cheap debt refinanced by more expensive debt, and (2) higher cost of variable-rate debt.

3 Projecting the cost of debt of the French Government

As a test use case for the model, we work on projecting the cost of the traded debt issued by the French government, as it combines several interesting characteristics:

- its structure is perfectly known from fully detailed public data;
- its issuance has been closely managed in such a way that its residual maturity schedule is very stable since 2019, in line with the main model assumption;
- its actual interest costs are published by the French government in its yearly accounts, which can be directly compared to model output.

3.1 Structure of the French government debt

The tradable part of the French government debt consists in securities which can be classified into three main types, cf. figure 6:

- **BTF** (*Bons du Trésor à taux Fixe*) are short-term securities (up to one year) with pre-paid interest — i.e. zero-coupons paying only the principal at maturity.
- **OAT** (*Obligations Assimilables du Trésor*) are medium- and long-term fixed-rate securities, paying coupons once a year and the principal at maturity. Their initial maturities range from 2 to 50 years.
- **OATi** and **OAT€i** are inflation-indexed versions of OATs: both their coupon and their principal follow the evolution of one of two consumer price indices, the one tracking prices in France (OATi) and the other in the euro area (OAT€i).

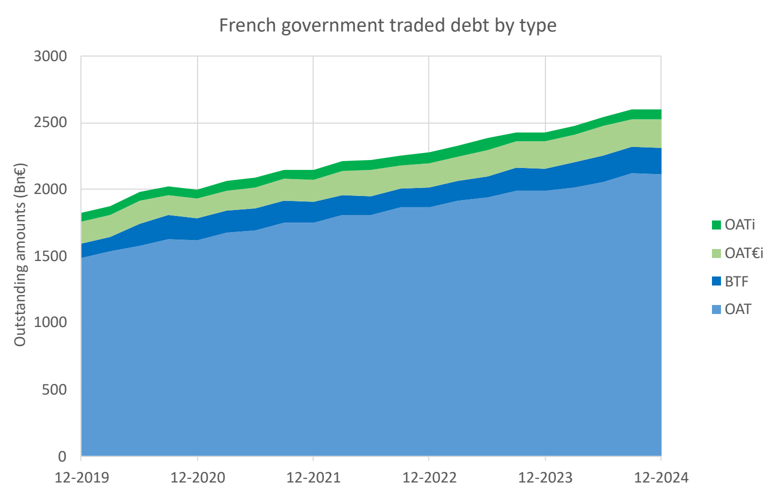


Figure 6: End-of-quarter outstanding amounts for the four traded French government debt security types, excluding issuance premia/discounts but including indexing effects for OAT(€)i. On average, OATs make up for about 82% of the total, BTFs for 7%, OAT€i for 8% and OATi for 3%.

All these securities are *fungible*: the government routinely issues additional amounts of a pre-existing security, the new issuance being immediately and wholly assimilated to the securities already in circulation.[5] This fungibility avoids fragmentation across many different securities, that would be harmful to market liquidity.

As a consequence, each security is typically issued dozens of times, with large and varying issuance premia or discounts, since the prevailing interest rate environment at issuance differs from the unchanged nominal coupon paid by the re-issued security. For accounting purposes, and in spite of fungibility, each successive issuance of a given security is tracked separately with its own yield and its own premium/discount amortisation schedule (cf. appendix B.2).

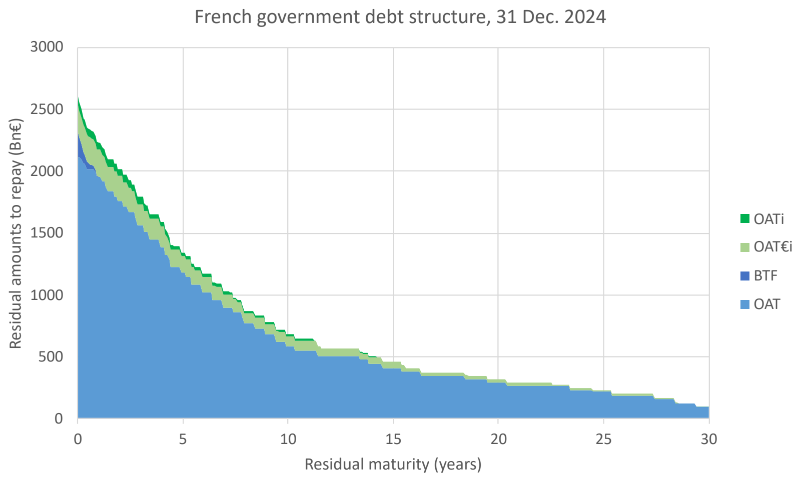


Figure 7: For each maturity on the x axis, y displays the principal amounts remaining to be repaid after that time elapses. For indexed securities, the considered principals are recomputed using index values as of 31 December 2024.

Figure 7 displays the residual maturity structure of the French government traded debt as of 31 December 2024. The profile is quite regular: beyond the first few months where BTFs repayment dominates, the largest part of the debt consists of OATs with residual maturities spread out rather evenly between 0 and 10 years. After 10 years, a sizeable longer-dated component extends up to well over 30 years (the longest OAT to date, issued with an initial maturity of 50 years, expires in 2072). The OAT€i profile is similar, spanning maturities up to 30 years, while OATi's only cover the medium-term segment ($<$ 15 years). Note that no variable-rate securities are issued.

Figure 8 shows how this maturity profile has evolved over the five years leading up to 2024: with a growing total amount of debt, new securities have constantly been issued across all maturities.

Remarkably, the French Treasury has managed these new issues in such a way that the *relative* maturity profile of each product category has hardly moved at all: for OATs, figure 9 shows an unchanged profile apart from a slight maturity increase around the 20-year pillar; the same holds for BTFs and for indexed securities, up to the irregularities caused by sparser maturity schedules.

[5] A detailed account of the French Treasury issuance process is provided for instance in Sirello and Vari (2025).

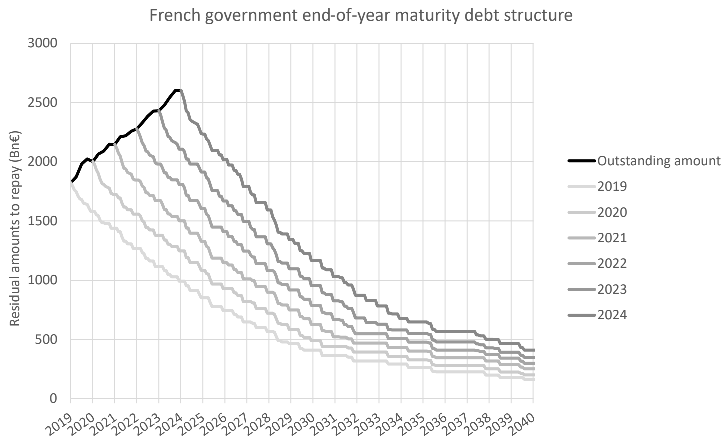


Figure 8: The black line shows the outstanding debt amount at each end-of-quarter date from December 2019 to December 2024. For each end-of-year date, a grey line represents the repayment schedule, i.e. the residual outstanding amounts for each future date in absence of any new issuance and without indexing effects.

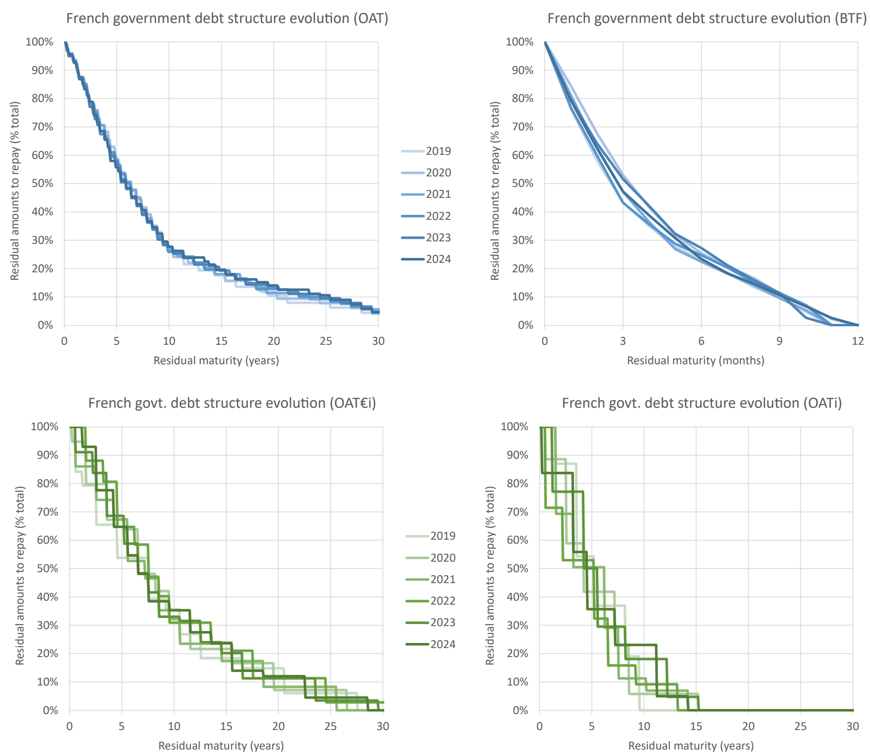


Figure 9: Maturity profiles for each type of securities. Each line represents a repayment profile as seen from a give year-end date, expressed in proportion of the total outstanding amount. E.g. at all six year-end dates, about 25% of the outstanding OATs (in principal) had a residual maturity larger than 10 years.

The observed changes in the long-term segment around 20 years have resulted in a small increase of the average residual maturity, from 8.2 years (Dec. 2019) to 8.5 years (Dec. 2024). Over the longer run, that average had been more dynamic (6.7 years en Dec. 2009, 7.0 years in Dec. 2014),[6] reflecting a progressive shift towards longer maturities, which seems

[6]Source: *Agence France Trésor* monthly bulletin (https://www.aft.gouv.fr/fr/bulletins-mensuels).

to have slowed down with the end of the low-rate era. Hence, while a model generalisation allowing for changes in the maturity profile would be useful to quantify the long-term effects of possible alternative issuance strategies, the current stable-profile hypothesis remains a good approximation of current issuance behaviour over the medium term.

3.2 Model performance

The publication of yearly figures of debt charges by the French government makes it possible to quantify model performance by directly comparing modelled outcome with actual outcome. When discussing model performance, it is important to remember that a model consists, ultimately, in an *if-then* relationship. In the present case, the debt projection model asserts that *if* a given scenario plays out in terms of input data (interest rates, amounts etc.), *then* output data (the cost of debt) can be computed in a certain way. A model-generated projection, such as presented in section 4, may turn out to differ from reality, but this may happen for two very different reasons :

- reality may turn out to play a different *scenario* (interest rates, amounts...) than presented in the projection,
- the *relationship* between input and output may turn out to differ from model predictions.

In the former case, the model is not to blame: only the latter case involves a breach of the *if-then* relationship.

The point of back-testing is to check model performance, isolated from any forecasting error in terms of input data, by retroactively running the model in known past situations, using past debt structures as starting points and realised market interest rates and amounts as scenario, and comparing the model output (computed interest charges) with actual data (interest charges incurred in reality).

To back-test the model on French government debt, the process is as follows. For each year-end date between 2019 and 2023, the model is run starting from the actual debt structure observed at that date, applying a scenario that reproduces the actual evolution of amounts, interest rates and consumer price indices. OATs and BTFs, being fixed-rate securities, are grouped into a single fixed-rate product category; OATi's and OAT€i's are modelled as two standalone categories. The interest rate scenario is taken from the observed evolution of the AAA-rated European sovereign rate published by the ECB.

To focus the back-testing results on "core" model performance, the model specifications are refined in the following way:

- the time step is shortened to 1 month instead of 3 months;
- divergences between the actual and modelled interest rates at issuance are minimised by using issuance spreads that (a) have a term structure distinguishing short-term and long-term spread (2-factor model with exponential term structure, see appendix D.2 for details), and (b) changes from step to step within the scenario in line with actual

observations instead of being kept constant.[7]

The model computes monthly interest charges for all dates following each starting point; the cumulative yearly charges can then directly be compared with the interest charges published by the French governments in its yearly accounts.[8] Figure 10 displays the comparison between modelled and observed quantities: using the refined version of the model (left-hand graph), the outcome is always very close from published figures, and even provides a nearly-perfect fit in most cases.

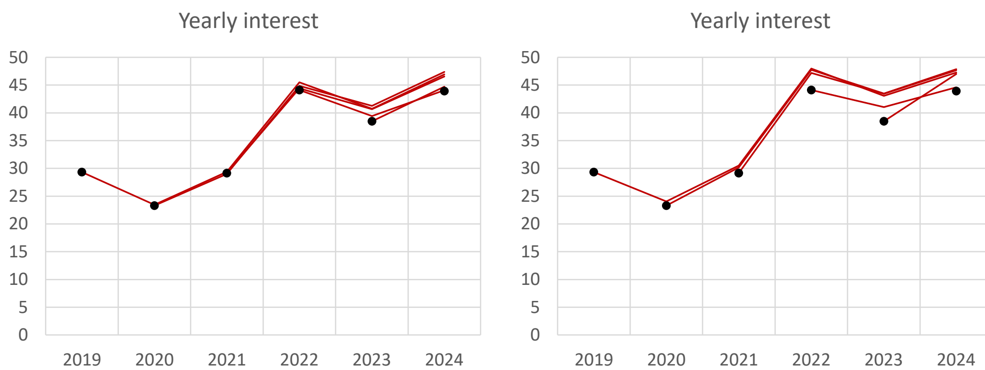


Figure 10: Back-testing results: on the left-hand side, the refined model (1-month step, variable issuance spread with term structure); on the right-hand side, the "base" model (quarterly time step, constant flat issuance spread). Black dots represent actual figures as published in the *Compte général de l'État* (CGE). The five red lines display the simulation trajectories starting from the five year-end structures (2019 to 2023). In a perfect model, all red lines should exactly fit black dots. Model imperfections are small for the refined model (left, average absolute deviation = 1 bn€, i.e. 3% of the interest cost); deviations are more significant for the base version of the model (right, average deviation = 2.5 bn€, i.e. 7% of the interest rate cost), but the trend is still correct.

In particular, all simulations correctly predict the interest rate charge for the year immediately following the start date; the first simulation starting at the end of 2019 provides three years of mostly correct predictions. However, all three simulations starting in 2019–21 predict charges for the years 2023–24 that over-shoots the CGE numbers by about 3 bn€. By contrast, the simulations starting in 2022 and 2023 correctly recover the CGE numbers.

The main source of this divergence stems from the strong seasonality of the maturity schedule that the model's maturity regularisation algorithm struggles to replicate. This leads the model to forecast too large a share of short maturity issuance and therefore to over-estimate the effects of the 2023 rate hike (a detailed analysis of this divergence is provided in appendix E). This

[7] The issuance spread for fixed-rate securities is usually positive, reflecting the credit spread of the French government, whereas the issuance spread for OATi's and OAT€i's is generally negative, as the bondholders subtract their expectation of future inflation from the nominal yield they demand.

[8] *Compte général de l'État* (CGE), published at **https://www.budget.gouv.fr/documentation/comptes-letat**. We use note 11.1.4 *Valeur actuelle de la dette financière négociable* (current value of tradable financial debt) for outstanding amounts, and note 20.1.2 *Charge nette de la dette négociable de l'État* (net charge of tradable government debt) for charges. The outstanding amounts are adjusted by excluding accrued interests, consistently with the model assumption of continuous coupon; we check that these adjusted amounts exactly match amounts computed from AFT security-by-security data. The interest charges are adjusted by excluding the profits and costs from repurchased securities, since these (rather marginal) operations are not considered in the model.

seasonality appears to be a feature of the market debt of the French Government, at least since 2019: debt gross issuance tends to decrease from its Q1 level, while there are little debt redemptions in Q3. Provided that these patterns are robust, a variant of the model specifically dedicated to the French sovereign market debt could take into account this seasonality. When using the model on more diversified sets such as aggregated NFC debt, such seasonalities tend to be smoothed by aggregation, so that the maturity regularisation algorithm plays a more minor role.

When using the "base" version of the model, the performance is less good, as might be expected (cf. figure 10, right-hand graph). As demonstrated in appendix E, the main source of noise is the shift from a 1-month to a 3-month step. While providing a significant gain in terms of computation time, this simplification comes at the cost of visible distortions in the periods of rapid interest rates moves, as in 2022 (for long-term rates) and 2023 (for short-term rates). As the model assumes that end-of-time-step interest rates apply over the whole time step, longer time steps lead to projections where the effects of interest rate fluctuations are felt too early. A first deviation can be observed in 2022; added to the overstatement bias mentioned above, it leads to interest charge overstatements of about 5 bn€ in 2023–24.

In spite of these various sources of error, the model performance still remains reasonable even in its "base" version, with projections that reproduce the general shape and order of magnitude of interest charge fluctuations through a period of large and rapid interest rate moves.

3.3 Projecting French sovereign debt cost over five years (2024–29)

Turning now to model projections for the future, we present the results of medium-term projections, starting from the December 2024 state of the debt and running until December 2029. To illustrate the model flexibility, we run one reference scenario plus three alternative scenarios: one with a different trajectory for amounts, and two with different trajectories for interest rates, implicitly providing cost-of-debt sensitivities to market interest rate movements. With an outstanding debt of 2,627 bn€ as of end-2024, a naïve sensitivity computation would state that a +100bp global rise of market interest should yield a +26 bn€ per year cost increase; however, as the French sovereign debt is mostly long term and fixed rate, this will actually take some time to materialize: the model can provide a precise timing and quantification of this lag effect.

For the purpose of this projection, we consider three debt sets: securities indexed on the French price index (OATi), on the Euro area price index (OAT€i), and non-indexed securities (BFT+OAT). This yields three different spreads, one for each debt set.

3.3.1 Scenarios of debt amounts, market interest rates and inflation

Debt amount scenarios The central scenario for sovereign traded debt amount is a *dynamic scenario*, consistent with Banque de France 3-year macroeconomic projections published in June 2025,[9] extrapolated to 2028–29 assuming that the rate of growth of sovereign debt normalises down to 4% in 2028 then 3.5% in 2029. (These are changes in *nominal* amount: the growth of more economically significant quantities such as Debt/GDP ratio is slower.) For comparison, an alternative scenario with *constant debt amount* is also run, cf. figure 11.

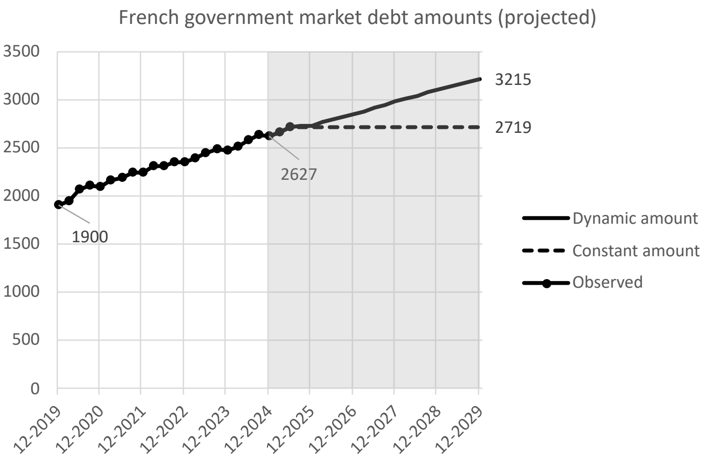


Figure 11: Two scenarios for projected French sovereign traded debt amounts (in bn€) over 2025–2029: dynamic following Banque de France June 2025 macroeconomic projections (plain), or constant amount frozen at its June 2025 value (dashed).

Interest rate scenarios We run three interest rate scenarios, for the sake of the exercise :

1. the reference scenario is the so-called *Risk-neutral* one, built from forward rates computed from the ECB AAA euro area sovereign market interest rate curve as of 15 August 2025,[10]
2. a *parallel shift* scenario obtained by adding a constant +100bp on top of this risk-neutral scenario,
3. a *slope increase* scenario obtained by imposing a maturity-dependent rate increment, ranging linearly from +0bp on the 3-month market interest-rate bucket to +100bp on the 10-year, on top of the risk-neutral scenario.

Figure 12 displays the yield curves for each scenario at the beginning and end of the projection period; figure 13 plots the interest rates at two different maturities through the projection period. As expected by construction, the risk-scenario features increasing rates (since the initial curve is upward-sloped) and progressive flattening.

Inflation scenario French and euro area inflation follow the Banque de France and ECB September 2025 macroeconomic projections. The French inflation is projected to flat-line in 2025 (1% pa), rising slowly to 1.8% in 2027. Euro area inflation averages at a higher rate in 2025 (2.1%), before decreasing to 1.7% in 2026 and ending at 1.9% in 2027. Both final

[9] No public debt projections are available in the September 2025 Banque de France macroeconomic projections

[10] This cut date is the same as the one used in the ECB macroeconomic projections of September 2025.

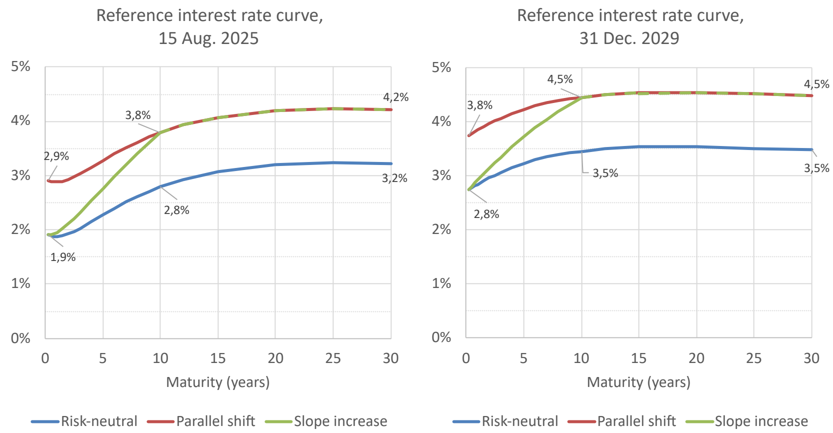


Figure 12: Market interest rate curves at the last known data point (August 2025, lhs) and at the final point of the simulation (December 2029, rhs). In the *Risk-neutral* scenario (blue), the curve follows actual observed values until 15 August 2025, after which its evolution is inferred using forward interest rates computations. In particular, the positive curve slope results in a scenario of progressive rate increase. The *Parallel shift* (red) and *Slope increase* (green) scenarios are designed as shocks over the risk-neutral scenario.

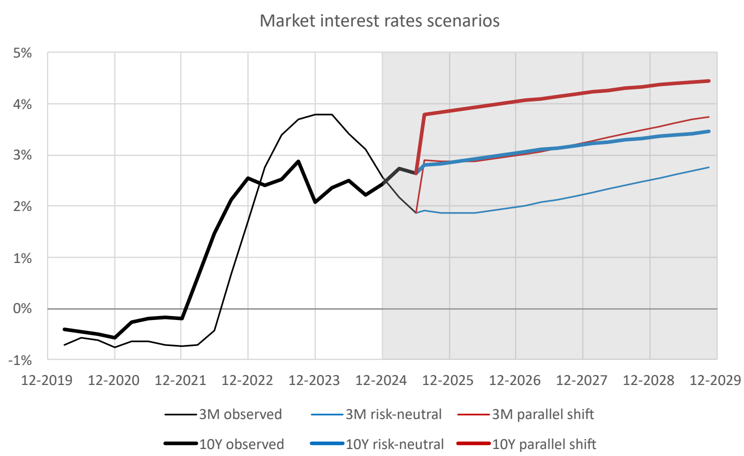


Figure 13: Individual past and projected trajectories of the 3-month (thin) and 10-year (thick) Euro area sovereign AAA yields. Blue curves represent the “risk-neutral” scenario, i.e. forward values implied by the market curve as of 15 August 2025. Red curves represent the “parallel shift” scenario, with a 1% shock above the risk-neutral one. In the “slope increase” scenario, the 3-month rate follows the blue line while the 10-year rate follows the red line.

projected values are extrapolated after 2027. For simplicity, the scenario features a smooth price increase, contrasting with historically observed price index seasonality: this only results in a different breakdown of indexing costs across quarters without affecting full-year outcomes.

3.3.2 The projected interest expense is increasing

In the risk-neutral scenario on interest rates, the model projects an increase in both the nominal and relative cost of debt on the French sovereign traded debt (cf. figure 14). Strikingly, even in the alternative scenario where debt amounts are constant (no public deficit), the nominal cost of debt is projected to increase during the entire projection. This follows from continued replacement of expired debt by issuances at prevailing interest rates, which remain on average higher than historical ones.

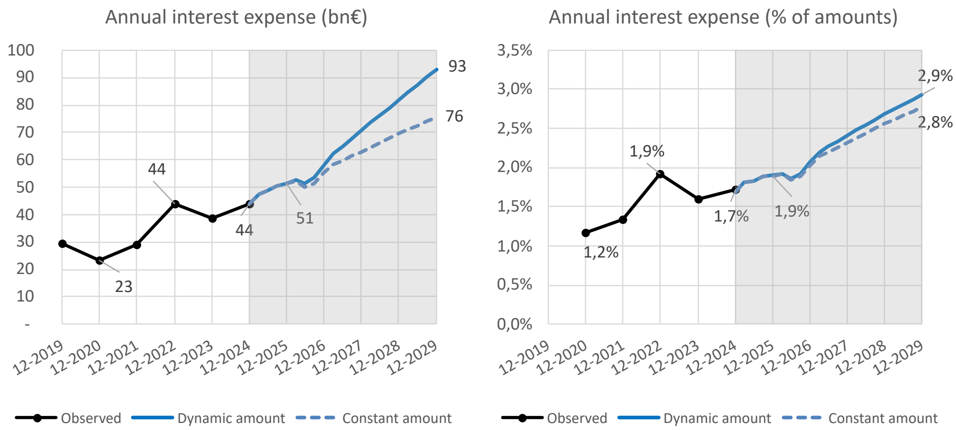


Figure 14: French sovereign traded debt cost, in nominal amounts (left) and relative to the debt amount (right). Projections start from December 2024; interest rates follow the risk-neutral scenario. In the constant amount scenario (dashed), each maturing security is renewed at the exact same nominal amount, while in the dynamic amount scenario (plain) the total amount increases over time. The yearly cost is computed as the sum of a running four-quarter window, so as to smooth out quarterly irregularities due to inflation seasonality. The odd intra-year behaviour in 2026 is an artifact of the transition from actual (seasonally irregular) values of the price indices, to projected (smooth) values.

Comparing both scenarios, about two-thirds of the overall projected rise in nominal cost of debt in the reference scenario is due to the rate environment, while the other third is due to projected new net issuances. Shifting from absolute costs in euros to the cost relative to outstanding amounts (i.e. average interest rate), the amount effect is factored out, and we find similar trajectories in both scenarios, with just a slightly higher relative costs with dynamic amounts, reflecting a larger inflow of new, more expensive debt.

Focusing now on the economically more realistic dynamic-amounts scenario, we can vary the interest rate scenario (figure 15). Comparing the outcomes of both alterative trajectories to the reference "risk-neutral" one, we get debt cost sensitivities to persistent interest rate moves.

As expected, the effects of such shifts only materialise progressively through time, as new debt is issued. The additional cost of a +100bp parallel shift is 17bn€ per year at a 5 years horizon, i.e. +52bp relative to amounts, showing that the model anticipates that new issuances will represent about half of the outstanding amounts in five years' time, consistently with the median maturity visible in figure 7.

The slope increase scenario is expectedly less severe; its importance compared to the parallel shift is initially small, but then grows to about two-thirds, reflecting the slow but steady issuance of long-term bonds, and confirming the importance of the 10-year maturity for French sovereign debt.

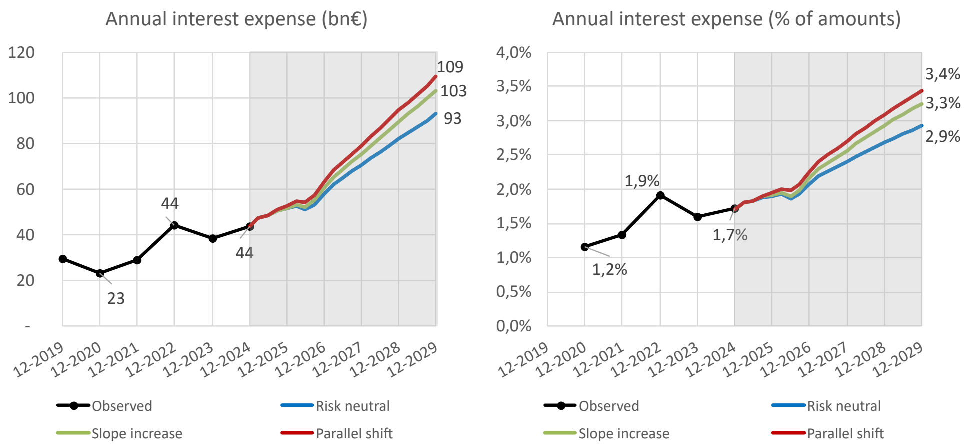


Figure 15: French sovereign traded debt overall cost, in nominal amounts (left) and relative to the total debt amount (right). Projections start in December 2024. The risk-neutral scenario (blue) is derived from the Euro area sovereign AAA market interest rate curve observed on 15 August 2025. Parallel shift of +100bp (red) and a slope increase scenario (green) between the 3-months (+0bp) and 10-years (+100bp) increase the cost of debt. Again, the 2026 twist is an artifact of the inflation scenario combined with the 4-quarter running window.

4 Application to European non-financial corporation debt

Unlike the French government, individual companies generally do not publish detailed debt-by-debt information. Until recently, available information on corporate debt mostly consisted in crude aggregate data from statistical surveys, insufficient to build a debt schedule as required to run our model. This changed with the launch of AnaCredit by the Eurosystem in 2018, that made it possible to build a near-exhaustive picture of the bank loans to corporate entities in the euro area. Completed with information on debt securities, it makes for a perfect model use case, especially as wide differences of debt structures emerge when considering aggregates by country, making it particularly interesting to compare future interest cost evolutions as projected by the model, as well as sensitivities to risk factors.

Preliminary analysis suggests that the aggregate use of derivatives by corporates to hedge their interest rate risk is of several order of magnitude smaller than their total debt amounts, and therefore remain out of scope of the present work (see Gueuder and Ray, 2022, Annex 1).

4.1 Data sources, coverage and quality

We built data sets aggregating the debt of non-financial corporations (NFCs) for each of the 20 euro area countries as of the end of 2024, based on two detailed databases maintained by the Eurosystem:

- AnaCredit (*Analytical Credit Dataset*), which records all loans extended by euro area banks to non-personal legal entities, over a 25,000€ threshold, which we limited to euro area NFC borrowers;
- CSDB (*Centralised Securities Database*), which lists all securities issued or held within

the euro area, which we limited to debt securities issued by euro area NFCs.

Both these databases provide precise information on each bank loan taken out and each debt security issued by companies, and in particular their current interest rate, type (fixed- or variable-rate), maturity and repayment schedule.

Though very extensive, these databases cover only part of companies' interest-bearing liabilities as they can be quantified using the Quarterly Sectoral Accounts (QSA), published by the European Central Bank. These accounts provide, country by country, the total amount of NFC debt instruments, i.e. debt securities and loans. For securities, the amounts can be reconciled — CSDB is actually used as a source to compute the QSA security amounts. In contrast, for loans, even considering the *consolidated* amounts, i.e. excluding loans between non-financial corporations within the same country, the coverage provided by AnaCredit is only partial, cf. figure 16.

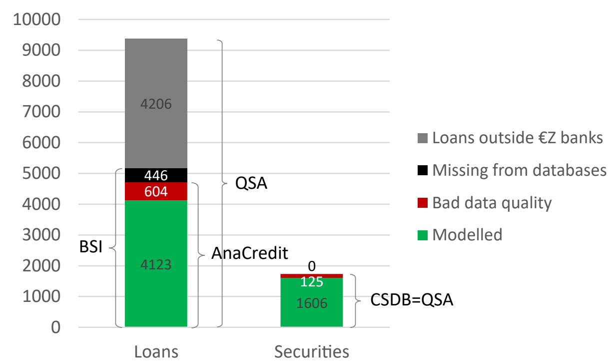


Figure 16: Euro area non-financial corporation debt amounts as of end-2024, in billion euros.
Left: National accounts (QSA) record 9379 bn€ of loans taken by NFC, excluding NFC-to-NFC loans within the same jurisdiction. The monetary statistics database (BSI) records 5173 bn€ of loans extended by euro area banks to euro area NFCs, of wich 4726 bn€ can be found in AnaCredit. Out of these, 4123 bn€ have sufficient data quality to be included our the data set and modelled.
Right: QSA record 1731 bn€ of securities issued by NFC, excluding those held by NFCs within the same country. A similar amount is found by summing individual bond outstanding amounts in CSDB, out of which 1606 bn€ have sufficient data quality.

There are two main identified reasons for this gap:

- Loans granted to companies by creditors other than banks in the euro area are not reported in AnaCredit: for example, the financing of a company by one of its foreign subsidiaries, or a loan granted by a bank in the United States, are not in scope. NFC loans taken outside euro area banks, displayed in grey in figure 16, can be quantified by comparing the overall consolidated loan amount found in QSA (summing all 20 countries) with the amount lent by euro area banks to euro area NFCs, as found in the ECB bank database on banks' balance sheets (BSI, *Balance Sheet Items*).
- The unit amounts reported in the detailed databases do not exactly add up to the aggregates calculated at national level. This may be due to threshold effects (small bank loans), incomplete or erroneous reports, or differences in sectoral classification. The mismatch is displayed in black in figure 16.

In addition, not all the data needed by the model are correctly recorded for each product in the detailed data bases, and we had to exclude some amounts, displayed in red in figure 16. In AnaCredit, about 13% of loans in terms of outstanding amounts had to be excluded because of data quality issues: mostly missing or inconsistent maturity dates (8%), and missing or inconsistent interest rates (5%). Likewise, in CSDB, 7% of debt securities in terms of outstanding amounts were excluded because of missing or inconsistent maturity dates (4%) or missing or inconsistent issuance prices (2%).

This exclusion process further reduces the coverage of the modelled debt compared to total NFC debt. Overall, the modelled debt set represents 52% of the NFC consolidated debt amounts recognised in the national accounts at end-2024, at euro area level. When splitting by NFC home country, this share varies widely, from 69% for Austria and 66% for France, down to 27% for Luxembourg or even 14% in the case of Ireland, cf. figure 17.

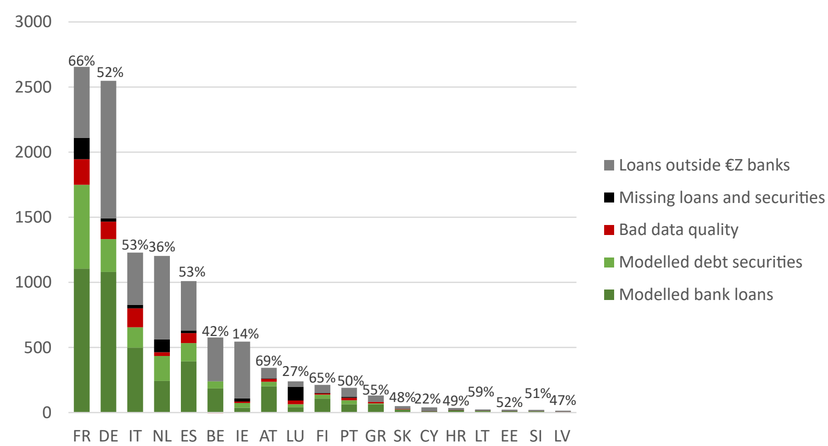


Figure 17: Coverage by country of consolidated NFC debt amounts as recorded in QSA at the end of 2024. The percentage corresponds to the ratio between green amounts (valid AnaCredit+CSDB data) and the total debt amount recorded in sectoral accounts. The coverage quality is quite heterogeneous, and falls to low levels in countries where NFCs borrow a lot from entities other than euro area banks (Ireland, Belgium, Netherlands), or with low AnaCredit coverage of loans to NFCs (Luxembourg).

4.2 Structure and evolution of NFC debt by country

First considering all euro area NFCs together, figure 18 displays the debt residual maturity structure by product type (bank loans vs. debt securities) and by interest rate type (fixed- vs. variable-rate products[11]).

The maturity profile is very smooth, as expected when combining the debt profiles of thousands of companies. 34% of the debt features a variable interest; it consists almost entirely of bank loans and tends to have a shorter maturity than fixed-rate debt. The median residual maturity[12] is 3 years and two months. This rather short time frame reflects the fact that we

[11]Some rare indexed securities are issued by NFCs; as they represent very small amounts, we merged them into fixed-rate products for simplicity.

[12]Our favoured metric is median, rather than average, maturity, as the distribution tail of very long maturities tends to skew up the average, whereas, for practical purposes, the difference between 20-year debt and 50-year

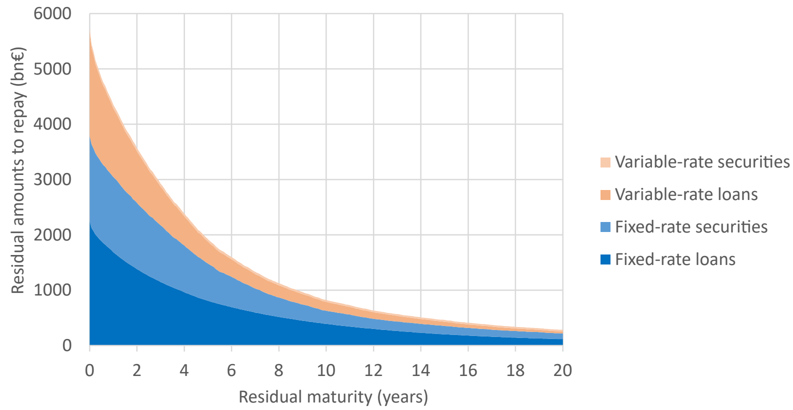


Figure 18: End-2024 structure of aggregated euro area NFC debt (modelled part). For each maturity on the x axis, y displays the principal amounts remaining to be repaid after that time elapses.

consider the *residual*, rather than initial, maturities, and that we consider actual principal payments rather than the final maturity date of each loan. This makes a large difference for the majority of bank loans which are amortising: an amortising loan with a nominal residual maturity of 6 years actually has, in terms of principal repayments, an average residual maturity of about 3 years. Very long-term debt is quite rare, but some products extend to very long periods; there are even a few perpetual bonds with no defined maturity.

Considering now the repartition of this debt by home country of the corresponding NFCs, we can compute the same indicators (median maturity and variable-rate share) for each of the 20 euro area countries, cf. figure 19

The chart shows a striking variety of profiles across countries. On the left-hand side, the debt of French, German and Dutch companies (60% of the total debt) has a fairly long median maturity — around 4 years — and pay a large majority of fixed rates (around 80%). This means that their interest expenses feature a high degree of inertia and only gradually react to any change in the interest rate environment. On the right-hand side, more than 80% of the debt taken on by companies in the three Baltic states have variable rates, with a median maturity of hardly 18 months: this profile means that interest expenses react almost immediately to any rise or fall in interest rates. Most other countries are located between these two profiles, with a small group (Austria, Finland, Greece) combining longer maturities with a large share of variable rates.

Figure 18 in appendix details the debt profile for a selection of these countries. The amplitude of cross-country differences of debt profiles is remarkable; an explanation of this finding is outside the scope of this paper and would make for a research topic of its own.[13]

Since the model assumes that debt keeps a stable residual maturity structure, we check this assumption by computing the evolution of the residual maturity schedules by rate type, cf.

debt is negligible over the horizons we consider in this paper. In addition, perpetual debt cannot be included in an average computation, whereas a median can still meaningfully include it.

[13]Potential factors of debt structure heterogeneity include banking traditions, repartition of NFCs by activity sector, legal or fiscal treatment of debt and interests, or market infrastructure.

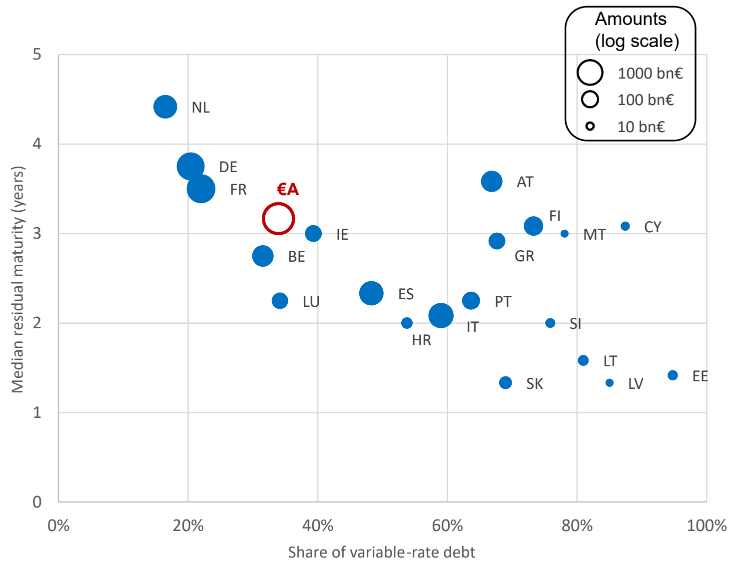


Figure 19: End-2024 structure of aggregated NFC debt by home country (modelled part): median residual maturity and share of variable-rate debt. Circle sizes represent the debt amount by country, on a logarithmic scale for readability. The aggregate euro area NFC debt is displayed in red.

figure 20.

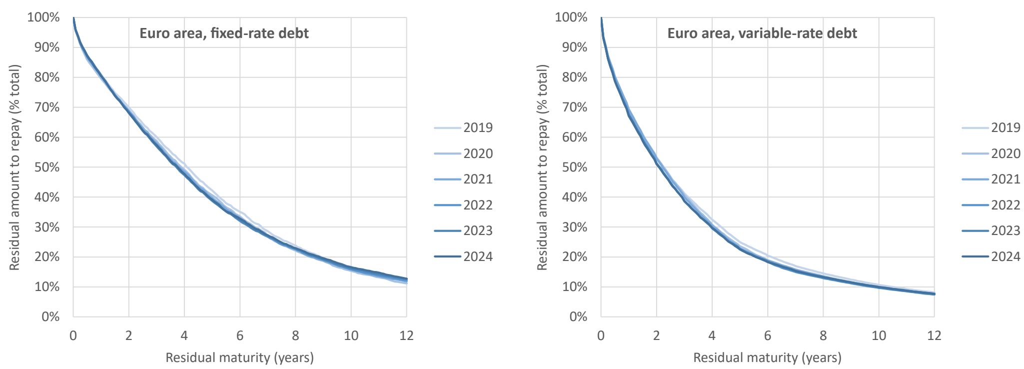


Figure 20: Evolution of the residual maturity structure for aggregate euro area NFC debt (modelled part).

At the aggregated level of the euro area, the structure is quite stable, with only a slight shortening in 2020 for intermediate maturities. This holds separately for the fixed-rate and variable-rate parts of the debt — in practice only the fixed-rate maturity schedule matters, since the variable-rate debt interest rate risk is lowly maturity-dependent.

When considered country by country, larger shifts appear, cf. figure 21 for the fixed-rate maturity schedules of the four largest national economies.

While the German NFC debt structure remains very stable, a noticeable shortening occurred in 2020 in France and Spain, in connection with the CoViD-19 crisis. The schedule in Italy has followed a more complex combination of lengthening of short-term debt (< 3 years) and shortening of long-term debt (> 4 years).

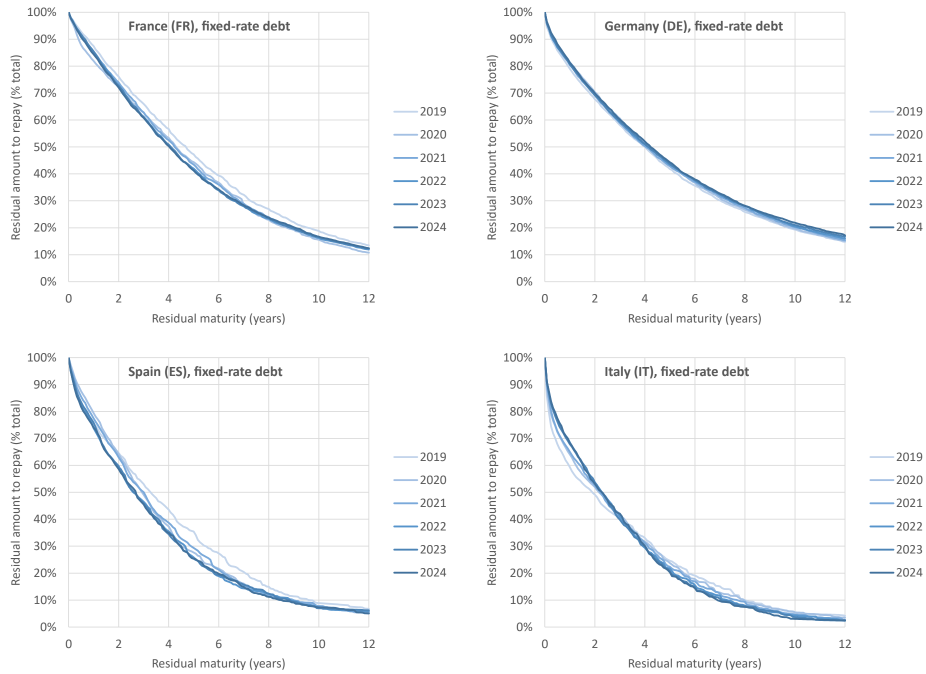


Figure 21: Evolution of the fixed-rate residual maturity structure for NFC debt of the four largest countries.

Overall, the NFC debt structure appears to move rather slowly, outside extraordinary events. The model assumption of stable structure is therefore reasonable at least for short-term projections.

4.3 Model performance

Ideally, the model performance for NFC debt should be checked by a back-testing method similar to the one detailed in section 3 for the French government debt. However, there is no known independent source providing the actual interest charge of the consolidated NFC debt of euro area countries.[14] Even if there were, the perimeter limitations discussed in section 4.1 would prevent a direct comparison with modelled interest rate charge.

Still, an approximate interest charge can be inferred from observed debt structures: e.g. for a quarterly time step, the quarter-end amount-weighted interest rate can be used as a proxy to compute the interest charge of the whole quarter. This computation is actually performed by the model itself at the start of each simulation: hence the 2021Q4 interest charge, as estimated by the end-2021-starting model, can be used as a benchmark to check the accuracy of the 2019- and 2020-starting models.

The results of that back-testing are displayed in figure 22, first for simulations using actual

[14]The sectoral accounts (e.g. ECB's QSA database) do provide a measure of aggregate NFC interest rate charge, as the debit part of aggregate D41G ("Total interest before financial intermediation services indirectly measured (FISIM) allocation") represents the total interest paid by a given economic sector. However, it is only computed at the non-consolidated level, which means that e.g. interest paid by French NFCs includes interest paid to other French NFCs.

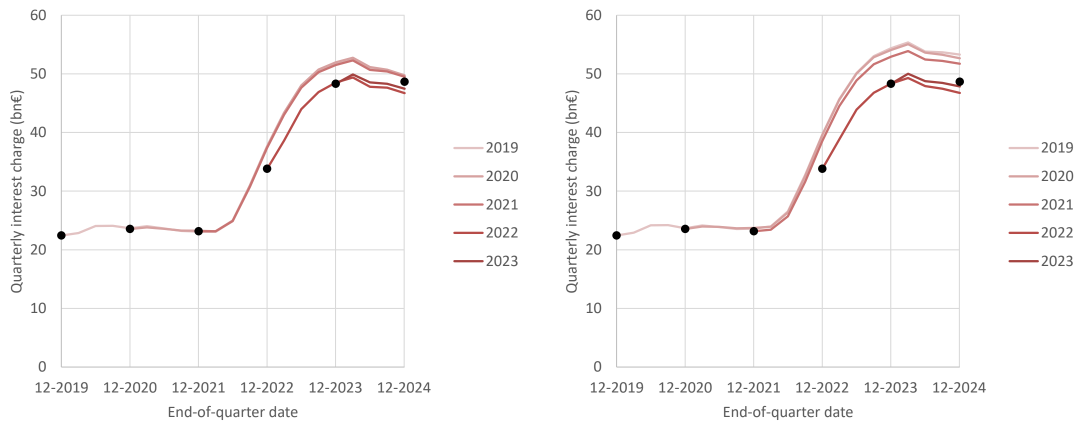


Figure 22: Model back-testing for the aggregate euro area NFC debt. Each black dots represents the starting point of one model run, i.e. the estimated quarterly interest charge computed from the observed year-end data only. Each red lines represent the modelled evolution of that quarterly charge. On the left-hand side the modelled issuance spreads are the observed ones; on the right-hand side they are assumed to remain constant on each simulation.

issuance spreads, second using the model assumption of constant spreads. In both cases the model performs very well except in 2022: projections starting before that date yield a significant and lasting over-estimation of the 2022 rise in interest rate charge.

To better understand these effects, we can split each set of results into a fixed-rate and a variable-rate part, cf. figure 23 (with actual spreads) and 24 (with constant spreads).

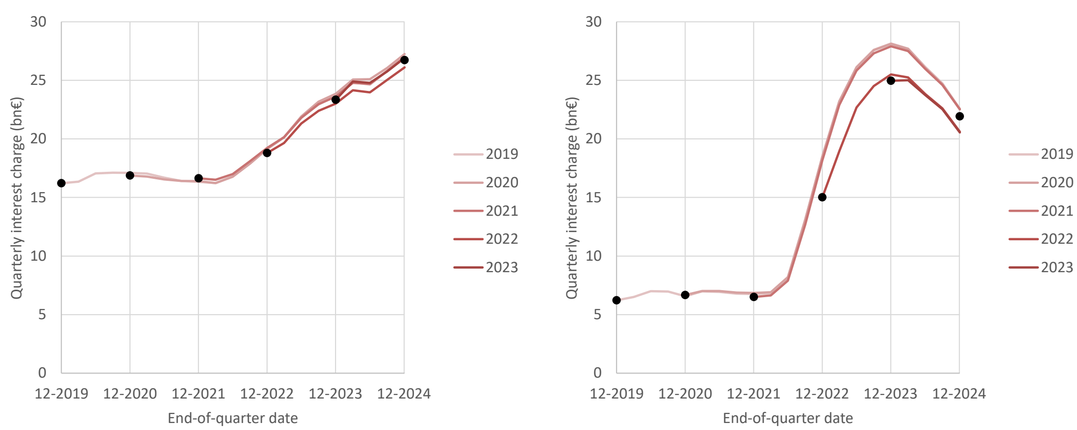


Figure 23: Separate model back-testing, with observed issuance spreads, for the fixed-rate part of the debt (left) and for the variable-rate part (right).

Using actual spreads (figure 23), the model performs remarkably well on the fixed-rate debt. In spite of using quarterly time steps, the back-testing quality is significantly better than for the French government debt. Indeed the aggregate NFC maturity schedule is very smooth, so that no significant issuance regularisation is needed as it was the case for French government debt. The whole of the 2022 deviation is attributable to variable-rate debt: the actual interest rate on that debt, as seen in the databases, has varied less during the 2022 rate hike than the model predicted — the modelled effect of the shock is over-estimated by about 3 bn€ per quarter, i.e. about 60 basis points in terms of annualised interest rate.

This one-off deviation is explained by the legal interpretation of variable rates during the negative-rate period: between 2015 and 2022, the negative values for benchmark euro rates such as EURIBOR have generally been floored at zero for variable-rate interest purposes. Hence, most variable-rate interests did not react when the rates rose from -0.5% to zero in the second quarter of 2022, and only picked up the hike when rates reached positive territory[15]. This behaviour could be captured by adding a floor on the proxy reference rate used by the model: such an improvement, that would be useful to model scenarios where rates go negative again, would require careful calibration given the variety of benchmark rates and practices regarding the zero-rate floor.

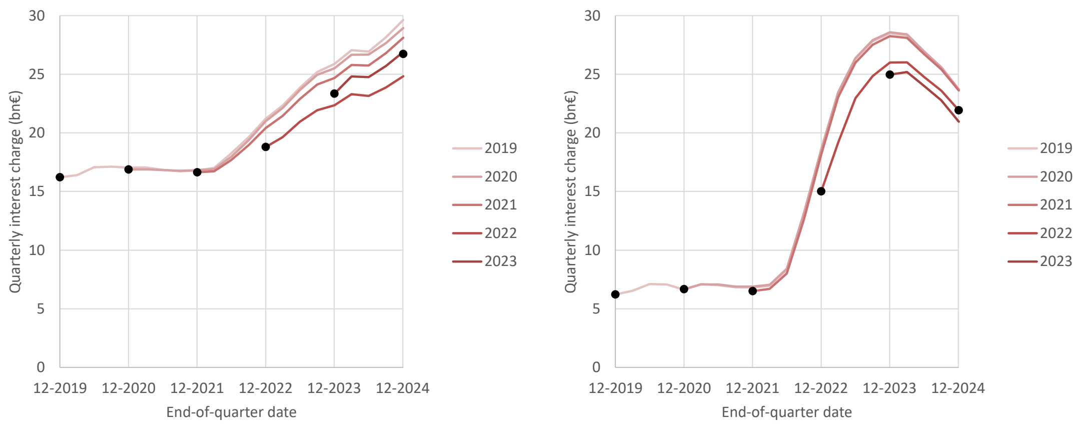


Figure 24: Separate model back-testing, with issuance spreads assumed constant, for the fixed-rate part of the debt (left) and for the variable-rate part (right).

When using a constant-spread assumption (figure 24), the model performance for variable-rate products is not significantly affected, but there is a clear deterioration of the model quality on the fixed-rate products. This reflects the observation that the interest rates for bank loans rose far more slowly in 2022–23 than the market rates, as the banks were unwilling to pass on the whole interest rate shock to their corporate borrowers. The issuance spread was thus temporary much lower for fixed-rate loans in 2022 and 2023, leading to a slower increase in interest charge than the constant-spread model predicted.

4.4 Projecting the interest expenses of European non-financial companies (2024–29)

We project the average interest rate paid by European NFCs over a 5-year horizon, starting from the known structure of their debt, aggregated by country, as of December 2024.

For the purpose of this projection, we consider debt sets defined by the *country of residence* of the debtor, the type of debt product (*bank loan* or *debt securities*), its type of interest rate (*fixed* or *variable*), and its rating for securities, summarised by whether it is in the *investment*

[15]Although the zero floor explains most of the deviation, a small additional shift seems to be attributable to data quality issues, as some banks seem to forget to change interest rates for variable-rate loans in AnaCredit.

grade category, or *high-yield*. Such a partition leads to 87 debt sets, on which 87 different spread values are estimated.

4.4.1 Debt amount scenario

Taking advantage of our choice to use a one-size-fits-all reference interest curve, the baseline market interest rate scenario is exactly the same as the one used for projecting the average cost of debt of the French sovereign market debt (Figures 12 and 13). Only the debt amount scenario differs.

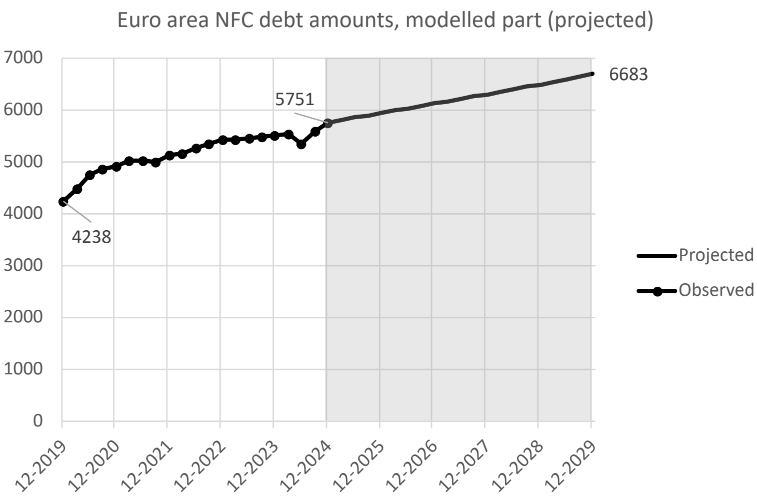


Figure 25: Non-financial corporates debt amount scenario. Past observed total Euro area debt amounts extracted from AnaCredit and CSDB after data quality filters (black dots) are extrapolated following an indicative 3% average annual growth rate (black line). The apparent drop in June 2024 results from a temporary AnaCredit data quality issue (large number of loans with invalid interest rate type).

Unlike the case of the French Sovereign debt, there is no macroeconomic projection available for NFC debt amounts. For the sake of the exercise, we assume that the debt amount of European NFCs increases uniformly with an annual growth rate of 3% (Figure 25), extrapolated from recently observed evolutions. In the case of NFCs, nominal interest amounts in euros have little interest in themselves, given the significant data gap between our inputs and actual debt amounts evidenced in figure 16, so that we will restrict ourselves to showing effective interest rate trajectories. The details of the debt amount scenario is then of limited importance since, as the French Sovereign cost of debt projections show, the average cost of debt dynamics is lowly sensitive to new amounts issued when expressed as a percentage of outstanding amounts.

4.4.2 A U-shaped trajectory for the cost of debt of European NFCs

Running the baseline market interest rate scenario on the NFC debt of the 20 euro area countries, we obtain the 2025–29 projections for each of the 20 average effective interest rates, displayed in figure 26, alongside the estimated past values of these interest rates as computed from the data. While the various costs of debt have diverged between 2022 and 2024 with the rapid interest rate changes[16], the projection forecasts a future convergence, with the NFCs' cost of debt of most countries following a U-shaped pattern consistent with the interest rate scenario.

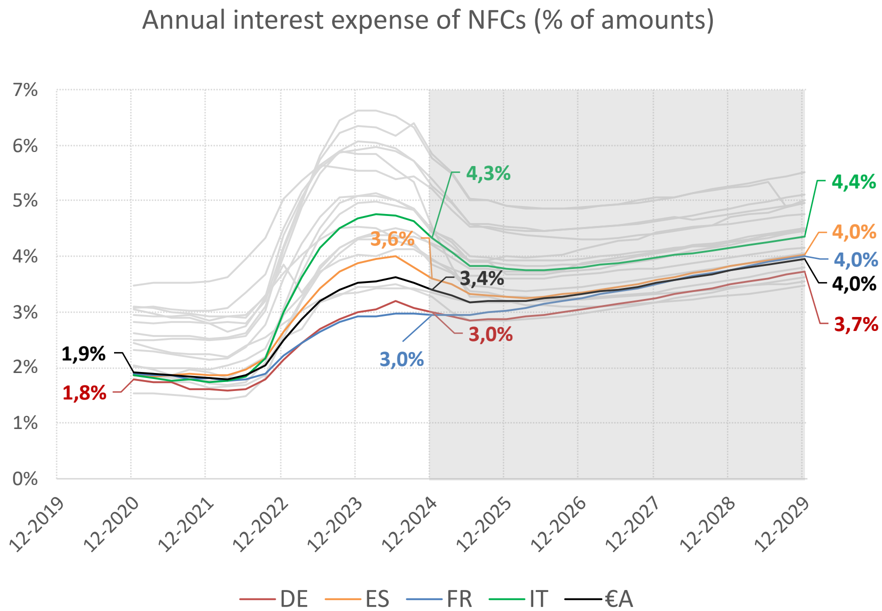


Figure 26: Average interest rate of the current debt of euro area non-financial corporates, aggregated by country. The four largest countries, as well as the aggregate euro area, are singled out in colour; the other 16 countries are left in grey for readability. Past rates are computed from actual interest rates read in Ana-Credit/CSDB; 2025–29 rates represent the model's projection of quarterly interest expense in the baseline ("risk-neutral") scenario.

On the short term, the projection features declining costs for countries with more short-term and variable-rate debt, a direct consequence of lower interest rates, that mirrors the sharper rise in costs in 2022–23. For countries with more long-term and fixed-rate debt, where the 2022–23 cost increase was much smaller, the 2025 cost decline is small or even (for French NFCs) absent, as a significant amount of low-rate pre-2022 debt is still outstanding, so that the gains from lower short-term rates are cancelled out by the losses from rolling over cheap maturing debt.

On the longer term, the slow increase in cost of debt in 2026–29 can be traced back to the scenario's slow but persistent interest rate rise. Absent any brutal market interest rate variations, the consequences of debt structure heterogeneity are not directly visible, but the overall increase in average interest rate appear to be projected higher for countries with longer debt structures: between Dec. 2024 and Dec. 2029, the model projects an average increase

[16] Simple descriptive statistics allow to qualitatively assess the link between shorter term debt structure and market interest rate, taking advantage of the general interest rate rise of 2022 and 2023, as developped in Gueuder and Ray (2024). This work has been updated in Appendix F.2.

of 0.5% for Italian NFCs, compared to 1.5% for French NFCs or 1.2% for German NFCs. This can be understood both in terms of the persistence and slow disappearance of old debt contracted in a low market rate environment, and in terms of a upward-sloping term structure featuring more expensive interest rates for longer maturities.

Structural differences are more obvious when turning to alternative interest rate scenarios. We use the same two scenarios as for the French government debt: a parallel 100bp shift and a slope increase, both built on top of the reference risk-neutral scenario (cf. figures 12 and 13).

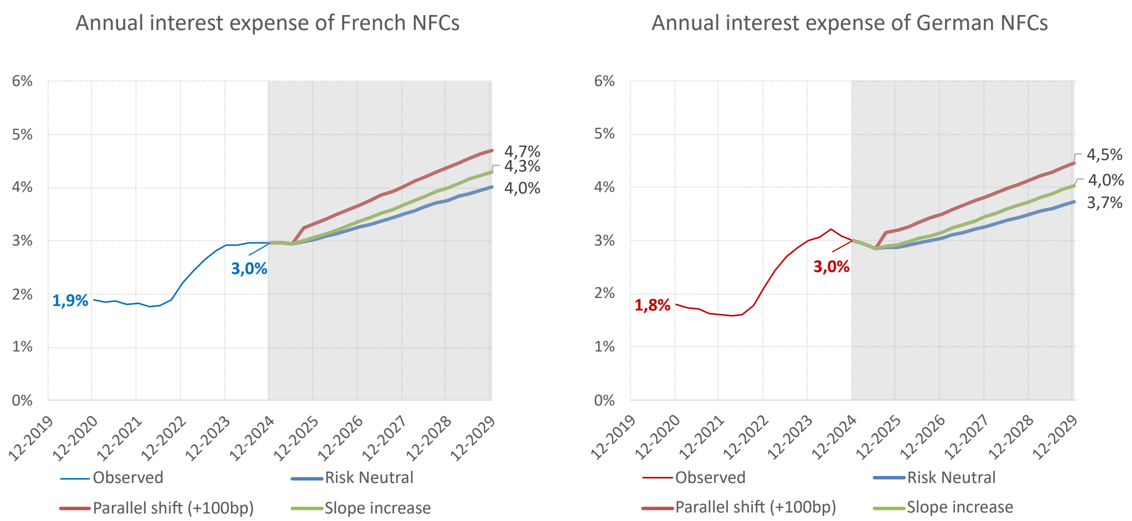


Figure 27: Interest rate cost sensitivity to interest rates for aggregate French and German NFCs. The debt structure in these countries is largely long-term and fixed-rate, hence the delayed effect of a parallel rate shift, and the comparatively high cost of a slope increase.

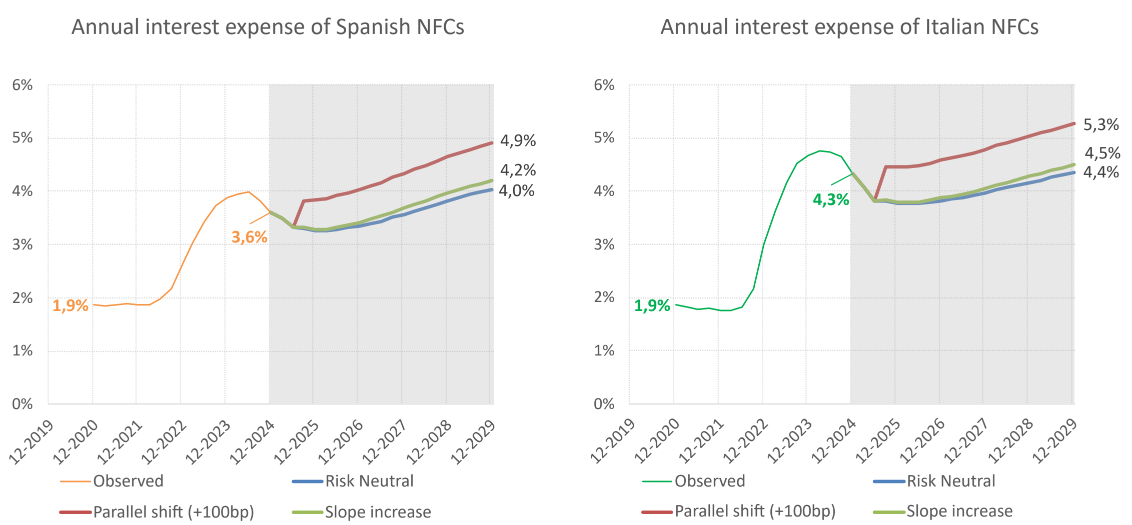


Figure 28: Interest rate cost sensitivity to interest rates for aggregate Spanish and Italian NFCs. The debt structure in these countries is more short-term and variable-rate (Italy more than Spain), hence the immediate effect of a parallel rate shift, and the limited cost of a slope increase.

Isolating the four largest economies of the Eurozone, we confirm the expected sensitivity differences between long-term, fixed-rate debt (France and Germany, figure 27) and shorter-term, variable-term debt (Spain and Italy, figure 28).
In the parallel shift scenario (table 3), the average cost of debt of European NFCs increases abruptly for Italian or Spanish NFCs, whereas the effect on French and German ones is initially low and only builds up progressively, consistently with their respective debt structures. After 5 years of projection, the entire +100bp shock on market interest rate has not yet been fully transmitted to the total debt amount: as shown on figure 21, the NFCs of each of these countries have some fixed-rate debt with residual maturities higher than 5 years, which would not have been refinanced at the simulation horizon.
The slope increase scenario (table 4) quantifies how much company borrowing costs are affected by longer-term interest rates. In this scenario, and after 5 years, the French and German NFCs are projected to pay on average 29bp and 31bp more on their debt compared to the reference scenario, whereas Spanish and Italian NFCs, where long-term funding plays little role, are hardly affected (+18bp and +14bp).

Parallel shift	France	Germany	Spain	Italy
After 1 year	+39	+42	+66	+74
After 2 years	+50	+54	+75	+80
After 5 years	+69	+72	+88	+91

Table 3: Differences in cost of debt between the *parallel shift* scenario and the *baseline* scenario, in basis point. The table reads as follows: one year after the August 2025 *+100bp* parallel shift shock, the average cost of debt of French NFCs is 39bp higher than in the baseline scenario.

Slope increase	France	Germany	Spain	Italy
After 1 year	+ 9	+10	+ 6	+ 4
After 2 years	+15	+17	+10	+ 7
After 5 years	+29	+31	+18	+14

Table 4: Differences in cost of debt between the *slope increase* scenario and the *baseline* scenario, in basis point. The table reads as follows: two years after the August 2025 slope increase shock, the average cost of debt of German NFCs is 10bp higher than in the baseline scenario.

5 Conclusion

The cost of debt of economic agents can be modelled and projected, following a simple financial approach, provided enough data on their debt structure. Such a model performs reasonably well when back-tested in the 2022–23 rising market interest rate environment in Europe, on several portfolios such as the French sovereign market debt, and the debt of European NFCs aggregated by country. These portfolios are both well-documented enough to extract precise accounts of their structures, (from public data in the case of the French government, or from Eurosystem detailed loan and market debt data in the case of NFCs), and large enough to verify the model hypothesis of a stable debt structure, at least on the short and medium run. Depending on data availability, new use cases may be onboarded to forecast interest cost evolution for other structurally important debtors such as the United States Treasury.

Several leads to further developments can be pursued to improve the model: First, the model is symmetric, as no anticipated payments are modelled; yet, for some asset classes such as retail bank loans, anticipated payments can play a crucial role in times of diminishing market interest rates, and reduce the cost of debt. Second, the constant-structure assumption may be relaxed to quantify the consequences of potential future changes in debt structure, which requires alternative ways of assigning new debt issuance by maturity.

Finally, beyond the financial consequences of debt structure outlined by our work, empirical studies would be needed to understand the factors underlying the large heterogeneity observed across categories of debtors, and in particular cross-country differences for NFCs.

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A Amortizing debt

A debt schedule must feature a chronicle of all future principal amount payments. In most instrument-per-instrument data, these chronicles must be reconstructed: raw data usually keep track of the *final maturity date* of the debt facility — that is the date of its final payment, which does not by itself summarize the entire schedule of principal amount payments. The latter depends on the principal repayment scheme:

- For *in fine* (or "bullet") instruments, no principal payment takes place before maturity;
- For amortised instruments, the principal is repaid progressively until maturity.

While most debt securities feature *in fine* repayment, amortisation is very common in bank loans to non-financial corporations. This appendix details how the debt model handles it.

In principle, a very wide variety of loan repayment schedules are possible : e.g. the borrower and lender could agree that half the principal is paid after two years and the other half after three years. While such *ad hoc* arrangements do exist, the study of AnaCredit loans to NFCs shows that amortisation schemes mostly follow one of two standard models:

- Linear amortisation: a constant fraction of the principal is repaid at each interest payment date;
- Constant-annuity amortisation: the principal repayment in spread over interest payment dates in such a way that the total payment (principal+interest) is the same for each date.

Examples for these two schemes are provided in table 5.

Year	Linear amortisation			Constant annuity		
	Principal	Interest	Total	Principal	Interest	Total
1	**100**	50	150	80	50	**130**
2	**100**	45	145	83	46	**130**
3	**100**	40	140	88	42	**130**
4	**100**	35	135	92	37	**130**
5	**100**	30	130	97	33	**130**
6	**100**	25	125	101	28	**130**
7	**100**	20	120	107	23	**130**
8	**100**	15	115	112	18	**130**
9	**100**	10	110	117	12	**130**
10	**100**	5	105	123	6	**130**
Total	1000	275	1275	1000	295	1295

Table 5: Standard amortisation schemes for a 10-year loan with annual payments: the initial principal is 1000 and the fixed interest rate is 5%. With linear amortisation, principal payments are constant and interest payments decrease with the residual principal. With constant annuity, the total payment (principal+interest) is constant; accordingly, principal payments get higher as the loan nears its end.

Amortisation cannot be neglected when analysing debt maturities. Indeed, taking intermediate payments into account, the average duration of an amortising banking loan is about *half* the remaining time to its final maturity. Table 6 shows how important amortisation is when building the maturity structure of NFC loans, in the case of the aggregate bank loans to French NFCs as extracted from AnaCredit as of December 2024: although only 12% of loans (by outstanding amount) have their final maturity in 2025, 25% of the outstanding principal are due be repaid that year, the gap being due to the progressive repayment of longer-maturity amortising loans.

Year	Current principal of loans maturing that year		Principal to be repaid	
2025	134	*12%*	280	*25%*
2026	97	*9%*	168	*15%*
2027	92	*8%*	129	*12%*
2028	92	*8%*	104	*9%*
2029+	692	*63%*	423	*38%*
Total	1,105	*100%*	1,105	*100%*

Table 6: Schematic maturity structure of French NFC bank loans as of end-2024 (source: AnaCredit). The total outstanding principal (1,105 billion euros) is apportioned in the left-hand column by final maturity of the loan. This ventilation differs widely from the actual amounts to be repaid each year (right-hand column). Indeed, most loans are amortising, so that their principal repayment is spread out.

In practice, we use AnaCredit information on loan amortisation type to assign each loan to one of three schemes:

- type=4: Bullet;
- type=3: Fixed amortisation;
- other values: Constant-annuity. This includes types 1 (“French”), 2 (“German”), and 5 (“Other”). The only difference between French and German types is the amortisation start date, that can anyway be read in a separate field in AnaCredit. The default assignment of “Other” amortisation schemes to Constant maturity is motivated by the overall predominance of that scheme.

Given the amortisation scheme, we derive the principal payment schedule for each loan. Payment frequency, which has a limited impact on in interest rate risk, is assumed for simplicity to be monthly for all amortised loans. The payment of the outstanding amount is therefore spread over each month between then end of the interest-only period (or the current date if that date is past) and the final maturity date, both dates being provided in AnaCredit.

For fixed-amortisation loans, the outstanding amount is spread evenly across dates. For constant-annuity loans, standard actuarial computations yield the following formula for monthly principal payments:

$$P_T(k) = \frac{1 - \left(1 + \frac{R}{12}\right)^{-1}}{1 - \left(1 + \frac{R}{12}\right)^{-T}} \times \left(1 + \frac{R}{12}\right)^{-(T-k)} P,$$

where T is the number of months over which amortisation is performed, P is the principal amount to amortise, $P_T(t)$ is the principal amount paid at the kth month, and R is the annualised interest rate. This formula ensures that the principal is repaid in whole ($\sum_{k=1}^{T} P_T(k) = P$) and that the sum of principal and interest payments is the same each month ($P_T(k) + \frac{R}{12} \times \sum_{l=k}^{T} P_T(l) = \frac{\frac{R}{12}P}{1-\left(1+\frac{R}{12}\right)^{-T}}$ independent on k).

In the special case of floating-rate amortising loans, the "constant-annuity" case is actually no longer constant, and the principal payment schedule should be recomputed at each interest rate reset. We choose to neglect this feature and to use a deterministic repayment scheme computed with the interest rate prevailing at simulation start date, since the effects of schedule change on interest cost are by nature second-order.

B Interest expense computation in amortised cost

The object of the model is interest *expense*, an accounting quantity feeding in the income statement of the borrower. Though closely related, it not completely aligned with actual interest payments. It is useful to remind here how interest expense is computed in general when using amortised cost accounting.[17] In particular, we detail the accounting conventions for the interest costs in the special cases of indexed debt and issuance discounts.

B.1 Nominal interest expense

Interest expense is a straightforward quantity in the simple case where the debt is contracted at par with predictable interests. For instance, if a company takes out a 100 M€ bank loan, payable at final maturity, with a fixed interest rate of 3.4% payable annually, then the interest expense for the company each year equals the 3.4 M€ yearly payment it issues to the bank.

Even then, the accounting representation of that expense differs from the actual payments, in that the expense is smoothed out over the year through the concept of *accrued interest*. For instance, if the 3.4 M€ payment to the bank is due on 25 October of each year, then no interest payment is made in the first three quarters of the year. However, the quarterly financial statements smooth this out and recognise an interest expense of 850,000 € each quarter. As a consequence, interest expense does not depend on interest payment frequency: the interest expense is the same for a 3.4 M€ annual payment as for a 1.7 M€ semi-annual payment.

Generically, a debt amount N with an annualised interest rate R yields, for a period of time of length Δ (measured in years), the interest expense:

$$InterestExpense_{t \to t+\Delta} = N \times R \times \Delta.$$

[17] In international financial reporting standards, amortised cost is the default accounting method for financial liabilities, cf. IFRS9 §4.2.1.

This very simple formula must be refined to account for two less straightforward ways of producing interest: issuance discounts or premia, and principal indexation. In both cases, the same general principle of smoothing out the expense applies.

B.2 Accounting for issuance premia and discounts

In many cases, the initial borrowed amount differs from the final repaid amount. This happens, for instance, when a bond is sold out to investors at a price which differs from par or, equivalently, when it offers some premium upon repayment. Even for bank loans, the bank may ask for upfront fees which decrease the amount effectively received by the borrower. Defining the *principal* as the non-interest amount due to be repaid at maturity,[18] the *issuance discount* is the difference between the principal and the effective amount initially received by the borrower, assuming it to be lower — a negative issuance discount is an *issuance premium*.

Consider the case of a 100 M€ 5-year bond with a 3.4% coupon issued at a price of 95%: the company initially receives 95 M€, pays 3.4 M€ each year, then repays 100 M€ after 5 years. The 5 M€ difference between the amounts the company paid and the amount it originally received is an interest expense, which must be added to the 17 M€ paid in coupons. Instead of concentrating these 5 M€ in the interest expense of the first year, or of the last year, the accounting convention is to smooth it out over the whole lifetime of the debt instrument.

Though this could be done linearly (1 M€ per year in the above case), the actual accounting rule is to compute an *effective interest rate*, defined as "the rate that exactly discounts estimated future cash payments or receipts through the expected life of the financial asset or financial liability to the gross carrying amount of a financial asset or to the amortised cost of a financial liability" (IFRS 9 Appendix A). Mathematically this writes:

$$IssuePrice = \sum_k Coupon_k \times e^{-yt_k} + Principal \times e^{-yT},$$

where $IssuePrice = Principal - Discount$ is the original issuance price (95 M€), which is also the initial accounting value of the issued security as a liability for the borrower; $Coupon_k$ is the kth coupon amount, paid as interest at time t_k after issuance (3.4 M€); $Principal$ is the principal paid at final maturity T after issuance (100 M€); y is the effective interest rate to be computed, here expressed in continuous-time convention.

In our implementation, we skip over the complexities created by the interest payment schedule[19] and use an approximation considering coupon payments to be continuous, i.e.:

$$IssuePrice = AnnualCoupon \times \frac{1 - e^{-yT}}{y} + Principal \times e^{-yT}.$$

[18] This simple definition may not be legally exact, but is a convenient convention in this exposition.

[19] With e.g. yearly interest payments, the accounting practice typically separates the current accrued interest, registered as a linearly growing liability, from the bulk of the loan, whose accounting value is computed by discounting all of the following cash flows at the effective interest rate. The time evolution of both quantities is registered as interest cost; when a coupon is paid, the accounts are balanced by the accrued interest falling back to zero. With the continuous-coupon approximation, accrued interest is always nil and only the discounted cash flows need to be tracked.

In the example above, this solves as an effective interest rate $y = 4.52\%$.

As time passes, the carrying amount for the debt instrument is recomputed using the same formula limited to residual cash flows, keeping a constant value for the effective interest rate y, i.e.:

$$CarryingAmount_t = AnnualCoupon \times \frac{1 - e^{-y(T-t)}}{y} + Principal \times e^{-y(T-t)}.$$

The carrying amount thus goes smoothly from its initial value $CarryingAmount_0 = IssuePrice$ to its final value $CarryingAmount_T = Principal$. This can be expressed more simply in terms of the updated discount value $Discount_t = Principal - CarryingAmount_t$:

$$Discount_t = Discount_0 \times \frac{1 - e^{-y(T-t)}}{1 - e^{-yT}}.$$

The interest expense between times t and $t + \Delta$ is then computed by summing the actual cash flows and the increase in carrying amount, i.e. the decrease in discount:

$$InterestExpense_{t \to t+\Delta} = AnnualCoupon \times \Delta - Discount_{t+\Delta} + Discount_t.$$

In the case of an issuance discount ($IssuePrice < Principal$), the effective interest rate is larger than the nominal interest rate ($y > \frac{AnnualCoupon}{Principal}$): the progressive decrease of the discount is added to the coupon payment as an extra interest cost. Conversely, in the case of an issuance premium ($IssuePrice < Principal$), the effective interest rate is lower than the nominal interest rate and the carrying amount decreases over time: the interest cost is lower than coupon payments. The limit case of par issuance corresponds to an effective interest rate equal to the nominal interest rate, so that the carrying amount remains constant, equal to the principal.

When building the debt schedule at model start date, we track the total principal, the net premium/discount and the annual coupon for each debt set and maturity bucket. A given bucket may aggregate debt instruments with several different effective interest rates: in such a case, a single effective interest rate is attributed to the bucket, computed as the average of all effective interest rates, weighted by carrying amount. Though this does not exactly reproduce the way the discounts spread over time with separate effective interest rates, the error remains second-order.

B.3 Accounting for indexed debt

Unlike variable-rate debt, where market conditions affect the *interests*, indexed-linked debt is characterised by changes in the *principal*. In most cases, the principal *and* coupon are both rescaled following the variations of a consumer price index, cf. section 3.1 for the case of French inflation-indexed sovereign bonds. From an accounting perspective, this increase in principal is registered as an interest expense, to be added to the expense linked to nominal interest payment and to the discount amortisation.[20]

[20] Consistently with the convention adopted by the French government for its accounts, the discount/premium amortisation ignores indexing effects subsequent to issuance.

When dealing with indexed debt, the initial schedule sums, for each debt set and maturity bucket, the value of the principals and annualised coupons as they stand at the model start date given the value of the index so far; it then evolves it based on the index evolution specified by the scenario. Accordingly, the equations of evolution applied by the model in the generic case of an indexed debt instrument with initial discount are as follows:

$$\begin{aligned} Principal_{t+\Delta} &= Principal_t \times \frac{Index_{t+\Delta}}{Index_t}, \\ AnnualCoupon_{t+\Delta} &= AnnualCoupon_t \times \frac{Index_{t+\Delta}}{Index_t}, \\ Discount_{t+\Delta} &= Discount_t \frac{1 - e^{-y(T-(t+\Delta))}}{1 - e^{-y(T-t)}}, \end{aligned}$$

$$\begin{aligned} InterestExpense^{nominal}_{t \to t+\Delta} &= AnnualCoupon_{t+\Delta} \times \Delta, \\ InterestExpense^{discount}_{t \to t+\Delta} &= Discount_t - Discount_{t+\Delta}, \\ InterestExpense^{index}_{t \to t+\Delta} &= Principal_{t+\Delta} - Principal_t. \end{aligned}$$

Note also that, when modelling future debt issuance, we assume zero discount for newly issued debt.

C The not so simple rules of new debt issuance

When simulating new debt issuance (cf.section 2.2.3), the central model assumption is that the maturity structure of each debt set in the model remains stable. This hypothesis, substantiated by data (figures 9 and 20), considerably simplifies scenario design, since only total amounts per debt sets remain to be specified. However, it cannot be strictly enforced when debt schedules are not decreasing in maturity, so that extra modelling choices are needed in such cases.

Consider a debt set for which the initial schedule at $t = 0$ specifies amounts[21] $Amount_{0,i}$ for each maturity bucket i. The total amount of debt in this set is $Amount_0 = \sum_i Amount_{0,i}$.

Then per the stable debt structure hypothesis, given a future amount for this debt set at a future time $t > 0$, as specified by the scenario ($ScenarioAmount_t$), the breakdown by maturity bucket should be:

$$TargetAmount_{t,i} = ScenarioAmount_t \times \frac{Amount_{0,i}}{Amount_0}.$$

When evolving from step $t-1$ to step t, the debt set already has outstanding amounts $ResidualAmount_{t,i}$ resulting from its natural evolution as described in the first modelling step (section 2.2.1): outside short-term debt, which goes extinct, the rest of the debt set is still present, with shorter maturities and, where adequate, reindexed principals and amortised

[21] Here "amounts" refer to the total carrying value, including indexing effects and/or issuance premia or discounts as appropriate. In the notations of appendix B.3, $Amount = Principal - Discount$.

issuance discounts. Hence the target debt amount to be issued for each maturity bucket should be:

$$TargetIss_{t,i} = TargetAmount_{t,i} - ResidualAmount_{t,i}.$$

If all of these quantities are positive, the model applies this issuance strategy as such, as illustrated in figure 5(d).

However, in some cases, there are some negative values for $TargetIss_{t,i}$, in which case the target profile cannot be restored since it would require negative amounts of new debt.[22] This happens, for instance, when the initial amounts are locally increasing in maturity and the total target amount is stable, cf. figure 29.

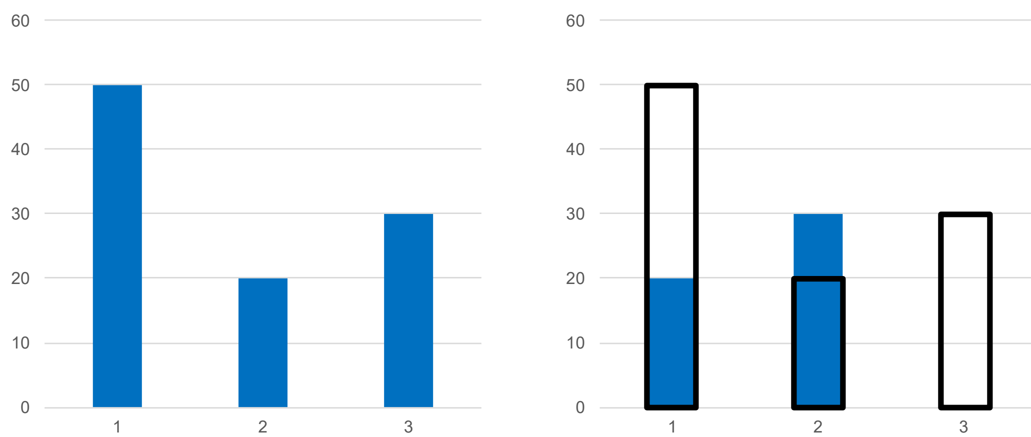

Figure 29: Example of a locally increasing debt maturity profile, represented by amounts at each maturity bucket: initial state at $t = 0$ (left) and its natural evolution at $t = 1$ after removal of expiring debt (right). New issuance cannot recover the original structure, represented by black frames on the right, since at maturity=2 the residual amount is already higher than the target amount.

To handle such cases, the model accepts a degree of deviation from the target maturity profile, while preserving, if possible, the total target amount: in practice this means issuing no debt at maturities where the target issuance amount is negative, and compensating by issuing less-than-target amounts of debt elsewhere.

Two polar cases are implemented in the model; the user can choose one or the other, or a weighted average of both:

- In the "short" strategy, the excess of debt on one bucket is compensated by issuing less debt on the adjacent higher-maturity buckets;
- In the "long" strategy, the excess of debt on one bucket is compensated by issuing less debt on the adjacent lower-maturity buckets.

Formally, these issuance strategies are based on the following quantity, representing the cu-

[22]Early repayment of existing debt is excluded by assumption. A model extension handling early repayment could be envisaged in general, but it would not be a realistic solution for the negative-issuance problem: whatever the reasons are for anticipating debt payment, they probably do not include maturity structure conservation.

mulative target amount to be issued starting from each maturity, floored at zero:

$$CumIss_{t,i} = \max\left(0, \sum_{j \geq i} TargetIss_{t,j}\right).$$

If the target issuance amounts are all positive, these cumulates should be decreasing in maturity. When they are not, the "short" strategy consists in forcing them to be decreasing by starting from short maturities and going forward ignoring increases, which writes:

$$Issue^S_{t,i} = \min_{j \leq i} CumIss_{t,j} - \min_{j \leq i+1} CumIss_{t,j},$$

The "long" strategy starts from long maturities and goes backwards ignoring decreases *and* increases above the total issuance $CumIss_{t,1}$, yielding:

$$Issue^L_{t,i} = \min\left(CumIss_{t,1}, \max_{j \geq i} CumIss_{t,j}\right) - \min\left(CumIss_{t,1}, \max_{j \geq i+1} CumIss_{t,j}\right).$$

Cf. figure 30 for an application to the simple example.

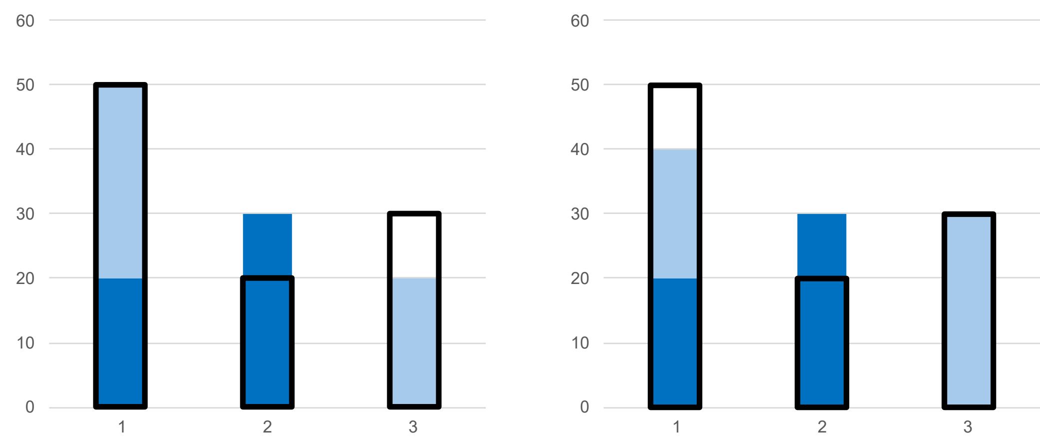

Figure 30: Outcome of the "short" (left) and "long" (right) issuance strategies applied to the example case of figure 29. Pale blue bars represent newly issued amounts. The excess amount at maturity 2 is compensated by lesser amounts issued at adjacent maturities.

D Estimating the spread of each debt set over the reference curve

Issuance spreads determine the cost of new debt given the level of the reference interest rate curve. This section goes into the details of their estimation.

D.1 Default method: constant spreads

For a given debt set, the model determines the issuance spread as the average difference between the interest rates of recently issued debt and the corresponding reference rates. In practice, for each maturity bucket, an amount-weighted average interest rate is computed over all debt products issued less than 3 months before the simulation starting point. A spread is then determined by subtracting the average value of the reference interest rate for that maturity over the same period.

These multiple spreads by maturity are then averaged into a single spread, weighting both by issued amount and by maturity. The maturity weighting takes into account the fact that higher-maturity debt remains in place for a longer time, and influences total interest cost in proportion.

D.2 Advanced method: exponential-shaped spreads

To check the effect of the single-spread assumption on model performance, we devised an alternative method where the value of the spread is maturity-dependant. The spread curve is calibrated using a 2-factor exponential of the form $s(T) = \alpha + \beta \exp(-\frac{T}{\tau})$, where T is the maturity of the newly issued debt, τ is a shape parameter, and (α, β) are computed from observed data.

This computation is performed by linear regression over the maturity-by-maturity spreads as computed above, retaining the amount and maturity weighting.

In practice, an up to numerical noise, average spread dependence on maturity is limited, except on the very short term where they tend to be lower ($<$ 1 year, cf. figure 31 for an example). Hence, the constant spread model tends to over-estimate the cost of short-term debt and to under-estimate the cost of long-term debt.

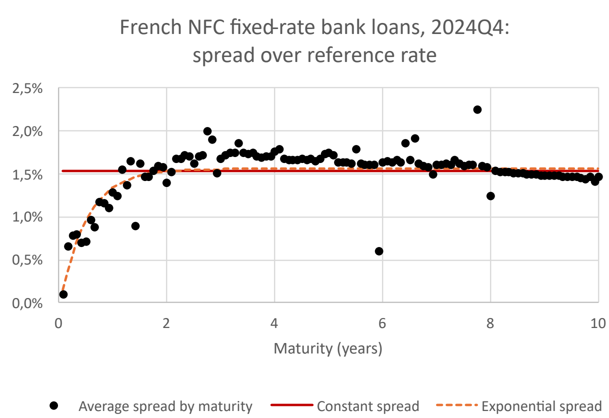

Figure 31: Spread estimation used to model French NFC fixed-rate bank loans with a Dec. 2024 starting point. The estimation sample contains all new *AnaCredit* fixed-rate bank loans taken during the previous quarter. Each black dot represents the difference between (a) the average loan rate within a one-month maturity bucket, and (b) the average reference rate observed for the same maturity during the quarter. The default version of the model uses a constant spread (plain red curve); a refined version adds an exponentially decaying component (dashed orange curve) to capture the observed short-term behaviour.

In terms of model performance, comparing the first and second graphs in figure 34 shows that using a single spread in the model leads to higher costs in the short term, but creates little bias on the long term. This is as expected: the immediate over-shooting is linked to over-estimated short-term debt interest, eventually balanced out by the accumulation of under-estimated long-term debt interest.

E Additional data on French Government debt model performance

Figure 10 shows that the model-projected charge for the French Government debt in 2023–24 is slightly higher than the actual charge for these years. Figure 32 provides the split of the interest charge between indexation charge and "ordinary" interest (coupon + premium/discount amortisation): the deviation is concentrated on the latter side, with a near-perfect prediction of indexation charges, including the exceptional 2022 charge triggered by the post-CoViD inflation episode ($>$ 10%).

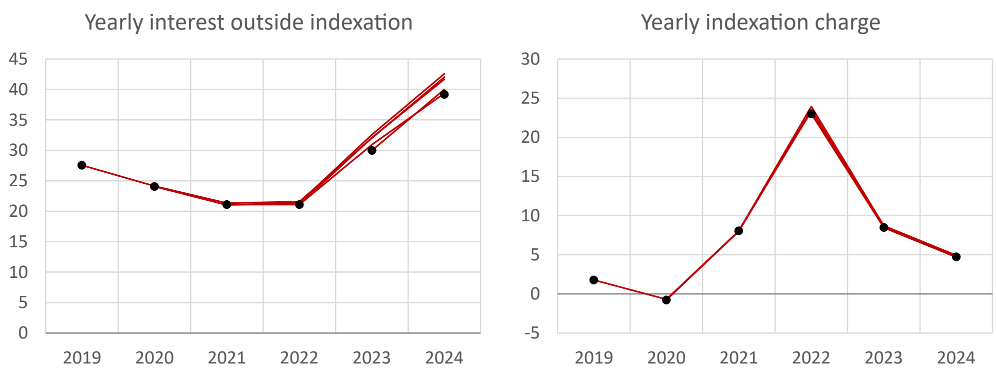

Figure 32: Back-testing results for the refined model: split of interest charges. Left-hand: fixed interests (coupon and premium/discount amortisation). Right-hand: variable interests (indexation charge).

This deviation is caused by a slightly distorted forecast, by the model, of the structure of the actual debt issuance in 2022. Indeed, as displayed in figure 33, the end-2022 term structure, as predicted by the model starting from previous year-ends, is a little shorter than the actual term structure observed at that date. As a consequence, the quantity of debt to be re-issued in 2023–24 is over-estimated by the model, hence the overstated impact of the 2023 interest rate hike on the total interest charge.

The reason for this short-term bias is well understood. Though very stable, the maturity schedule of the French government debt is strongly seasonal, with a significant concentration of payments due in Spring and Autumn of each year, giving it a staircase-like shape that cannot be preserved when using infra-annual steps. As a result, the model resorts to the maturity regularisation algorithm to compute emission schedules; in its "short" version, this algorithm tends to over-weight short maturities.

Though not wholly satisfactory, the "short" regularisation is actually still the best available algorithm: the "long" version produces irrealistic volumes of long-term debt issuance and performs significantly worse than the "short". Even intermediate algorithms based on weighted averages of both approaches do not bring any performance improvement.

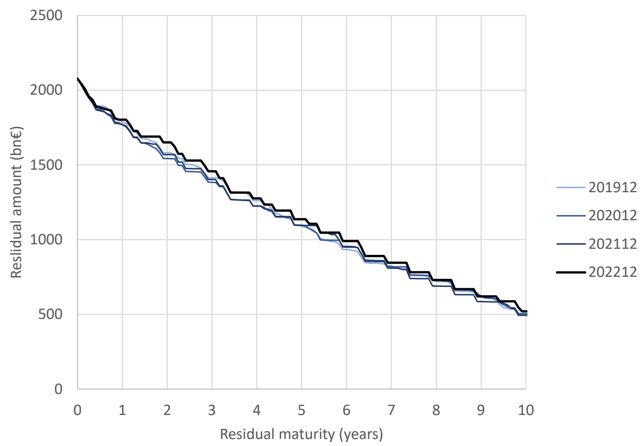

Figure 33: End-2022 term structure of fixed-rate debt (OAT and BTF) as predicted by the model starting from end-2019 to end-2021 (thin blue lines), compared to the actual term end-2022 structure (thick black line). The forecast weight of short-term emissions (6 months to 2 years) is larger than actual practice.

To complete the back-testing exercise, we successively lift the three model refinements introduced above: the modified back-testing results provide a quantification of the respective model performance losses.

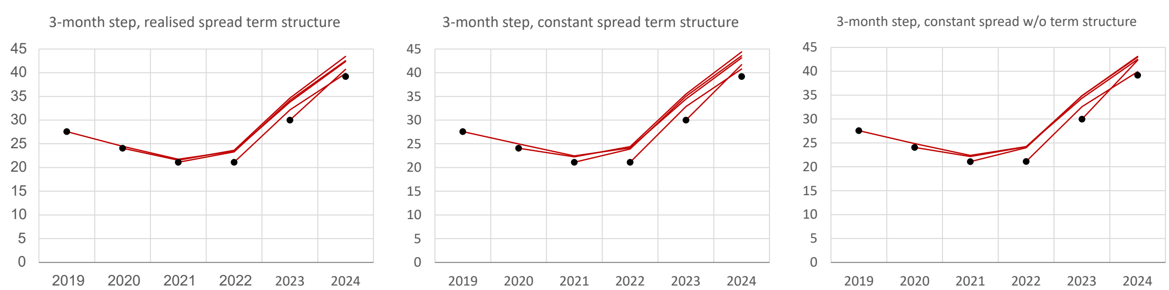

Figure 34: Back-testing results for three successively less refined models: (left) using a quarterly instead of a monthly time step, then (center) applying a single issuance spread per product instead of a term structure, then (right) keeping a constant issuance spread over the risk-free curve instead of applying actual spread fluctuations. The back-testing is performed on interest charges excluding indexation charge, as the model performance on indexation charge remains excellent for all model versions.

The main source of performance loss is the time step shift from 1 to 3 months (left-hand graph). By comparison, the use of a constant issuance spread, both across maturities (center graph) and through time (right-hand graph) brings more limited distortions. They could be avoided altogether by using tweaking the model to use an *ad hoc* OAT curve instead of ECB's AAA reference curve plus a spread, though this option would make it less easy to compare the projection of the French sovereign debt costs with other debt sets such as aggregate NFC debt.

F NFCs Appendix

F.1 Additional data on NFC debt structure

The aggregate debt structure of Euro area NFCs as displayed in figure 18 hides significant structure heterogeneity across countries. Figure 35 displays four very different country-level aggregate NFC debt structures, picked from four different regions of the graph of figure 19.

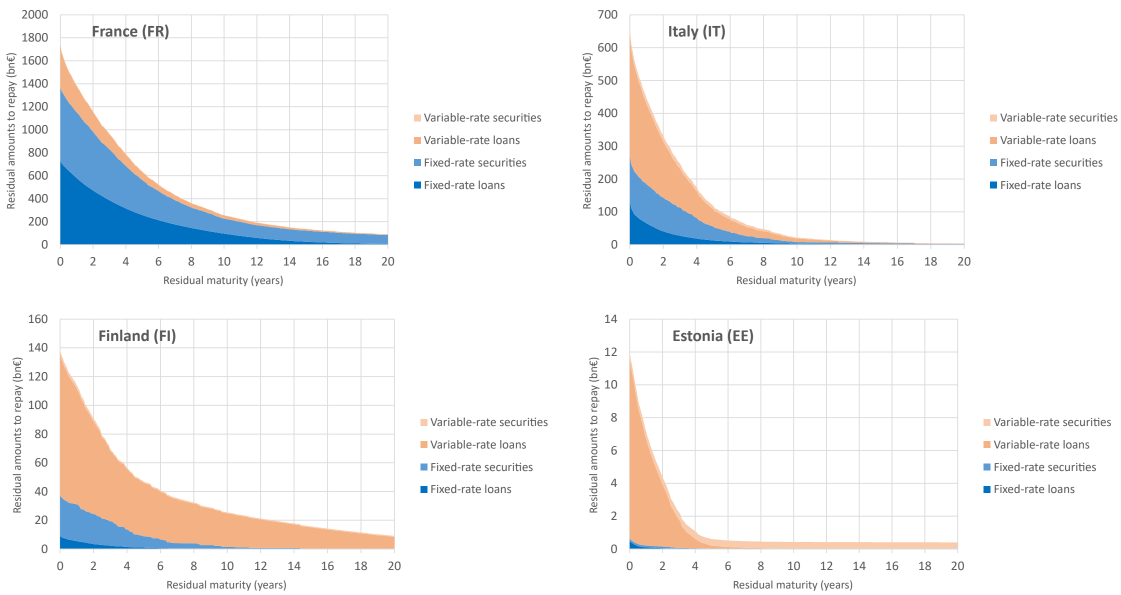

Figure 35: End-2024 structure of aggregated NFC debt (modelled part) for sample countries.

F.2 Debt structures and rise of market interest rate in 2022 and 2023

The market interest rate rise of 2022 and 2023 allows to qualitatively assess the differences in cost of debt sensitivities among Euro area NFCs. Between July 2022 and September 2023, the money market overnight unsecured interest rate went from circa -0.58% (11 July 2022) to +3.9% (21 September 2023), while the 10-year AAA Euro area sovereign bond yield went from 1.33% to 2.80%. Given the above-mentioned heterogeneity in debt structures between Euro area non-financial corporates, their respective cost of debt should have increased at different pace during the period: the shorter term and the more variable rate the debt, the faster the increase. The following paragraphs update a blog post published in 2024 (Gueuder and Ray (2024))

A useful metric to assess the sensitivity of the cost of debt to market interest rate increase is the so-called "interest rate revision factor". The interest rate revision factor stands for the share of total debt which will be affected by a change in market interest rate at a given time horizon, either because it will mature or reprice within this time horizon. Such metric combines the two dimensions of debt sensitivity to market interest rate, that is its term and interest type structure, as shown on Figure 19. It provides a qualitative but ordered assessment of such sensitivity, as economic agents with a higher interest rate revision factor will exhibit a total cost of debt more sensitive to market interest rate than other agents.

As the rise in market interest rates happened between July 2022 and September 2023, a time span of 21 months, comparing the 21-months interest rate revision factor between July 2022 and September 2023 and realised changes in average cost of debt (Figure 36) provides two sets of information: Firstly, it shows that, in December 2021 and at country level, the interest rate revision factors were heterogeneous, with as much as 97% of the debt repricing within 21 months for Estonian NFCs, and as low as 36% for French NFCs. Although 3 years separate this data point with Figure 19, the ordering between countries remain stable. Secondly, as assumed, the higher the interest rate revision factor, the larger the increase in average cost of debt in the period. However, on such a large time span, the correlation between interest rate revision factor and actual increase in average cost is not perfect: the timing of both the rise in market interest rates and the renewal or repricing of debt is not apprehended by the interest rate revision factor, as well as shocks on spreads. The full model embarks those two supplementary dimensions.

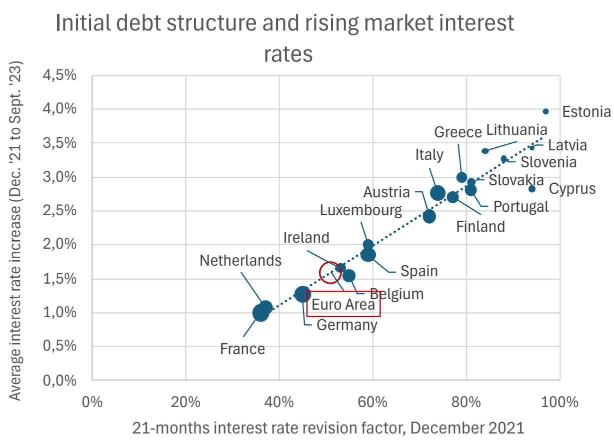

Figure 36: 21-months interest rate revision factor and observed change in average interest rates for European NFCs. The 21-months interest rate revision factor stands for the share of total debt either repricing or maturing within the next 21 months.