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METHODOLOGY

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Economic Forecasting Process & Scenario Generation

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This paper focuses on the Moody's Analytics scenario generation process. We first describe the framework of the Moody's Analytics Global Macroeconomic Model. Then we provide details on how the model is used in the Moody's Analytics forecasting process. We also discuss how the macroeconomic indicators are used in market risk and credit risk models, respectively.

Executive Summary

The global macroeconomic model captures both interconnectedness among economic regions and country-specific idiosyncracies. The linkages among countries and regions are characterised by trade and financial flows and by the systemic nature of (liquid) markets for financial assets, such as stocks and bonds. We illustrate integration of financial markets in the case of the euro area, where short-term interest rates are connected to the policy rate set by the European Central Bank and long-term rates are generally modelled in terms of a premium over the yields on the 10-year German government bonds. The cross-country linkages include the impact of global prices and exchange rates on economic performance. The global model is a set of country models that are based on a similar model structure with exogenous variables, core variables and tailpipe variables. They are simultaneous equations models that reflect fluctuations of aggregate demand but also include a long-term anchor based on potential GDP. While the model structure is similar across countries, the framework allows for country-specific variations of key equations and for inclusion of tailpipe equations for variables important for some countries.

The models are built using historical macroeconomic series. In principle, Moody's Analytics collects data from original sources and the series in the datasets are updated as soon as the series are updated by the source. This includes both newly available values and adjusted history. Moody's Analytics also ensures consistency for economic concepts. For example, real GDP and its components are comparable across countries. The model equations have gone via internal validation processes that include standard in-sample-fit assessment as well as accuracy of forecasts and model shock properties under stress scenarios. The equations have been implemented in Scenario Studio, which is a web-based tool enabling economists to use the model for forecasting. The Scenario Studio platform enables a team of economists to work jointly by distributing control over specific regions and series. The tool can keep track of purely model-driven forecasts as well as qualitative overlays based on assumptions, for example setting a monetary policy rate.

Moody's Analytics uses its global forecasting framework to quantify its economic outlook in the form of a baseline forecast. It generates the baseline forecast on a monthly basis. The forecast is produced based on globally consistent assumptions that reflect the view regarding the economic outlook. The forecast flow starts with assumptions and forecasts regarding key global variables (for example, the U.S. policy rate and the price of oil) that are used as inputs into the global model. The global assumptions are augmented by region and country-specific assumptions if required. Regional aggregates such as euro area GDP are based on aggregation across countries.

The baseline is used as an anchor for Moody's Analytics scenarios that capture the key risks to the global outlook as well as for regulatory and custom scenarios. Regulatory scenarios are based on qualitative and quantitative assumptions provided by regulators such as the Federal Reserve, Prudential Regulatory Authority of the Bank of England, European Central Bank and European Banking Authority, and others. The global model is employed to expand given assumptions to additional regions and economic indicators. Custom scenarios are constructed to capture risks based on a client's exposures. In some cases, targets are provided for aggregates such as euro zone GDP. In this case, we employ a disaggregation procedure that ensures consistency between country-level and aggregate forecasts.

The Moody's Analytics scenarios updated on a monthly basis are calibrated to particular severity. Severity is defined as the likelihood that the actual outcome based on a selected economic indicator is worse than in a given scenario. An example of such an indicator is average deviation from the baseline GDP forecast in levels. Severity of 4% implies that in only 4% of all simulated projections, or in 1 out of 25 cases, the outcome is worse than the one based on the selected metric. We target particular severities such as 4%, 10%, 50% (baseline), 90% and 96%. While the actual baseline forecast and the corresponding scenarios change over time, assumptions are adjusted to match the target severity. This is important for using scenarios for types of excercises in IFRS 9 and the Internal Capital Adequacy Assessment Process, or ICAAP.

The macroeconomic indicators forecast using the global model are used as drivers to forecast various market risk indicators such as swap rates, global stock market indexes, and corporate default swap indexes. We use a variety of asset pricing econometric models. In this paper, we provide a variation of the Nelson-Siegel methodology for forecasting swap rates where we link levels and slope to macroeconomic drivers. For stock market indexes, we model global financial factors created using principle components analysis as a function of macroeconomic drivers. Finally, corporate default spreads are modelled as a function of time varying risk premiums depending on macroeconomic drivers. Similar to modelling of the stock market indexes, one of the drivers is typically the global growth factor, an unobserved first principal component analysis factor capturing the global business cycle obtained by spanning real GDP growth for key economies into a single vector. Another possible driver is stock market volatility.

The key element of modelling market risk variables is their relationship to macroeconomic drivers. We use a systemic optimal variable search procedure that considers a set of macroeconomic indicators (including nonlinear functions and various transformations) and produces a list of statistically plausible models with significant coefficient estimates and with signs as predicted by economic theory. The models are ranked based on various criteria comparing in-sample fit and forecasting accuracy. The degree of collinearity can be restricted based on correlation among the drivers employed in a given equation.

Because of stress-testing exercises and IFRS regulation, macroeconomic scenario forecasting has become a key component of the credit risk models used by financial institutions. Macroeconomic indicators are linked to risk parameters such as probability of default or loss given default. The procedure to select key macroeconomic features is in principle a version of the OVS procedure used for market risk variables but augmented by a cross-sectional dimension to leverage on the instrument-level data, which are typically available. We illustrate how macroeconomic drivers are incorporated in the credit risk models for a loan portfolio in the United Arab Emirates and on the Mortgage Portfolio Analyzer. MPA is a tool embedding a collection of models built using data on U.K. mortgages. The PD is modelled in a panel data framework estimating the impact of both macroeconomic variables and loan-level attributes jointly. LGD depends on the macroeconomic drivers via time-varying loan-to-value ratios.

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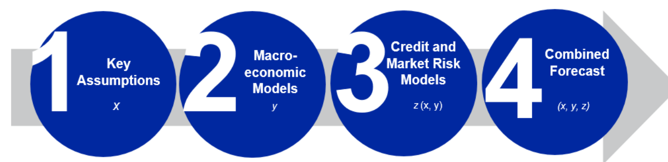
Introduction

This paper presents the Moody's Analytics approach to generating forecasts for a variety of economic scenarios that are needed to meet various regulatory requirements. Moody's Analytics produces scenarios capturing risks to the baseline view on a monthly basis. In addition, the forecasting framework is used to prepare custom scenarios reflecting assumptions provided by clients and regulatory scenarios based on assumptions from regulators such as the Federal Reserve, Prudential Regulation Authority of the Bank of England, or European Banking Authority working with the European Central Bank.

The process of forecast generation starts with a set of initial assumptions, formally captured in a vector x in Chart 1. These assumptions can include regulatory, custom, or internal Moody's Analytics scenario assumptions. They can also take various forms. For example, they can include specific targets or shocks for key series provided by the regulator or the client, a narrative of how the scenario is unfolding, or desired severity of a particular scenario, either as a reference to a baseline perspective or using a particular risk metric such as a peak-to–trough GDP contraction. In many instances we use a combination of these different kinds of assumptions.

Chart 1: Phases of Scenario Workflow



Source: Moody's Analytics

The next step consists of translating these assumptions and shocks into forecasts for core macroeconomic and financial series, collected in a vector y in the diagram. For this purpose Moody's Analytics is using its global model, which covers more than 12,000 equations and variables for 73 countries.

With the information from the pair (x,y), which includes key macroeconomic and financial forecasts and scenario assumptions, we can generate projections for various market risk and credit metrics. These are generated in satellite models and the list and types of specific metrics can vary across clients. The satellite models use macroeconomic and financial forecasts coming from the global model as inputs. The resulting projections are then grouped in what we refer to as the vector of satellite models (z(x,y)).

The final output of the scenario phase combines the assumptions, macroeconomic and financial forecasts, and satellite model projections for market and credit risk metrics, summarized in the triplet (x,y,z).

The paper is structured as follows. The second section presents the structure of the Moody's Analytics Global Macro Model and Scenario Studio, which is a platform used to develop the projections. Section three describes the process of generating the key macroeconomic and financial forecasts under different assumptions. Sections four and five provide an overview of market risk and credit risk models, which use the global model forecasts as inputs.

Global Macro Model Framework

The Moody's Analytics global macroeconomic model produces forecasts for more than 12,000 time series across 73 countries that collectively constitute more than 95% of global GDP.

Moody's Analytics employs the structural approach, in which economic theory puts restrictions on econometric specifications and represents a compromise between purely data-driven and purely theory-driven models. The model consists of a single, simultaneous system of structural economic equations that allows for a variety of interactions across variables. Exogenous variables such as potential GDP or population are typically forecast outside the model and are used as starting points of the forecast process. They also serve as an anchor for the short-term fluctuations by making sure that after a shock is introduced to the economy, the forecasts will, after a certain period, return to their long-term trend. This reflects the key goal of the global model: to balance dynamics and responsiveness to shocks in the short run with equilibrium convergence in the long run. Forecasts for each country are done in individual equation blocks, and although the structure is similar across countries, equations can differ somewhat because of, for example, data availability, the composition of industry and exports, and/or differences in historical experience that can affect the signs and significance of key right-hand-side variables. At the same time, the country-level equation groups are tied together through a specific set of cross-country linkages including trade, financial markets, commodity prices, etc.

Such a setup allows for efficient estimation and better long-run forecast performance than can be achieved by pure time-series methods such as vector autoregression. At the same time, it allows for a straightforward generation of alternative scenarios and does not rely on some of the extreme, often unrealistic theoretical assumptions that are needed in the case of dynamic stochastic general equilibrium models. The structural models are generally superior to either the VAR or DSGE setup, especially in the case of stress-testing, where in most cases the regulators provide specific targets for series such as GDP and inflation, which then need to be used as inputs and extrapolated out to a much broader set of economic indicators[1].

Data

The historical data series forecast in the model are sourced directly from national statistical offices wherever possible, to ensure that the forecasts reflect the most accurate and timely information available. Data from third party aggregators such as the World Bank and the International Monetary Fund are used to supplement these sources when primary sources are not available, or to improve cross-country consistency. Often, to maximize the quality, methodological consistency and cross-country comparability of forecasts, historical data are sourced from proprietary estimated series.

Moody's Analytics maintains an in-house data group, which maintains databases with time series data for more than 500 million variables; however, only a fraction of these are used to produce macroeconomic forecasts. The database engineers pull data directly from their sources. It then goes through rigorous procedures and controls to ensure data accuracy, completeness, auditability, timeliness, consistency and integrity.

The data group also maintains a robust documentation process for all historical data stored in Moody's Analytics databases. For each series there is detailed information about the source, definition, how often the series is updated, and any additional imputations performed by the Moody's Analytics data group, such as seasonal adjustment.

The historical data as well as the documentation can be accessed via the Moody's Analytics Data Buffet platform https://www.economy.com/databuffet/. The data can be also accessed directly using the Application Programming Interface.

For forecasting purposes, updated historical data are extracted from the Moody's Analytics databases each month and incorporated into the macroeconomic model. Most of the data, especially data used for projecting the core variables in the global model, come from official government sources such as national statistics offices or central banks, and they are not prone to estimation error or subject to assumptions.

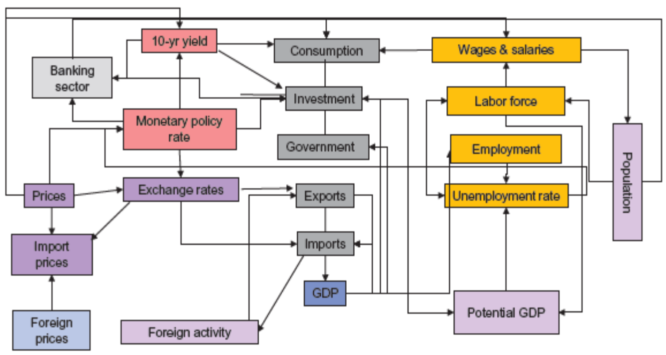
Model Setup

As mentioned in the introduction, the Moody's Analytics Global Macro Model consists of separate blocks of equations capturing relationships across series within each national economy. Each equation is specified not merely to maximize its predictive value, but also to abide by macroeconomic theory. Wherever possible, theoretical relationships are applied directly and with equation parameters having a clear structural interpretation. In other cases, theory is applied in a much broader sense, for example by employing first order Taylor rule expansions to generate log-linear regression specifications between dependent and independent variables, or specifying equations according to empirically validated rules of thumb. In each case, parameters are estimated econometrically based on the observable historical covariation over the equation's macroeconomic time series. Initially, every country equation group is estimated according to a standard template; however, the setup is flexible, allowing to account for important cross-country differences, for example between fixed versus floating exchange rates, or net energy exporters versus importers.

Various exogenous variables are introduced in the global model that are typically forecast outside of the system. Potential GDP, nonaccelerating inflation rate of unemployment, and population growth are typical exogenous variables in the model. Some variables such as monetary policy rates and

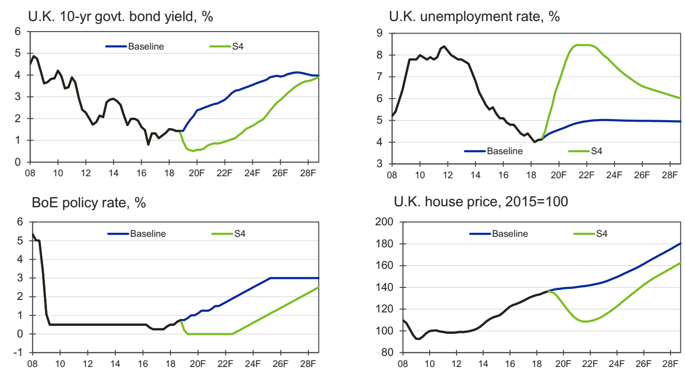
1 For more details please refer to M. Hopkins, "Moody's Analytics Global Macroeconomic Model Methodology", March 2018. https://www.moodysanalytics.com/-/media/whitepaper/2018/global-macroeconomic-model-description-short-version

Chart 2: Sample Country Model Structure



Source: Moody's Analytics

Chart 3: Examples of U.K. Forecasts



Sources: ONS, Moody's Analytics

global energy prices can be predicted within the model, but are often set as exogenous to reflect information outside of the econometric framework. These are also potential sources of shock origination when developing alternative scenarios. Endogenous variables of the model are either core variables or tailpipe variables. Core variables are the model's most important and decisive variables that drive the rest of the equations. The core variables include:

- Aggregate demand (GDP)
- Trade
- Labour market
- Prices
- Monetary policy and key interest rates
- Housing market

These variables interact with each other to form a simultaneous system of equation. Chart 2 illustrates these interactions in a simplified diagram.

Core variables are typically driven by other core and/or exogenous variables. Core variables can also take the form of identities to preserve macroeconomic relations. For instance, GDP is an identity equal to the sum of its components—consumption, investment, government spending and net exports. Tailpipe endogenous variables are a model's second-tier variables that complete the architecture of the macroeconomy of a country. To create a manageable model that is easy to re-estimate and control, tailpipe variables are driven by core and/or exogenous variables but do not become drivers for core variables. Examples include the lending rate and the GDP deflator.

Each equation in the global model is judged to be acceptable if it has coefficients that produce a stable, accurate baseline forecast, and if it generates appropriate shock responses in scenario tests. See Table 1 for examples of some key specifications.

Chart 3 shows examples of the projections for key series for the U.K., including 10-year bond yields, unemployment rate, Bank of England key policy rate, and the house price index, under the Moody's Analytics baseline and S4-Protracted Slump scenarios.

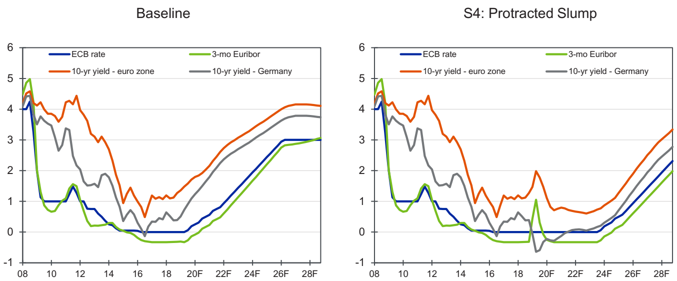
The equation for 10-year government bond yields, with forecasts presented in the top-left chart, is specified as a spread between the 10-year government bond yield and the monetary policy rate, and it distinguishes between short-term fluctuations in interest rates and long-term anchors. The short-term component includes responses to changes in U.S. and German 10-year yield spreads, which account for the strong co-movement among global bond yields, and changes in the spread between U.K. money market and monetary policy rates, which capture the effect of changes to risk percep-

Table 1: Examples of Variables and Their Model Specifications

Variable	Specification suggested by economic theory draws on…
Unemployment rate	Okun's law
Labour force	Participation rate & demographics
Private consumption expenditure	Keynesian consumption function / Euler equation
Public consumption expenditure	Baumol's disease w/ endogenous responses to fiscal space
Fixed investment	Accelerator model / Tobin's Q
Inventory investment	Adjustment process in deviations of final spending to firm output
Exports	Trading partner import demand and real effective exchange rate
Imports	Imports reflect domestic demand + re-exporting demand
Labour income (wages & salaries)	Wage bargaining over revenue product of labour
Central bank target rate	Policy assumption, based on an augmented Taylor rule
10-yr govt bond yield	Fisher rule w/ sovereign risk premium, global interest rate parity
Yield curve & market lending rates	Term-structure of interest rates
Exchange rate (floating)	Interest rate parity (short run) & purchasing power parity (long run)
Import price deflator	Exchange rate pass-through of foreign prices, global commodity prices
Consumer price index	Expectations augmented Phillip's curve based on firm price setting
House prices, stock prices	Asset pricing theory
Government total expenditure	Sum of government consumption + debt service + net transfers
Government total revenues	Revenues equal the effective tax rate multiplied by income
Industrial production	IP tracks the aggregate value added of goods-producing industries
Domestic credit (money supply)	Liquidity demand depends on transactions value and interest rates
CA balance	(Identity) CA = net exports + net income + net transfers

Source: Moody's Analytics

Chart 4: Euro Zone Financials



Sources: ECB, Moody's Analytics

tion and adjustments to monetary policy. The equation also takes into consideration the foreign exchange movements. The long-term anchors include the difference between the lagged 10-year government bond yield and the growth of potential GDP.

The setup of the specification for the policy rate forecast, depicted in the bottom-left chart, is set to distinguish between short-term fluctuations and the long-term equilibrium rate. The latter is based on the Taylor rule including long-term factors such as the growth rate of potential GDP and equilibrium inflation, and size of the output gap. The short-term variation accounts for differences between U.S. and U.K. policy rates, as well as stock market, government bond yields, and foreign exchange movements. However, as mentioned before, the policy rate is frequently set exogenously in the forecasting process, as it is usually provided by a regulator in the case of stress-testing, or is set by the country analyst to account for the information from outside the model, for instance, statements from the central bank.

The unemployment rate, illustrated in the top-right chart, is forecast as the first-difference version of Okun's law, including long- and short-term drivers. The former is the difference between the unemployment rate and NAIRU, which provides a long-term anchor ensuring the convergence to the natural rate. The latter includes monetary policy rate as well as the polynomial distributed lag of changes in the output gap and lagged-dependent variable ensuring that the effect of shocks is propagated through time.

House prices forecasts, included in the bottom-right chart, also depend on the equilibrium projection of house prices, or trend, as well as short-cyclical drivers. Equilibrium house prices are determined by per capita income and population. Therefore, the change in house prices is determined by the deviation of the house price index from the equilibrium house price. As short-term drivers we include in particular the change in the unemployment rate and the change in the variable mortgage rate.[2]

Estimation output tables for these variables can be found in the Appendix.

Financials

The global financial crisis in 2008 as well as the euro area debt crisis from 2010 to 2014 showed the critical importance of financial markets. Our approach to forecasting key interest rates reflects the historical relationship captured by an econometric model but also allows for a straightforward qualitative overlay. We have already seen the policy rate and the 10-year bond yield for the U.K. We will illustrate our approach further by describing our forecasting equation for the U.K. three-month money market rate and our modelling framework for euro zone financials.

The three-month money market rate typically follows closely the movements of the monetary policy rate, diverging only in periods of stress in global financial markets. In these instances, money market rates around the world tend to rise and move in tandem. Therefore, the U.K. money market rate is forecast as a spread between the rate itself and the BoE policy rate and is driven by its own lag as well as spreads between three-month money market and central bank policy rates in the euro area and the U.S.

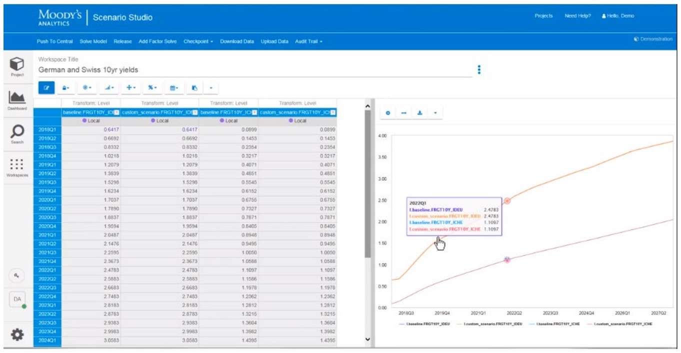
Because of the unified financial market in the euro zone, key interest rates for the region are forecast together. Equations for interest rates are similar in structure to the example of the U.K. 10-year government bond yield described above, in the sense that they are divided into two sections: the equilibrium value and the movements around this equilibrium value. The model for euro zone financials is separated into two broader blocks, which are weakly related: a block for short-term interest rates, including the ECB policy rate and money market rates, and a block for government bond yields (see Chart 4).

The policy rate is assumed to reflect macroeconomic developments, namely inflation, potential output growth, and output gap. The Euribor is forecast as a spread between the rate and the policy rate; forecasting is again split into two parts and the movements around this equilibrium value, reflecting stress in global financial markets as proxied by the U.S.-Libor spread, together with additional assumptions.

The long-term rates block consists of 10-year government bond yields for Germany and average euro zone 10-year government bond yields. The German bond yield is the single benchmark, with other bonds (and hence the average euro zone bond yield) priced in relative terms to this benchmark. The equilibrium value of interest rates depends on the main macroeconomic variables including inflation rate, potential output growth, and output gap. The movements around the equilibrium rate depend on changes in the monetary policy rate and developments in the rest of the global bond markets. Changes in the attitude of global investors to long-term bonds are proxied by changes in U.S. bond yields, inclusion of which ensures rough consistency between the U.S. and euro zone bond yields in the short run. Additionally, since German bonds act as a safe-haven asset in times of crisis, the German bond yield is used to reflect stress in the euro zone bond markets proxied by the spread between the euro zone bond yield and the German bond yield.

2 For a more detailed discussion of our national and subnational models for house prices see A. Carbacho-Burgos, "U.K. House Prices: The Moody's Analytics Forecast Model", Moody's Analytics Regional Financial Review, July 2016

Chart 5: Examples of Scenario Studio Tools



Source: Moody's Analytics

The euro zone 10-year bond yield is the sum of two components: the German 10-year yield (the risk-free yield) and the spread between the German and euro zone yield (the risk component). These two components produce the 10-year yield as a matter of identity. This decomposition ensures that the yields on German and euro zone bonds are consistent throughout the forecast. The spread itself is split into equilibrium value and movements around this equilibrium value, which depend on the general risk aversion in financial markets proxied by the volatility of the Standard & Poor's 500 index and on specific scenario assumptions.

Estimation output tables for these variables can be found in the Appendix.

Cross-Country Linkages

In the global model, the country-level macroeconomic models are tied together through a specific set of cross-country linkages of the following types:

- **Trade linkages:** Exports are tied to a trade-weighted average of the imports of the exporter's five largest export markets. Exports also depend on the real effective exchange rate, which depends on foreign prices and exchange rates.
- **Financial linkages:** While short-maturity interest rates are driven largely by central bank policy, longer-maturity bond yields in convertible currencies are linked through uncovered interest rate parity to a global benchmark rate, proxied by the U.S. Treasury yield.
- **Price linkages:** Inflation rates in economies with a fixed exchange rate are anchored by the growth rate of foreign prices. Inflation in countries with a floating exchange rate is anchored by inflation expectations, but influenced by a number of global factors, including commodity prices (particularly oil prices), exchange rates, and the price of foreign goods.
- **The balance of payments**: Direct and portfolio investment flows are modelled as part of the financial account of the balance of payments. Direct investment flows in and out of the country are assumed to depend on investor expectations of growth and a country's competitiveness, defined by its real effective exchange rate. Portfolio capital flows are forecast on a net basis, with a specification motivated by the balance of payments identity that the current, capital and financial accounts must sum to zero.
- **Investment linkages:** Foreign direct investment into an economy is one determinant of fixed capital formation, providing a second demand linkage beyond exports. In practice, this effect is much weaker than trade linkages

For example, since stock markets are to a large degree globalized, they move strongly together around the world. For instance, this means that (short-run) movements in the U.K. stock market should be consistent with movements in the U.S. stock market. For this reason, our model for the U.K. stock market index includes explicitly the movements in the U.S. stock market (as well as other countries' stock markets). This ensures consistency in scenario forecasts of those two stock market indexes. These linkages are also important in regulatory scenarios such as the Comprehensive Capital Analysis and Review, for which the Fed provides quantitative targets for the U.S. Dow Jones stock market index, but not for other countries' stock market indexes. By including explicit linkages we avoid the need for additional assumption when creating forecasts for the U.K. stock market index.

Model Validation and Governance

The Moody's Analytics forecasts and underlying equations are continually evaluated both externally, by, for example, clients and regulators, and internally by the Model Validation team and country analysts. Moreover, each month the Model Development team undertakes various ongoing control processes of the estimated equations. Internal validation standards are designed to meet regulatory requirements.[3]

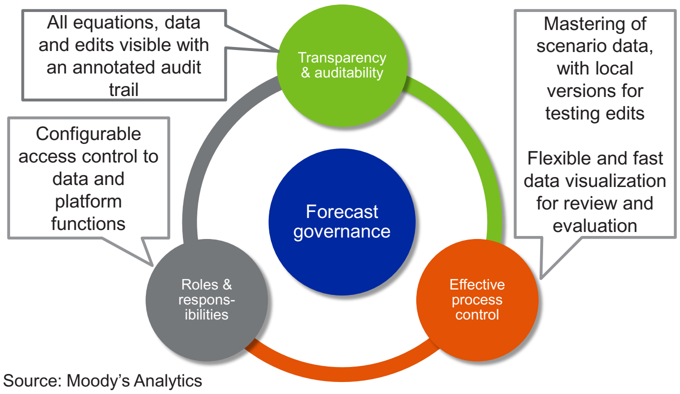
The model is never completely static, and equation changes can be introduced to address circumstances that can impact coefficient estimates, such as rebasing of the underlying historical time series or change of regulatory requirements. Therefore, the Model Development team compiles a list of equations requiring re-estimations or any other model changes. Once potential changes are proposed they go through various testing procedures before they are documented and ultimately implemented. Moody's Analytics uses a combination of in-sample performance, back-testing, benchmarking and sensitivity analysis to validate individual forecasting equations and ensure the model's systemic integrity.

Scenario Studio

Scenario Studio is an online platform that houses the Moody's Analytics Global Macro Model. This solution enables users to produce custom scenarios in a multi-user environment with rigorous process controls. Scenarios can be created simultaneously for all of the more than 70 countries covered by the global model, by adjusting more than 10,000 economic and financial time series to match specific assumptions. It also allows users to visualize introduced changes through interactive dashboards, charting and data tables (see Chart 5).

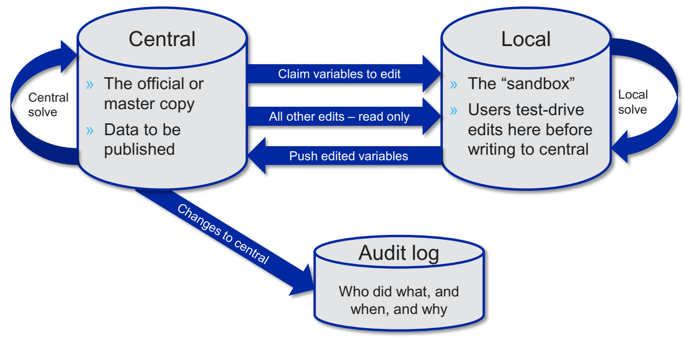
3 PRA – Supervisory Statement (SS3/18), Model risk management principles for stress-testing, April 2018
EBA – Final Report (EBA/GL/2017/06), Guidelines on credit institutions' credit risk management practices and accounting for expected credit losses, May 2017
Fed – SR Letter (11-7), Supervisory guidance on model risk management, April 2011

Chart 6: Forecast Governance



Source: Moody's Analytics

Chart 7: Basic Collaborative Architecture



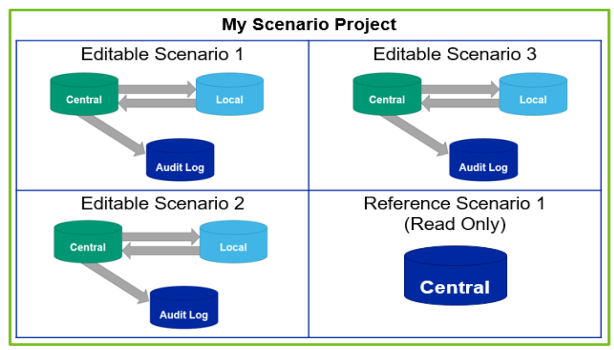
Source: Moody's Analytics

The platform is accessible wherever there is internet access, as there is no need to download any application to the computer; this supports working remotely. Moreover, the work is automatically stored in the cloud, so there is no risk of losing any unsaved adjustments made to the forecasts.

Since the key goal of the Scenario Studio was to allow multiple users to work on a project simultaneously, the platform was built around transparency, which is crucial for forecast governance. Chart 6 illustrates a simplified process for the forecast governance. Roles and responsibilities can be configured within the platform by the project lead. Users can be granted administrative, editor or observer access, and administrators can restrict what other users can edit. Scenario Studio provides an easy-to-follow audit trail, which allows users to trace which user changed which series, when and why, as well as any model solves, variable claims, and pushes to central copy. Additionally, all equation specifications, variable dependencies and summary statistics of the global model are easily available.

The Scenario Studio framework was developed around the key objective to allow multiple contributors efficiently develop high-quality scenarios. This is achieved through the local sandbox (see Chart 7), where each user can test edits, using various visualization tools, making it easy to see how a particular change flows through the model. While multiple users can work on the same scenarios at the same time, only one user can make changes to a particular variable at a time. To make changes users claim the variable and make adjustments in their local copy. Once they are satisfied with the forecasts they have to commit them to central copy, which then allows other users to see the final projections.

Chart 8: Working on Several Scenarios



Source: Moody's Analytics

In Scenario Studio, we refer to groups of scenarios as projects. In a project with multiple users working at the same time, users can edit and solve multiple scenarios at the same time (see Chart 8).

For more details, please check the Scenario Studio web site.

Forecasting Process

Moody's Analytics produces four types of forecasts (see Chart 9):

- **Baseline:** This captures our view of the most likely outcome.
- **Standardized scenarios**: Moody's Analytics produces eight standard alternative scenarios for all countries included in the global model, which capture the main risks to the baseline outlook as determined by Moody's Analytics. Over the last few years some of these have been used extensively by banks within the EMEA region for purposes of the International Financial Reporting Standards (IFRS 9).
- **Custom scenarios:** These are based on specific requirements and/or assumptions provided by individual clients. These are used, for example, in the Internal Capital Adequacy Assessment Process.
- **Regulatory scenarios:** Moody's Analytics produces forecasts for alternative macroeconomic scenarios created by regulators who usually provide assumptions in the form of targets for selected series and a brief narrative. Examples include scenarios generated for the Federal Reserve's Comprehensive Capital Analysis and Review, the Prudential Regulation Authority stress test, or the European Banking Authority EU-wide stress test.

Scenario Assumptions and Forecast Generation

Generation of a scenario begins with setting up the assumptions. This can be done in various ways, which are described in the sections below.

On a monthly basis Moody's Analytics updates the baseline forecast and eight standard scenarios. Regulatory scenarios are usually generated once a year, with the exception of the EBA, which publishes its stress test once every two years. Custom scenarios are specific to client needs and can be generated on a one-off or regular basis. For ICAAP purposes the scenarios need to be generated or updated at least once a year.

Baseline Forecast

For the baseline we first estimate forecasts endogenously, starting from the latest available historical point for the next 30 years, constrained by the long-term anchors such as potential GDP and NAIRU, which are determined to a large extent by population growth. All these long-term anchors are exogenous to the system. Once the initial forecast is ready, the economists covering individual countries can then alter it to reflect qualitative expert judgement. This is particularly relevant for the short-term dynamics such as the GDP growth over the next few years or the central bank policy rate path, which often depend on political developments and cannot be easily captured by the model. This is done by exogenising a particular variable, meaning that it then becomes external to the system and independent from it, acting as a constraint and driving other projections. In the long run, the projections are expected to go back to the long-term anchors.

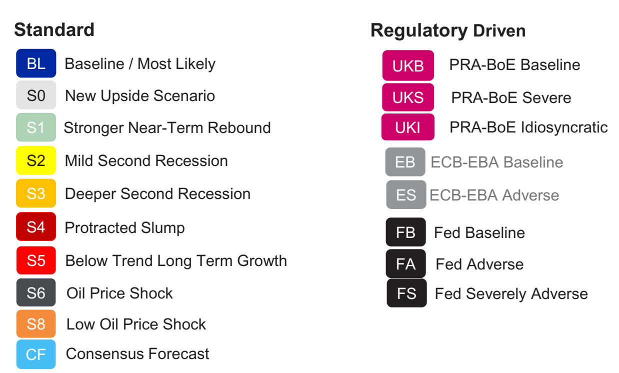
For efficiency and to ensure cross-country consistency this process starts with the forecasts for the U.S. economy, as this country segment is the biggest in the global model and it has the most direct linkages to other country equation blocks, via trade and financial linkages. Once the key U.S. projections are set, the second round is reserved for Tier 1 countries such as Germany, the U.K. and China. These countries, after the U.S., have the most linkages and influence on the forecasts of other countries. Also at that time the euro zone financials are being set, such as the ECB policy rate, 10-year average bond yield, and money market rate (as described in Section 2.2.1), together with exchange rate against the U.S. dollar, as these are the key series that will impact individual euro zone members. In the last step, forecasts for the remaining countries are updated, checked, and if needed adjusted by the country analysts. In each iteration, to generate forecasts, the whole global simultaneous equations model is solved given the specified conditions.

Moody's Analytics Standard Scenarios

The process of generating Moody's Analytics standard scenarios is similar to the baseline. In each scenario explicit hypothetical events push the economy away from the baseline outlook. These events are considered most likely at the time the scenario is constructed or later updated and can evolve over time. The scenarios are divided into two main groups depending on the nature of the scenario, which affects the way initial targets for the key series are specified.

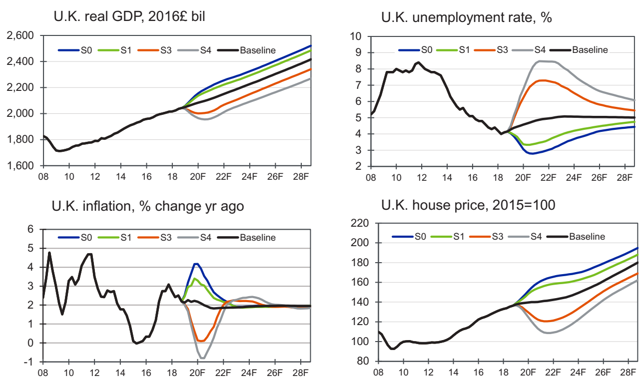
First, for scenarios including S0, S1, S2, S3 and S4, especially those used for IFRS 9 purposes, the initial stage of generating scenario includes assigning a severity to it, based on the simulations of the GDP paths. This process is described in more detail in Section 3.2. Once the GDP path is set, the forecast is expanded to other variables for each country by using the global model and utilising a set of assumptions that we generate to reach a particular GDP path. These probability-calibrated scenarios are generated through a collection of shocks that adhere to a strict

Chart 9: Examples of Alternative Scenarios



Source: Moody's Analytics

Chart 10: IFRS 9 Scenarios for U.K.



Sources: ONS, Moody's Analytics

Table 2: Comparing Stress-Test Scenarios: Real GDP, Start-to-Trough Contraction

	U.S.	U.K.	Euro zone
PRA Annual Cyclical Scenario	-3.5%	-4.7%	-3.6%
EBA Adverse Scenario	-2.3%	-5.6%	-3.8%
Fed CCAR Severely Adverse Scenario	-7.5%	-5.4%	-4.6%

Source: Moody's Analytics

narrative of assumptions deemed most likely to produce the desired outcomes. Additional assumptions and narratives are needed since many different economic developments can lead to a particular GDP forecast. Therefore, apart from GDP we need to provide assumptions specifying behaviour of some other key variables such as the response of the central banks or commodity price movements, which would result in a particular scenario developing globally.

Chart 10 shows examples of the U.K. forecasts for the key series (GDP, unemployment rate, CPI and HPI) for the baseline, two upside and two downside scenarios, which are used for the IFRS 9 exercises.

Second, Moody's Analytics produces several standard scenarios (S5 to S8) in which specific alternative assumptions are the key target, as opposed to choosing assumptions to target outcome severity. These assumptions include a specific trigger. In the case of S6 and S8, the key driver of the projections is the oil price, which rises sharply in S6 and falls significantly in S8. Depending on whether a country is an oil importer or exporter each of these can either be a recession or a strong growth scenario. S5 is based on an assumption that output growth is below baseline and potential for an extended time, which again starts with setting paths for GDP and a response from central banks to such a development, etc.

Additionally, Moody's Analytics developed the consensus scenario (CF), which is based on the review of a variety of surveys of baseline forecasts. Moody's Analytics creates consensus targets for GDP and CPI for each country for the first four years of the scenario, since that is the most typical duration in the surveyed results. These are then expanded to all other variables forecast in the global model.

An example of narratives for these scenarios can be found in the Appendix.

Regulatory Scenarios

For stress-testing scenarios, the regulators usually provide specific targets for key macroeconomic and financial variables, which need to be directly implemented into the forecasts. For example, in the case of PRA the banks are provided with quarterly paths[4] for key series for the U.K., including GDP, the unemployment rate, CPI, house prices, commercial property prices, the stock price index, and government bond yields and swap rates curves, among others. Additionally they provide many series for the euro zone, the U.S., and a few key Asian economies. The EBA provides annual targets[5] for growth rates or levels for a similar series as PRA but for all EU countries individually, plus the U.S. and a few global economies. In CCAR, the Fed provides quarterly targets[6] for 13 quarters ahead for key U.S. variables such as GDP, the unemployment rate, CPI, and main interest and foreign exchange rates, as well as targets for GDP and CPI for key regions such as the euro zone, developing Asia plus Japan, and the U.K. These specific targets or paths are then implemented directly into the model by overlaying these series with the targeted values for specified countries and exogenising them. Once these are set, the global model is solved to obtain forecasts for other countries and variables.

Table 2 presents the comparison of the targeted contractions in economic output prescribed by each of the regulators in their 2018 stress tests for the key economies, including U.S., U.K., and the euro area.

The regulators usually also supply a high-level narrative explaining the source of the shocks that trigger the stress and how they propagate in the global economy:

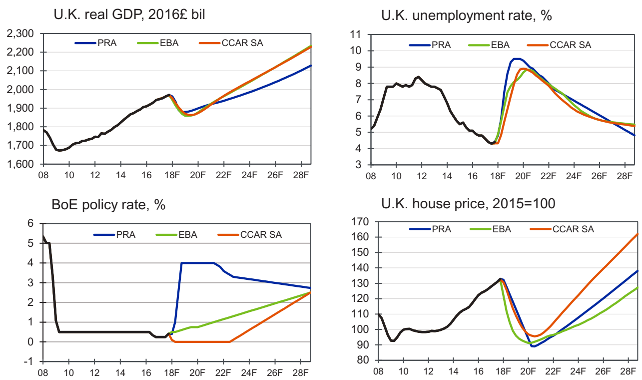
- **PRA Annual Cyclical Scenario:** In this scenario, vulnerabilities in financial markets and the global economy combine with unexpected declines in property prices in emerging markets, particularly China, to cause global financial panic that results in a sharp decline in credit availability, precipitating a deep global recession. While the U.S. economy contracts 3.5% in the stress scenario, the U.K. economy falls 4.7%. The start-to-trough decline for the euro zone is 3.6%.
- **EBA Adverse Scenario:** This scenario is based on the assumption that an abrupt reversal of compressed global risk premiums has negative spillover effects on the global economy. The tightening of credit conditions squeezes domestic spending, while the sharp decline in asset prices sends shock waves via the effect on confidence and uncertainty, swiftly leading to global recession, with the euro zone GDP contracting by 3.8%. The U.K. is hit hard with economic output falling by 5.6%, while the U.S. is impacted to a much lesser extent with a peak-to-trough decline of 2.3%.

4 https://www.bankofengland.co.uk/news/2018/march/key-elements-of-the-2018-stress-test

5 https://eba.europa.eu/-/eba-launches-2018-eu-wide-stress-test-exercise

6 https://www.federalreserve.gov/supervisionreg/files/bcreg20180201a1.pdf

Chart 11: Regulatory Scenarios for U.K.



Sources: ONS, Moody's Analytics

- **CCAR Severely Adverse Scenario:** This stress scenario is characterized by a severe global recession that is accompanied by a global aversion to long-term fixed-income assets. Risk premiums and money market rates rise swiftly as heightened risk aversion causes a severe liquidity squeeze and a deep global recession. The U.S. economy is hit hard, with GDP contracting for seven consecutive quarters and dropping by 7.5% before slowly recovering. Economic output in the euro area drops by around 4.6%, while in the U.K. it falls by 5.4%.

Chart 11 shows an example of the forecast under these three regulatory scenarios for the U.K. for GDP, the unemployment rate, central bank policy, and the house price index.

Custom Scenarios

Generation of the custom scenarios can vary depending on a client's needs and sophistication, and can be based on the combination of the above approaches.

In most cases, when a financial institution is developing its own custom scenarios, it still has to abide by strict regulatory guidelines. Moody's Analytics has long-term experience in assisting banks in the ICAAP. It requires each financial institution to develop a scenario that would sufficiently stress its own idiosyncratic exposures and potential vulnerabilities. This varies across institutions through their regional exposures, funding sources, concentration of lending types, etc. The scenario itself needs to be timely based on the current global macroeconomic situation and most probable risks, as well as the financial situation of the financial institution. Therefore, to develop a custom scenario fulfilling regulatory needs, Moody's Analytics often cooperates closely with the bank in setting up the scenario assumptions, ensuring that the stress included in the scenario is tailored to the bank's specific business.

Once the assumptions of a particular custom scenario are finalised by the client, they can be provided to Moody's Analytics in any of the ways described in the section above or its combinations:

1. Specific paths for key variables that are being overlaid in the model
2. Annual growth/level targets
3. Severity, for example scenario 1-in-100
4. Narrative for a global and/or local shock

An example includes Brexit scenarios that we developed in summer 2018. The U.K. is set to leave the EU on March 29 at 11:00 p.m. local time. If the U.K. leaves the EU without reaching a withdrawal agreement, many of the numerous rules that regulate the U.K.'s relationship with the EU and with the rest of world via the EU's legal structure no longer apply. Given the myriad issues and the difficult politics, there seems an almost infinite range of potential outcomes of the negotiations. We consider five scenarios that encompass the range of possible outcomes, and their global economic impacts:

- **Baseline – Customs Union for Goods (50% probability)**: The U.K. and EU are expected to come to terms, with the U.K. staying in the customs union for goods—it will continue to fully abide by the EU's tariffs on other regulations on goods—but not for services, for which it negotiates a type of free-trade deal. Under the agreement, the U.K. maintains control over immigration into the country, but allows for the free flow of EU skilled and temporary workers. The U.K. also continues to pay some of the EU's budget.
- **Soft Brexit – Norway+ (20% probability):** The U.K. adopts a relationship with the EU similar to that of Norway. Under this arrangement, the U.K. would have access to the EU market (except for food and drinks, which are subsidized by the EU) in return for implementing all EU laws relating to the market. This option is often called pay with no say.
- **No Brexit (5% probability):** As it becomes clearer that negotiations with the EU are headed for collapse, U.K. Prime Minister Theresa May decides to hold a second referendum, in which the public changes its mind and votes to remain in the EU.
- **Hard Brexit – Canada FTA (20% probability):** The relationship between the U.K. and EU is assumed to be similar to the current free-trade agreement between the EU and Canada.
- **No Deal (5% probability):** The U.K. and EU fail to come to terms on Brexit by the March deadline, and the U.K. crashes out of the customs union and single market. Trade between the U.K. and EU would revert to rules governed by the World Trade Organization. This means border controls will be necessary, tariffs will increase, and regulations and standards will ultimately diverge.

Chart 12 illustrates these fours scenarios for a few key macroeconomic variables for the U.K.

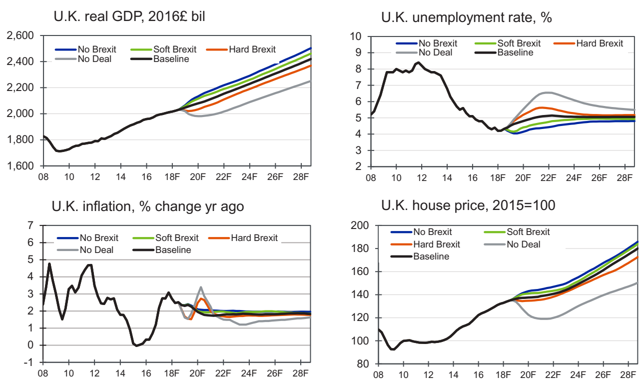
Targeting Procedures

As mentioned above, a standard feature of scenario development, especially regulatory scenarios, is the specification of macroeconomic targets. The key target is GDP, either at a country level or for an aggregate concept such as euro area GDP.

Country Level GDP

In general for each country real GDP equation is an identity, that is, a sum of individual GDP components including private

Chart 12: Brexit Scenarios for U.K.



Sources: ONS, Moody's Analytics

consumption, government spending, investment and net exports. However, implementing a country GDP target, for example provided by the EBA or the PRA, by adjusting individual components would be a cumbersome endeavour. Therefore, a so-called intermediate GDP term has been added for all countries included in the global model, with the exception of the U.S., which has a much more elaborate, bottom-up setup. Specifying and exogenising this intermediate term forces real GDP to follow the explicit path and distributes the difference equally among private consumption and fixed investment, which ensures that the equation of the main GDP identity holds.

GDP Disaggregation

Targets are often provided at the aggregate level for the euro zone, rather than at the level of individual euro zone countries, although the practice varies. Since clients are often interested in forecasts at the country level because of their exposure to local markets, Moody's Analytics translates these aggregate targets into country-level forecasts. Importantly, these country-level forecasts need to add up to the aggregate euro zone target. For this purpose, Moody's Analytics developed its own disaggregation framework for producing country-level forecasts based on aggregate targets.

The disaggregation is based on the difference (gap) between actual and potential GDP growth rates defined as

$$\Delta\widetilde{GDP} \equiv \widetilde{GDP} - \widetilde{GDP}_{potential}$$

We forecast the growth gap for individual euro zone countries based on the euro zone growth gap, which is constructed from the euro zone target provided by the regulator and our estimate of the potential euro zone growth rate:

$$\Delta\widetilde{GDP}_{country} = \beta_1\Delta\widetilde{GDP}_{eurozone} + \beta_2\Delta\widetilde{GDP}_{eurozone} \cdot D_{FC} + \beta_3\Delta\widetilde{GDP}_{eurozone} \cdot D_{EC}$$

where D_{FC} is a dummy indicator for the period 2008Q1-2009Q4, and D_{EC} is a dummy indicator for the period 2011Q3-2012Q4. The coefficient estimates have the following interpretation: β_1 is the sensitivity of the country to economic shocks during normal times (based on the full sample) , while β_2 and β_3 measure the difference in the sensitivity of a given country during the financial crisis and the euro zone sovereign debt crisis, when compared with normal times. Once we have forecast the growth gap we construct a forecast for the level of GDP for each country. To do so, growth gaps are combined with potential output growth to obtain overall implied output growth. The GDP growth is then translated into level of GDP.

In Tables 3 and 4 we illustrate the general framework for two countries: Germany, the largest euro zone economy, and Spain, an economy representative of the euro zone periphery. Table 3 presents coefficient estimates for Germany and Table 4 for Spain.

According to the estimates, Germany experiences larger growth gaps than does the euro zone during normal times, which partly reflects the composition effect, since the German economy constitutes one-quarter of the euro zone economy. This sensitivity is smaller during the two regimes, and substantially so during the euro zone crisis. The combined regime coefficients are 1.21 and 0.83. This corresponds to Germany experiencing a deeper recession during the financial crisis than the rest of the euro zone, but

Table 3: German Disaggregation - Estimation Coefficients

Variable	Coefficient	Std. error	t-statistic	Prob.
@MOVAV(FGDPL$Q_GGAP_IEUZN,4)	1.50	0.09	17.46	0.00
@MOVAV(FGDPL$Q_GGAP_IEUZN,4)*FINANCIALCRISIS	-0.29	0.10	-2.90	0.01
@MOVAV(FGDPL$Q_GGAP_IEUZN,2)*EUROCRISIS	-0.67	0.14	-4.63	0.00

Source: Moody's Analytics

Table 4: Spain Disaggregation - Estimation Coefficients

Variable	Coefficient	Std. error	t-statistic	Prob.
@MOVAV(FGDPL$Q_GGAP_IEUZN,4)	0.51	0.16	3.13	0.00
@MOVAV(FGDPL$Q_GGAP_IEUZN,4)*FINANCIALCRISIS	0.33	0.19	1.75	0.09
@MOVAV(FGDPL$Q_GGAP_IEUZN,2)*EUROCRISIS	1.17	0.28	4.27	0.00

Source: Moody's Analytics

a milder one during the euro zone sovereign debt crisis.

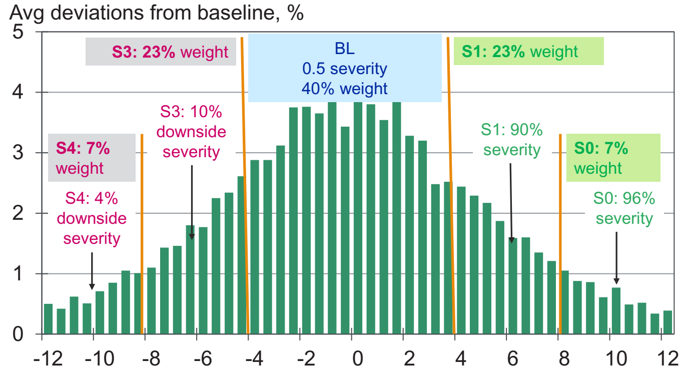
The results are markedly different for Spain. In normal times, Spain's economy reacts mildly to shocks to the euro zone economy, likely reflecting its lower reliance on exports than Germany. The sensitivity is greater during the financial crisis regime, possibly corresponding to Spain's sensitivity to financial shocks. Nevertheless, in this regime Spain still experiences milder drops than does the euro zone, with a combined coefficient of 0.85. In contrast, the combined coefficient for the euro zone crisis is 1.69, implying that the country experiences drops in its output growth gap 70% larger than the rest of the euro zone. This clearly reflects that Spain was one of the peripheral countries hurt by the negative sentiment of investors, leading to a large drop in GDP.

Severity Targets for Moody's Alternative Scenarios

This section describes the process through which we generate our standard alternative scenarios based on severity targets. Severity is defined as probability that economic conditions based on a given metric are worse than in a given scenario. For example, 4% severity indicates that out of all 10,000 simulated paths, 96% of them were above the chosen scenario, while only 4% were below, which could be described as a one-in-25 type of a recession. The metric we employ is the percentage deviation of a given GDP forecast from the benchmark baseline forecast in each quarter and then average the deviation across all quarters of our forecast. This measure reflects both booms and drops in economic activity (similar to a start-to-trough) as well as the overall performance over the whole forecast period (such as average growth rates). Additionally, it can be applied to both upside and downside scenarios, and it works exactly the same way for variables with and without long-term growth.[7]

The process starts with a choice of severity for the Moody's Analytics Standard Alternative Scenarios, which are updated on a monthly basis. We first construct five scenarios in addition to the baseline forecast. The upside scenarios S1 and S0 have severities of 90% and 96%, respectively. Three downside scenarios, S2, S3 and S4, have severities of 25%, 10% and 4%, respectively. The scenarios are consistent in terms of timeline with severity increasing from S0 to S4. The profiles of scenario pairs S1 and S3, and S0 and S4 are symmetric around the baseline according to their severity. This is by design to allow financial institutions to calculate the expected credit loss of the IFRS 9 regulation. The remaining Moody's Analytics scenarios are narrative-driven with varying severity.

Chart 13: Severity Distribution



Source: Moody's Analytics

To evaluate the severity of a given forecast we need simulations of GDP paths. For this purpose, we employ a country model module extracted from our global model, a simple autoregressive (univariate and multivariate) model, or a Markov regime switching model, in each case using bootstrapping technique to draw a set of shocks. We generate 10,000 GPD paths using the selected model and use them to determine the value of severity metric corresponding to the target severity. Chart 13 gives the histogram of severity according to deviations from the benchmark measure of severity in the case of GDP. The y-axis shows the percentage share of each outcome out of the 10,000 simulations, while the x-axis indicates deviations of each outcome from the baseline with pinpointed values corresponding to the four percentiles of interest (4%, 10%, 90% and 96%). These values are our quantitative target for a given scenario. For example, the 10% percentile of the distribution corresponds to around 6%, meaning the scenario with 10% severity should be on average 6% below the baseline over the three-year forecast horizon. In addition to severity based on GDP simulations using average deviations from the baseline forecast, we also assess severity using various metrics, economic indicators and historical data.

To determine the exact profile of GDP we need to have an economic narrative that will determine when GDP will diverge from baseline. This is the key role played by our global narratives. The global narratives specify the nature, size and timing of major economic shocks that drive our scenarios. While such shocks are not quantitative, they provide guidance for analysts when specifying the GDP path for our alternative scenarios. The use of global narratives also ensures consistency across countries, since all countries face the same set of global shocks (which can nevertheless affect each country differently). The global nature of our scenarios gives plausibility to truly adverse scenarios, since very adverse economic conditions are typically possible only when business cycles are synchronized around the world, turning typical stabilizers such as external demand into a negative force. Finally, narratives make understanding and interpretation of our scenarios much easier.

With the full GDP path settled, we can proceed to forecasting other series for all countries using the Moody's Analytics Global Macro Model. Here, we rely to a large degree on the linkages between different variables for a given country and between variables across countries. Many domestic variables are forecast this way, but obviously not all of them are directly pinned down by the path of GDP. For example, while interest rates set

7 For a detailed discussion of alternative severity metrics see M. Janicko, K. Kovar, P. Zemcik, "Scenario Severity and Probability Weights: Moody's Analytics Tool Kit", October 2017

by central banks are likely to decrease as the central bank tries to stimulate an economy in recession, there is less clarity about the path for government bond yields. With lower short-term rates for the foreseeable future, long-term rates should also decrease. However, a worsening fiscal situation and lower long-run GDP means a higher debt burden, possibly raising fears over the sustainability of government debt. This would cause an increase in government bond yields. Here the global narrative provides guidance, as it specifies whether given sentiments in financial markets are prevalent, and to what degree.

To summarize, our scenario generation relies on three pillars: quantitative severity, scenario narratives, and global model linkages. All three pillars are indispensable in the process of generating our standard alternative scenarios. Severity calculations produce our GDP target in terms of severity metric, which is then translated into the actual path of GDP in combination with scenario narratives. The narratives together with model linkages across variables and across countries then allow us to extend our scenarios beyond GDP, providing our clients with detailed, coherent and consistent projections.

Linkages to Market Risk

The concept of market risk refers to the risk of losses due to changes in financial variables such as interest rates, foreign exchange rates, asset prices, volatilities, etc., whose values are set in financial markets.

Some of the market risk metrics such as country stock price indexes or foreign exchange rates are forecast within the framework of the global model. However, there are other various risk metrics such as stock market returns or credit default swaps, that are not part of the global model. In order to generate forecasts for these additional market risk variables, Moody's Analytics constructed satellite models, conditional on projections of core macroeconomic and financial series derived in the Moody's Analytics Global Macro Model described in the previous section. Such a setup can produce reasonable in-sample fit and generate consistent, sensible, out-of-sample forecasts for stressed scenarios. Similar to the equations structure in the global model, the architecture of each satellite model is based on a combination of economic theory, regulatory assumptions, and the statistical properties of the estimated model. We utilize extensive academic literature that has developed a large number of financial models adopted by practitioners. Both time series and cross-sectional methodologies play an important role in the empirical investigation of financial series.

The market risk satellite models are usually divided into groups depending on the type of market risk variables. For example:

» **Swaps and Sovereign Curves (term structure models for interest rates)**
Principal component analysis, Nelson-Siegel approach

» **Stock Market Returns, Historical and Implied Volatilities**
Time series model with conditional heteroskedasticity and global equity factor related to global economic conditions

» **Mortgage-Backed Securities: Agency and Nonagency**
Term structure models with GEF and prepayment factor

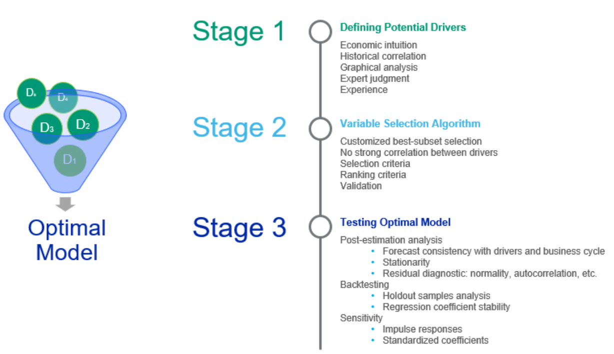
» **Corporate CDS and Corporate Bond Spreads by Sector and Rating**
Time series model with global credit factors, combined with PCA

» **Sovereign CDS by Country and Maturity**
Time series model with long memory, combined with PCA

Variable Selection Algorithm

The procedure of building a satellite model is based on the variable selection algorithm developed by Moody's Analytics, which in an efficient, transparent and concise way allows identification of which core drivers best explain the dynamic behavior of the market risk variable in question.

Chart 14: Optimal Variable Search



Source: Moody's Analytics

Chart 14 summarizes the procedure of selecting optimal drivers, which consists of three stages.

First, potential drivers are identified based on relevant economic theory, historical correlations, regulatory or custom assumptions, expert judgment, etc. These potential drivers come from the series forecast within the Moody's Analytics Global Macro Model or from other available risk metric models.

In the second stage, these potential drivers undergo an exhaustive search process, using the customized best-subset variable selection algorithm, where all possible combinations of selected potential drivers are tested. To avoid model over-fitting, up to three uncorrelated core drivers are typically selected. Moreover, only the models with significant coefficients at a conventional level and expected sign are included in the short list of potential models. In this step the analyst can specify expectation on the signs of coefficients, threshold p-values, and correlation between drivers and number of lags used. The output of the second stage is a list of ranked models from which the optimal model is ultimately selected.

The final stage of the satellite model development includes validation of the optimal model selected in the second stage. We analyze the forecasts relative to historical developments, consistency with drivers, and scenario assumptions, and perform backtesting and sensitivity analysis.[8]

The next three sections include examples of satellite model specifications for swap rates, global stock price indexes, and corporate spreads. For more details about these market risk models and further examples please see Bocchio et al. (2015).[9]

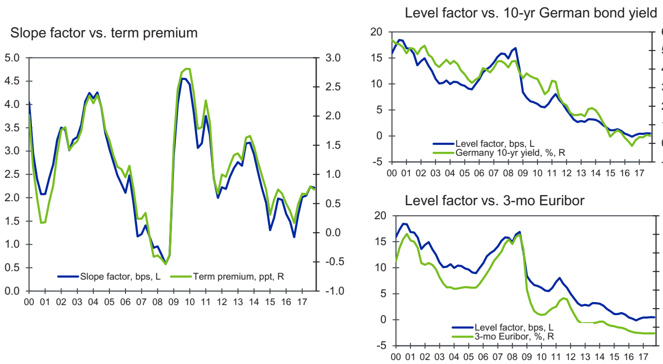
Swap Rates

In order to forecast the term structure of any rates, including swap rates, we first decompose the curve into its principal components. In the second step we forecast the first principal component (the level) and second principal components (the slope) in models

8 For more details about the Optimal Variable Search procedure please see J.M. Licari, O. Loiseau-Aslanidi, D. Vikhrov, "Dynamic Model-Building: A Proposed Variable Selection Algorithm", MoodysAnalytics.com/RiskPerspectives, January 2018

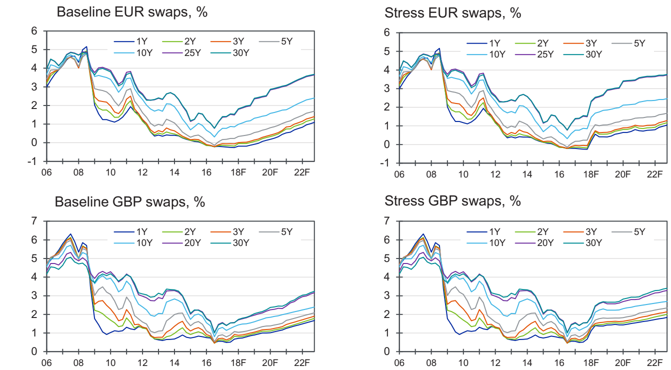
9 C. Bocchio, J.M. Licari, O. Loiseau-Aslanidi, A. Tsharakyan, D. Vikhrov, "Stressed Scenarios and Linkages to Market Risk Instruments", Moody's Analytics white paper, December 2015. https://www.moodysanalytics.com/-/media/whitepaper/2016/2016-01-01-stressed-scenarios-and-linkages-to-market.pdf

Chart 15: Model Drivers for EUR Swaps



Source: Moody's Analytics

Chart 16: EBA Forecasts for EUR Swaps



Sources: EBA, Moody's Analytics

where macroeconomic and financial series from the global model are used as drivers. This is a 'modified-Nelson-Siegel' approach, which is used frequently to model the term structure of interest rates. For example, the level component for the EUR swaps model is determined by the three-month Euribor and German 10-year government bond yield, while the slope component is forecast by the term premium, which is a difference between long- and short-term rates, and in the case of EUR swaps this is the difference between the German 10-year government bond yield and the three-month money market rate. Chart 15 illustrates the historical co-movements of these two principal components with their model drivers.

In the third step the key tenor rates of the swap curve are predicted, using the forecasts of the level and slope components as drivers. Last, remaining tenors are generated using interpolation based on the relative distance to key tenors. See Chart 16 for the example of projections for the entire term structure of EUR and GBP swaps for the baseline and stress scenario from the 2018 EBA stress test.

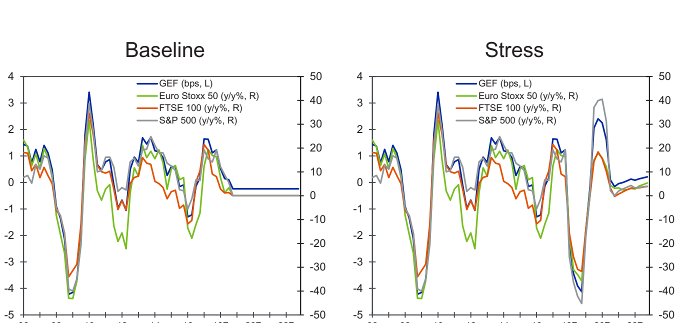
Global Stock Market Indexes

Forecasts for benchmark national stock price indexes for almost all countries are forecast within the global model framework. However, in cases where such forecasts are not available or when we want to generate projections for some regional or global stock price indexes, we use satellite models that are consistent with non-structural macro-finance literature, relying on factor analysis.

The model-building process starts with reducing the dimensional space of the explanatory variables. For that purpose we create the global equity factor, which captures the dynamics of global stock markets, spanning forecasts for stock price indexes from the U.S., U.K. and euro zone into a single vector using standard principal component analysis. The first principal component, the GEF, explains more than 90% of the variability of the three financial variables. The reason for such strong co-movements can be explained by the high integration in financial services in the developed markets. Charts 17 and 18 show examples of the GEF forecast against the projections of the annual changes of individual stock price indexes for the U.S., U.K. and euro zone for the baseline and stress scenarios from the 2018 EBA and PRA stress tests, respectively. It is important to note that under the EBA baseline, stock prices are assumed to remain unchanged, following a specific guideline from the regulator; hence the annual changes are flat at zero.

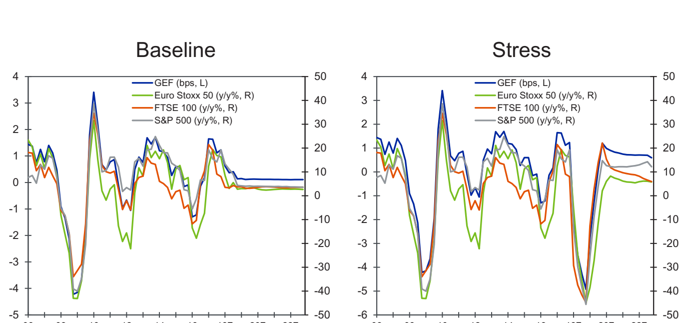
In the next step the desired stock price index is forecast in a satellite model using the GEF as a direct driver. Chart 19 illustrates the historical co-movements of the MSCI World Equity Index and the constructed GEF. Chart

Chart 17: Global Equity Factor – EBA



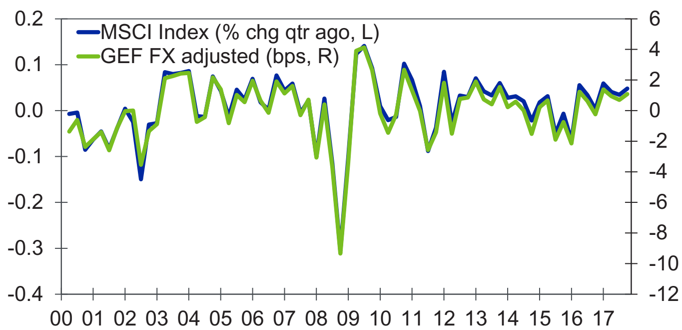
Sources: EBA, Moody's Analytics

Chart 18: Global Equity Factor – PRA



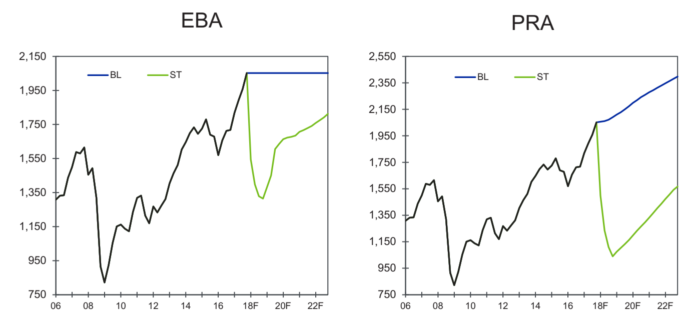
Sources: PRA, Moody's Analytics

Chart 19: World MSCI Index vs. GEF



Source: Moody's Analytics

Chart 20: World MSCI Index – Forecasts



Source: Moody's Analytics

20 presents the forecast of the MSCI Index for the two EBA and PRA scenarios.

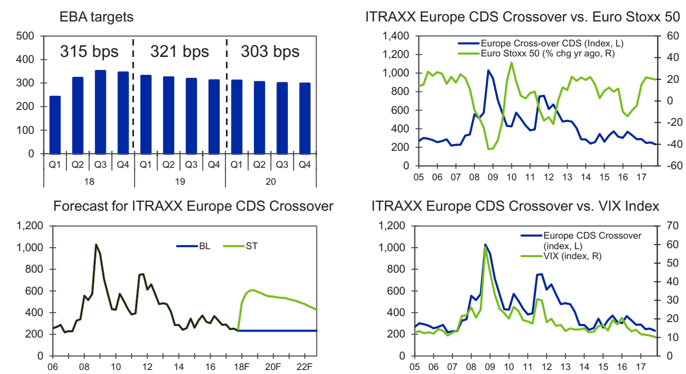
CDS Indexes

The corporate default swap indexes are important indicators of financial markets' risk aversion.

CDS spreads move in opposite directions in comparison with the dynamics of business cycles and they tend to rise in periods with increased uncertainty. Hence we expected a negative correlation between the CDS indexes and stock price index movements and a positive relationship with the volatility indexes. This volatility index measures uncertainty, which increases during economic downturns. Chart 21 shows an example of a forecast for the ITRAXX Europe CDS Crossover index for the EBA baseline and stress scenarios. The key drivers of the model include the annual change of the European stocks index, which looking at historical developments is clearly negatively correlated with the CDS index, and VIX index exhibiting a positive correlation.

After the initial forecast is generated, in the case of regulatory scenarios we often have to impose specific targets provided by the regulator. Under the baseline, iTraxx indexes are assumed to remain unchanged, based on the EBA specification, which requires model results to be overlaid with a flat projection. For the stress scenario the EBA provides targets for the iTraxx Crossover as deviations from the baseline in basis points. So in 2018 on average the forecast of the CDS index in stress needs to be higher by 315 basis points relative to the baseline. For 2019, this difference reaches 321 basis points, and for the following year, 303 basis points. Moody's Analytics translates these annual targets into quarterly targets, ensuring consistency with other macroeconomic and financial projections. After 2020 the forecast is set to gradually return toward baseline.

Chart 21: EBA – iTraxx Crossover Index



Source: Moody's Analytics

Linkages to Credit Risk

Macroeconomic series forecast in the Moody's Analytics Global Macro Model framework are crucial inputs into credit risk modelling, particularly within the IFRS 9 regulatory framework. First, the macroeconomy plays an important role in the riskiness of individual facilities, both for retail and the corporate side of the business, and in case of their default, in potential losses banks incur. Second, a forecast of the "most likely" macroeconomic conditions is crucial for co-determining future performance of the individual facilities as well as the whole portfolio, and constitutes an important aspect of the IFRS 9 modelling since this regulation requires that provisions be calculated on a forward-looking basis. Also, given that the expected credit loss calculation has to be scenario-weighted, while three scenarios approximating all future states of the economy are conventionally used, definition and correct specification of the alternative macroeconomic scenarios are an indispensable part of the IFRS 9 modelling. Finally, nearly all models of risk factors used in the credit risk modelling, in particular probability of default, loss given default, and probability of prepayment, would ideally use macroeconomic drivers in their specification if they are to be considered "best estimates". We illustrate how the macro drivers are used in a PD model for a portfolio of personal loans in United Arab Emirates and on a U.K. Mortgage Portfolio Analyzer that uses PD and LGD models dependent on macro drivers.

Macro Driver Selection for Probability of Default Models

Selection of relevant model drivers and rigorous justification of the variables to be included are an essential part of the modelling process. PD model drivers are selected in two steps. First, loan (and obligor) characteristics that have good power in predicting the default outcome are chosen. What we call a "pre-macro" model is estimated based on selected loan characteristics. In the second step, macroeconomic drivers are added to the pre-macro model.

Chart 22 summarizes the process of optimal driver selection. Loan characteristics are chosen based on single-factor and multifactor analysis. Macroeconomic drivers are selected using the Moody's Analytics Optimal Variable Search tool, which helps find an optimal model in terms of a set of performance criteria.

The macro-drivers are first pre-selected. The basic algorithm is as follows:

1. Screen for variable quality (subjective judgement required)
2. Apply necessary transformations (to meet Gauss-Markov assumptions and in line with Box-Jenkins methodology)
3. Screen using correlations (subjective judgement required)
4. Verify no unit roots and test model robustness

The same as in the case of market risk modelling, the Optimal Variable Search algorithm, described in more detail in Section 4.1, is used to select optimal divers from the pool of macro series selected in the previous steps for each portfolio.

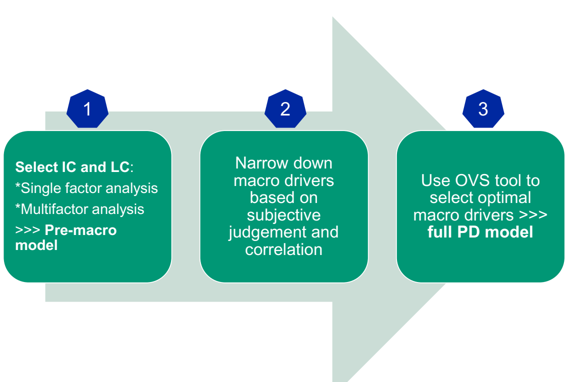
Full PD Model

In-sample performance and out-of-sample scenarios forecasts for a PD model for a financial institution in the United Arab Emirates are shown in Chart 23.

In addition to loan and obligor characteristics, macroeconomic drivers are also included in the model, in particular year-over-year percent change in the Brent crude oil price, quarter-over-quarter percent change in monetary aggregate M3, and quarter-over-quarter percent change in the stock price index. The macroeconomic variables have highly significant negative coefficients, which is consistent with economic theory and intuition. Stronger oil price growth would result in a lower default rate (that is, the default rate will be lower in good times). Similarly, higher M3 and stock price gains are also typically associated with robust economic activity.

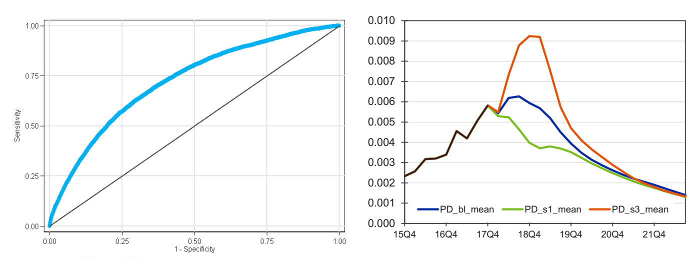
The area under the ROC curve is about 72%, which is a reasonable in-sample performance. Scenario forecasts in Chart 23 show variation across alternative scenarios. Average predicted default rate spikes in the adverse scenario, but goes below baseline in the upside scenario. Scenario forecasts are consistent with the default rates observed in history. All scenarios gradually decline as the

Chart 22: Driver Selection for PD Model



Source: Moody's Analytics

Chart 23: PD In-Sample Performance



AUROC	Model Performance
0.9 – 1.0	Very good
0.8 – 0.9	Good
0.7 – 0.8	Fair
0.6 – 0.7	Poor
0.5 – 0.6	Fail

Source: Moody's Analytics

life cycle effect pushes the portfolio default rates down (forecasts do not incorporate potential new loans that will be added to the portfolio during the forecast period). There is some evidence of seasonality, which may be remedied using seasonal dummies.

Macroeconomic Drivers for Other Risk Factors

Besides using macroeconomic drivers for the probability of default models, other risk factors may include macroeconomic overlay. The selection procedure is similar to the PD algorithm; however, the use of macro drivers is much more contingent on the data availability.

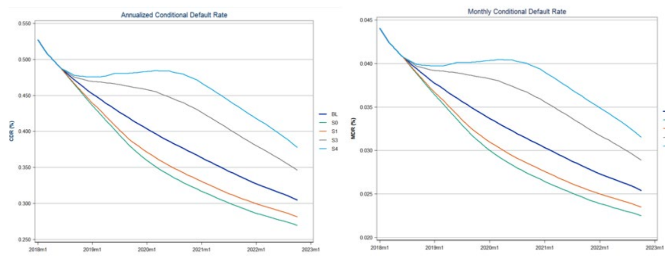
The most usual risk factors modelled with the inclusion of the macroeconomic drivers are prepayments (PPS; probability of prepayment) and loss given default (LGD; ratio of losses on exposure at default in case a facility defaults). For LGD models, macroeconomic variables may play a crucial role to determine recoveries (variables such as labour market indicators and wages and salaries), while the value of collateral as well as its haircut can be estimated using nominal or real house price indexes and their forecasts, if such data are available for the geography in question. Likewise, the lifetime determination of the loss given default values per alternative scenario is frequently estimated with the help of macroeconomic forecasts.

Macroeconomic Aspects in the Expected Credit Loss Calculations

The macroeconomy also co-determines the final expected credit loss calculation. First, macroeconomic interest rates such as the money market rate, representing the cost of acquiring additional funds for the bank, if available, are used for discounting when the ECL calculation is performed. This is usually the case when the interest rate on the facility is unavailable or zero, and hence the effective interest rate cannot be determined with precision. In case the money market rate is not available for the selected geography, other interest rates may be considered, including the lending rate or monetary policy rate.

Finally, the ECL is calculated for each scenario (in case of three scenarios used in the calculation: baseline, upside and downside) and the final ECL is a weighted average of these scenarios, with the weights being 40% for the baseline, 30% for the upside scenario S1, and 30% for the downside scenario S3. If five scenarios are used the recommended weights are 7% for S4 and S0, 23% for S3 and S1, and 40% for the baseline. The optimal weights are based on integrating the likelihood of GDP paths that are closest to the corresponding Moody's Analytics scenario.[10]

Chart 24: Conditional Default Rate Forecast



Source: Moody's Analytics

For stage 1 and 2 facilities, we use the following formula to compute scenario-weighted ECL:

$$ECL_{it} = \sum_{S} w_s \sum_{k=1}^{Ti} PD_{i,t+k}(S)\ EAD_{i,t+k}\ LGD_{i,t+k}(S)\ (1+r_i)^{-3k}$$

where ECL_{it} is expected credit loss for facility i at accounting date t. w_s is scenario weight, where $S = \{S1, BL, S3\}$ or $\{S0, S1, BL, S2, S3\}$. T_i is a lifetime of a facility. For stage 1 facilities, this is 12 months from snapshot date. For stage 2, this is the contractual or behavioral lifetime of the facility. r_i is the facility-specific monthly coupon rate used to discount flow ECL values to reporting date. Finally, for stage 3 accounts, we set the probability of default to 1.

Mortgage Portfolio Analyzer Tool

The Mortgage Portfolio Analyzer is a platform developed by Moody's Analytics to assess credit risk measures, capital levels, and stress scenarios for residential mortgage portfolios, and comprises loan-level econometric models for default, prepayment and LGD. These models incorporate loan and borrower characteristics, along with a common set of macroeconomic factors, which are used in a multiperiod setting.

MPA analyzes mortgage portfolios in four main steps. In the first step, it either generates trajectories of economic scenarios through simulation or uses pre-defined macro forecasts produced by Moody's Analytics, either standard or regulatory-based scenarios. In the second step, for each loan in the portfolio, the loan-level econometric models calculate the monthly default and prepayment probabilities over the analysis horizon as a function of loan and borrower specific characteristics, as well as the macroeconomic forecasts. Next, based on these probabilities, it calculates the monthly cash flows and loan-level losses. In the final step, the loan level losses are aggregated to obtain the portfolio-level expected credit loss.

The expected credit loss on a loan over a horizon depends not just on the macroeconomic environment at the loan origination and maturity, but also on the specific economic path taken by the macroeconomic drivers. The econometric models, in combination with the macroeconomic scenario forecasts, take care of this aspect of the credit losses by incorporating macroeconomic drivers at the loan level, in a multiperiod setting, resulting in a richer representation of the mortgage behavior. Furthermore, linking macroeconomic drivers to the default and prepayment probabilities lets us determine the correlation between the behaviour of different macroeconomic variables and the correlation between the default probabilities of different borrowers implicitly, through their dependence on common factors.[11] Figures in Chart 24 show examples of forecasts for the annualized and monthly conditional default rates across five Moody's Analytics alternative scenarios.

10 M. Janicko, K. Kovar and P. Zemcik, "Scenario Severity and Probability Weights: Moody's Analytics Tool Kit", October 2017.

11 S. Chinchalkar and P. Mashayekh, "Mortgage Portfolio Analyzer: A Model of Losses for the Mortgages", 2016.

Appendix

A.1 List of Acronyms

Application Programming Interface (API)
Bank of England (BoE)
Comprehensive Capital Analysis and Review (CCAR)
Corporate Default Swap (CDS)
Dynamic Stochastic General Equilibrium (DSGE)
European Banking Authority (EBA)
European Central Bank (ECB)
Expected Credit Loss (ECL)
Federal Reserve (Fed)
Global Credit Factors (GCF)
Global Equity Factor (GEF)
Global Growth Factor (GGF)
Internal Capital Adequacy Assessment Process (ICAAP)
Loss Given Default (LGD)
Mortgage Portfolio Analyzer (MPA)
Non-Accelerating Inflation Rate of Unemployment (NAIRU)
Optimal Variable Search (OVS)
Polynomial Distributed Lag (PDL)
Principal Component Analysis (PCA)
Probability of Default (PD)
Prudential Regulation Authority (PRA)

A.2 Estimation Results

Table A1: U.K. 10-Year Bond Yield - Estimation Output

Interest Rate: 10-year discount bond yield, (%, NSA)

Dependent variable D(FRGT10YQ.IGBR-FRMPOLQ.IGBR)
Method: Least Squares
Date: 10/10/17 Time: 19:36
Sample (adjusted): 1999Q2 2017Q1
Included observations: 65 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(FRGT10Y.IUSA-FRFED.IUSA)	0.162	0.079	2.041	0.046
D(FRGT10YQ.IDEU-FRMPOLQ.IEUZN)	0.650	0.096	6.774	0
FRGT10YQ.IGBR(-1)-FRGT3MQ.IGBR(-1)	-0.036	0.019	-1.894	0.063
FRGT10YQ.IGBR(-1)-@PCY(FGDP_POT.IGBR(-1))	-0.014	0.024	-0.588	0.559
FTFXIUSAQ.IGBR(-1)	0.384	0.093	4.112	0.000

R-squared	0.759	Mean dependent var	0.034
Adjusted R-squared	0.743	S.D. dependent var	0.446
S.E. of regression	0.226	Akaike info criterion	-0.061
Sum squared resid	3.070	Schwarz criterion	0.106
Log likelihood	6.985	Hannan-Quinn criter.	0.005
Durbin-Watson stat	1.899		

Notes

Variable description	Mnemonic	Source
Interest Rate: 10-year Discount Bond Yield, (%, NSA)	FRGT10YQ.IGBR	Bank of England; Moody's Analytics Forecast
Potential GDP - Nominal, (Bil. EUR, SAAR)	FGDP_POT.IGBR	Moody's Analytics
Interest Rates: Federal Funds Rate, (% p.a., NSA)	FRFED.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
Interest Rate: 10-Year Bond Yield, (% p.a., NSA)	FRGT10YQ.IDEU	Deutsche Bundesbank; International Monetary Fund (IMF); Moody's Analytics Forecast
Interest Rates: 10-Year Constant Maturity Securities, (% p.a., NSA)	FRGT10Y.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
Interest Rate: Government 3 Month Bond Yield, (%, NSA)	FRGT3MQ.IGBR	Bank of England; Moody's Analytics Forecast
Interest Rate: Bank Rate - Refinancing Rate - ECB, (%, NSA)	FRMPOLQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
Interest Rate: Official Discount Rate - Bank of England, (%, NSA)	FRMPOLQ.IGBR	Bank of England; Moody's Analytics Forecast

Source: Moody's Analytics

Table A2: U.K. Unemployment Rate - Estimation Output

Labor force survey: Unemployment rate, (%, SA)

Dependent variable: D(FLBRQ.IGBR)
Method: Least Squares
Date: 09/26/18 Time: 13:21
Sample (adjusted): 1971Q2 2017Q4
Included observations: 187 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FRMPOLQ_I.IGBR	0.189	0.062	3.068	0.003
FRMPOLQ_I.IGBR	0.091	0.038	2.374	0.019
FLBRQ.IGBR(-1)-FNAIRUQ.IGBR(-1)	-0.033	0.011	-2.912	0.004
PDL01	-0.035	0.007	-4.836	0
PDL02	0.009	0.005	1.747	0.082
PDL03	-0.000	0.001	-0.143	0.887
PDL04	-0.000	0.000	-0.922	0.358

R-squared	0.501	Mean dependent var	0.003
Adjusted R-squared	0.484	S.D. dependent var	0.267
S.E. of regression	0.192	Akaike info criterion	-0.425
Sum squared resid	6.641	Schwarz criterion	-0.304
Log likelihood	46.753	Hannan-Quinn criter.	-0.376
Durbin-Watson stat	0.944		

LAG DISTRIBUTION OF D(FGAPQ.IGBR)			
i	Coefficient	Std. Error	t-Statistic
0	-0.050	0.017	-2.855
1	-0.054	0.011	-5.006
2	-0.052	0.010	-5.124
3	-0.045	0.009	-5.172
4	-0.035	0.007	-4.836
5	-0.027	0.008	-3.287
6	-0.020	0.009	-2.309
7	-0.019	0.008	-2.344
8	-0.025	0.014	-1.753
Sum of Lags	-0.327	0.050	-6.492

Notes

Variable description	Mnemonic	Source
Labor Force Survey: Unemployment Rate, (%, SA)	FLBRQ.IGBR	U.K. Office for National Statistics (ONS); Moody's Analytics Forecast
Output Gap: Real GDP as % deviation from potential GDP, (%, SA)	FGAPQ.IGBR	Moody's Analytics
Non-accelerating inflation rate of unemployment [NAIRU], (%, SA)	FNAIRUQ.IGBR	Moody's Analytics

Source: Moody's Analytics

Table A3: BoE Policy Rate - Estimation Output

Monetary policy rate, (%, NSA)

Dependent variable: FRMPOLQ_I.IGBR-FRMPOLQ_T.IGBR
Method: Least Squares
Date: 08/31/18 Time: 02:53
Sample (adjusted): 1985Q2 2017Q4
Included observations: 131 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FRMPOLQ_I.IGBR(-1)-FRMPOLQ_T.IGBR(-1)	0.940	0.023	40.533	0
D(FRFED.IUSA(-1)-FRMPOLQ_I.IGBR(-1))	0.018	0.097	0.182	0.856
D(FRGT10YQ.IGBR)	-0.129	0.270	-0.476	0.635
DLOG(FSTOCKPQ.IGBR)-@MOVAV(DLOG(FSTOCKPQ.IGBR),4)	1.030	1.174	0.877	0.382
@MOVAV(DLOG(FTFXIUSAQ.IGBR),2)*DUM_FINCRISIS_IGBR	2.967	2.453	1.210	0.229

R-squared	0.927	Mean dependent var	0.616
Adjusted R-squared	0.924	S.D. dependent var	2.595
S.E. of regression	0.714	Akaike info criterion	2.201
Sum squared resid	64.219	Schwarz criterion	2.311
Log likelihood	-139.186	Hannan-Quinn criter.	2.246
Durbin-Watson stat	1.657		

Notes

Variable description	Mnemonic	Source
MONETARY POLICY RATE [INTERMEDIATE TERM], (%, NSA) [INTERNAL]	FRMPOLQ_I.IGBR	Bank of England; Moody's Analytics Forecast
Interest Rates: Federal Funds Rate, (% p.a., NSA)	FRFED.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
MONETARY POLICY RATE TARGET [INTERMEDIATE TERM], (%, NSA) [INTERNAL]	FRMPOLQ_T.IGBR	Bank of England; Moody's Analytics Forecast
Stock Market: FTSE-100 Index, (Index, NSA)	FSTOCKPQ.IGBR	SIX Financial Information; Moody's Analytics Forecast
Nominal Bilateral Exchange Rate, (USD per GBP, NSA)	FTFXIUSAQ.IGBR	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
Financial crisis regime dummy variable	DUM_FINCRISIS_IGBR	Moody's Analytics

Source: Moody's Analytics

Table A4: U.K. House Prices - Estimation Output

Average house price , (£, SA)

Dependent variable: DLOG(FHPLQ.IGBR/FPDICQ.IGBR)
Method: Least Squares
Date: 03/26/17 Time: 03:30
Sample (adjusted): 1982Q3 2015Q4
Included observations: 134 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(FHPLQ.IGBR(-1)/FPDICQ.IGBR(-1))-LOG(FHPLTQ.IGBR(-1)/FPDICQ.IGBR(-1))	-0.006	0.009	-0.691	0.491
DLOG(FHPLQ.IGBR(-1)/FPDICQ.IGBR(-1))	0.703	0.061	11.486	0
D(FLBRQ.IGBR)	-0.021	0.006	-3.381	0.001
D(FRMORTVRQ.IGBR(-1))	-0.009	0.002	-4.081	0.000
DLOG((FYPDLQ.IGBR/FPDICQ.IGBR)/FPOPQ.IGBR)	0.111	0.085	1.311	0.192

R-squared	0.621	Mean dependent var	0.010
Adjusted R-squared	0.609	S.D. dependent var	0.023
S.E. of regression	0.014	Akaike info criterion	-5.616
Sum squared resid	0.026	Schwarz criterion	-5.508
Log likelihood	381.287	Hannan-Quinn criter.	-5.572
Durbin-Watson stat	2.197		

Notes

Variable description	Mnemonic	Source
Average house price, (GBP, SA)	FHPLQ.IGBR	U.K. Office for National Statistics (ONS); Moody's Analytics Estimated and Forecast
Labor Force Survey: Unemployment Rate, (%, SA)	FLBRQ.IGBR	U.K. Office for National Statistics (ONS); Moody's Analytics Forecast
Household Disposable Income Gross, (Bil. GDP, SAAR)	FYPDLQ.IGBR	U.K. Office for National Statistics (ONS); Moody's Analytics Forecast
Average house price - Trend, (GBP, Trend)	FHPLTQ.IGBR	Moody's Analytics
Implicit Price Deflator: Private Consumption, (Index 2013=100, SA)	FPDICQ.IGBR	U.K. Office for National Statistics (ONS); Moody's Analytics Forecast
Population - Total, (Mil. #, SA)	FPOPQ.IGBR	U.K. Office for National Statistics (ONS); European Commission: Eurostat, © European Union, 1995-2014 [proj_13npms]; Moody's Analytics Estimated
Mortgage Rate: Variable Rate, (%, NSA)	FRMORTVRQ.IGBR	Bank of England; Moody's Analytics Forecast

Source: Moody's Analytics

Table A5: U.K. Three-Month Money Market Rate - Estimation Output

Interest rate: Money market rate, (%, NSA)

Dependent variable: D(FRMMQ.IGBR-FRMPOLQ.IGBR)
Method: Least Squares
Date: 09/25/18 Time: 23:18
Sample (adjusted): 1999Q2 2018Q2
Included observations: 77 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.012	0.012	1.042	0.301
FRMMQ.IGBR(-1)-FRMPOLQ.IGBR(-1)	-0.157	0.042	-3.710	0.000
D(FRSPRMMQ.IEUZN)	0.214	0.077	2.767	0.007
D(FRSPRMMQ.IEUZN)^2	0.605	0.122	4.973	0
D(FRILIBOR3M.IUSA-FRFED.IUSA)	0.427	0.053	8.078	0

R-squared	0.703	Mean dependent var	0.006
Adjusted R-squared	0.686	S.D. dependent var	0.154
S.E. of regression	0.086	Akaike info criterion	-1.998
Sum squared resid	0.537	Schwarz criterion	-1.846
Log likelihood	81.928	Hannan-Quinn criter.	-1.937
F-statistic	42.560	Durbin-Watson stat	1.389
Prob(F-statistic)	0		

Notes

Variable description	Mnemonic	Source
Interest Rate: Money Market Rate, (%, NSA)	FRMMQ.IGBR	Bank of England; Moody's Analytics Forecast
Interest Rates: Federal Funds Rate, (% p.a., NSA)	FRFED.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
LIBOR Rates: 3-Month U.S. Dollar Deposits - Period average, (% p.a., NSA)	FRILIBOR3M.IUSA	ICE Benchmark Administration Limited (IBA); Moody's Analytics Forecast
Interest Rate: Official Discount Rate - Bank of England, (%, NSA)	FRMPOLQ.IGBR	Bank of England; Moody's Analytics Forecast
INTEREST RATE: SPREAD - 3-MONTH EURIBOR TO ECB POLICY RATE, (% PTS., NSA) [INTERNAL]	FRSPRMMQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast

Source: Moody's Analytics

Table A6: ECB Policy Rate - Estimation Output

Interest rate: Bank rate - Refinancing rate- ECB , (%, NSA)

Dependent variable: FRMP_I.IEUZN-FRMP_T.IEUZN
Method: Least Squares
Date: 09/26/18 Time: 17:37
Sample (adjusted): 2004Q4 2017Q3
Included observations: 52 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FRMP_I.IEUZN(-1)-FRMP_T.IEUZN(-1)	0.927	0.040	23.251	0
D(FRFED.IUSA(-1)-FRMP_I.IEUZN(-1))	0.002	0.184	0.009	0.993
D(FTFXIUSAQ.IEUZN)	-0.255	0.313	-0.816	0.419
DLOG(FSTOCKPQ.IEUZN)-@MOVAV(DLOG(FSTOCKPQ.IEUZN),4)	2.634	1.044	2.522	0.015
DLOG(FTFXIUSAQ.IEUZN)*FTFXIUSAQ.IEUZN	-3.014	2.876	-1.048	0.300

R-squared	0.916	Mean dependent var	-0.576
Adjusted R-squared	0.909	S.D. dependent var	1.430
S.E. of regression	0.432	Akaike info criterion	1.251
Sum squared resid	8.775	Schwarz criterion	1.438
Log likelihood	-27.522	Hannan-Quinn criter.	1.323
Durbin-Watson stat	1.604		

Notes

Variable description	Mnemonic	Source
Interest Rate: Bank Rate - Refinancing Rate - ECB [Intermediate term], (%, NSA)	FRMP_I.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
Interest Rates: Federal Funds Rate, (% p.a., NSA)	FRFED.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
INTEREST RATE: BANK RATE - REFINANCING RATE - ECB [TARGET], (%, NSA) [INTERNAL]	FRMP_T.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
Stock Price Index, (Index 2010=100, NSA)	FSTOCKPQ.IEUZN	Moody's Analytics Calculated and Forecast
Nominal Bilateral Exchange Rate, (USD per EUR, NSA)	FTFXIUSAQ.IEUZN	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast

Source: Moody's Analytics

Table A7: Three-Month Euribor - Estimation Output

Interest rate: EURIBOR - 3-mo, (%, NSA)

Dependent variable: D(FREURIBOR3MQ_I.IEUZN-FRMPOLQ.IEUZN)
Method: Least Squares
Date: 09/25/18 Time: 23:28
Sample (adjusted): 2001Q1 2018Q2
Included observations: 70 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
(FREURIBOR3MQ_I.IEUZN(-1)-FRMPOLQ.IEUZN(-1))-(FRSPRMM_EQ.IEUZN)	-0.310	0.049	-6.309	0
D(FRILIBOR3M.IUSA-FRFED.IUSA)	0.272	0.044	6.178	0
D(FRILIBOR3M.IUSA-FRFED.IUSA)*FRMP_I.IEUZN	1.049	0.335	3.131	0.003
D(FRMPOLQ.IEUZN-FRMDEPQ.IEUZN)*FDUM_EXTRALIQUIDQ.IEUZN	-0.639	0.245	-2.613	0.011

R-squared	0.781	Mean dependent var	-0.009
Adjusted R-squared	0.771	S.D. dependent var	0.173
S.E. of regression	0.083	Akaike info criterion	-2.087
Sum squared resid	0.454	Schwarz criterion	-1.958
Log likelihood	77.044	Hannan-Quinn criter.	-2.036
Durbin-Watson stat	1.543		

Notes

Variable description	Mnemonic	Source
INTEREST RATE: EURIBOR - 3-MONTH [INTERMEDIATE TERM], (%, NSA) [INTERNAL]	FREURIBOR3MQ_I.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
EXTRA LIQUIDITY REGIME DUMMY, (BOOLEAN, NSA) [INTERNAL]	FDUM_EXTRALIQUIDQ.IEUZN	Moody's Analytics
Interest Rates: Federal Funds Rate, (% p.a., NSA)	FRFED.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
LIBOR Rates: 3-Month U.S. Dollar Deposits - Period average, (% p.a., NSA)	FRILIBOR3M.IUSA	ICE Benchmark Administration Limited (IBA); Moody's Analytics Forecast
Interest Rate: Deposit rate, (%, NSA)	FRMDEPQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
Interest Rate: Bank Rate - Refinancing Rate - ECB, (%, NSA)	FRMPOLQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
INTEREST RATE: EQUILIBRIUM SPREAD - 3-MONTH EURIBOR LESS MAIN REFINANCING RATE, (% PTS., NSA) [INTERNAL]	FRSPRMM_EQ.IEUZN	Moody's Analytics

Source: Moody's Analytics

Table A8: German 10-Year Government Bond Yield - Estimation Output

Interest rate: 10-year bond government (% P.A., NSA)

Dependent variable: D(FRGT10YQ.IDEU)
Method: Least Squares
Date: 09/27/18 Time: 15:52
Sample (adjusted): 1973Q1 2017Q4
Included observations: 180 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FRGT10YQ.IDEU(-2)-FRGT10Y_EQ.IDEU	-0.027	0.013	-2.036	0.043
D(FRGT10Y.IUSA)	0.384	0.039	9.787	0
D(FRSPR10YQ.IEUZN)	-0.514	0.073	-7.055	0
D(FRMPOLQ.IEUZN)	0.126	0.049	2.543	0.012
@MOVAV(D(FRMPOLQ.IEUZN),8)	0.247	0.086	2.867	0.005

R-squared	0.546	Mean dependent var	-0.045
Adjusted R-squared	0.536	S.D. dependent var	0.379
S.E. of regression	0.258	Akaike info criterion	0.159
Sum squared resid	11.690	Schwarz criterion	0.248
Log likelihood	-9.326	Hannan-Quinn criter.	0.195
Durbin-Watson stat	1.432		

Notes

Variable description	Mnemonic	Source
Interest Rate: 10-Year Bond Yield, (% p.a., NSA)	FRGT10YQ.IDEU	Deutsche Bundesbank; International Monetary Fund (IMF); Moody's Analytics Forecast
INTEREST RATE: 10-YEAR BOND YIELD - EQUILIBRIUM VALUE, (%, NSA) [INTERNAL]	FRGT10Y_EQ.IDEU	Moody's Analytics
Interest Rates: 10-Year Constant Maturity Securities, (% p.a., NSA)	FRGT10Y.IUSA	U.S. Board of Governors of the Federal Reserve System; Moody's Analytics Forecast
Interest Rate: Bank Rate - Refinancing Rate - ECB, (%, NSA)	FRMPOLQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
INTEREST RATE: SPREAD - 10-YEAR GOVERNMENT BOND YIELDS - EUROZONE LESS GERMANY, (% PTS., NSA) [INTERNAL]	FRSPR10YQ.IEUZN	European Central Bank (ECB); Deutsche Bundesbank; Moody's Analytics Forecast

Source: Moody's Analytics

Table A9: Euro Zone 10-Year Government Bond Yield - Estimation Output

Interest rates: Central government bond yield curve - All bond ratings total - Spot rate - 10 year maturity (%, NSA)

Dependent variable: D(FRGT10YQ.IEUZN-FRGT10YQ.IDEU)
Method: Least Squares
Date: 09/25/18 Time: 23:28
Sample (adjusted): 1998Q1 2018Q2
Included observations: 82 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
@MOVAV(FRGT10YQ.IEUZN(-1)-FRGT10YQ.IDEU(-1)-(FRSPR10Y_EQ.IEUZN),2)	-0.263	0.059	-4.488	0
D(FSPVOL.IUSA)	0.031	0.022	1.394	0.167
FREURIBOR3MQ_I.IEUZN*D(FSPVOL.IUSA)	0.488	0.073	6.672	0
D(FRGT10YQ.IEUZN(-1)-FRGT10YQ.IDEU(-1))	0.232	0.088	2.641	0.01

R-squared	0.625	Mean dependent var	0.008
Adjusted R-squared	0.610	S.D. dependent var	0.152
S.E. of regression	0.095	Akaike info criterion	-1.823
Sum squared resid	0.704	Schwarz criterion	-1.705
Log likelihood	78.737	Hannan-Quinn criter.	-1.776
Durbin-Watson stat	2.019		

Notes

Variable description	Mnemonic	Source
Interest Rates: Central government bond yield curve - All bond ratings total - Spot rate - 10 year maturity, (%, NSA)	FRGT10YQ.IEUZN	European Central Bank (ECB); Moody's Analytics Forecast
Interest Rate: 10-Year Bond Yield, (% p.a., NSA)	FRGT10YQ.IDEU	Deutsche Bundesbank; International Monetary Fund (IMF); Moody's Analytics Forecast
INTEREST RATE: EQUILIBRIUM SPREAD - 10-YEAR GOVERNMENT BOND YIELDS - EUROZONE LESS GERMANY, (% PTS., NSA) [INTERNAL]	FRSPR10Y_EQ.IEUZN	Moody's Analytics
S&P 500 Volatility, (30 day MA, NSA)	FSPVOL.IUSA	S&P Dow Jones Indices LLC; Moody's Analytics Forecast

Source: Moody's Analytics

A.3 U.K. Standard Scenario Narratives January 2019

- **Baseline:** The U.K. economy has downshifted to a subpar growth path as the impact of the decision to leave the European Union drags on sentiment and economic activity. The Moody's Analytics baseline assumption is that the U.K. and EU will ultimately manage to pass the withdrawal deal. However, there is significant concern about how the next few months will unfold. Because of that, U.K. economic growth is projected to remain subdued in the near term as Brexit-related uncertainty weighs on business investment.
- **Exceptionally Strong Growth ("S0") Scenario:** This scenario is based on the assumption of a confluence of extremely favorable events around the world. In the U.S., the tax overhaul combined with the large gains in corporate earnings leads to a greater than expected rise in business investment. Solid gains in U.S. employment and rising productivity cause wage rates to rise, boosting household incomes and spending. Furthermore, the U.S. and China successfully negotiate their future trade relationship, providing a boost to international trade. The U.K. and the EU reach a mutually advantageous agreement on the U.K.'s departure from the EU, with the U.K. keeping unhindered access to the single market and staying in the customs union after its exit from the EU. As a result, U.K. growth accelerates substantially, far faster than in the baseline projection.
- **Stronger Near-Term Growth ("S1") Scenario:** In this upside scenario the U.K. economy receives a near-term boost as signs emerge that the nation will reach an acceptable separation agreement with the EU, allowing for the desired bespoke trade deal after the transitional period ends on 31 December 2020, easing uncertainty and boosting business sentiment and financial markets. Furthermore, the Trump administration is successful in its negotiation with trading partners, particularly China. In addition, easing uncertainty about the U.S. Federal Reserve's normalization cycle reduces risk aversion in capital markets, supporting credit conditions and growth across the industrialized world, while emerging markets experience steadier expansion and greater financial stability. As external threats to the economy dissipate, improved confidence lifts consumption and business investment spending above the baseline. As a result, GDP increases faster than in the baseline in the near term, moderating slightly thereafter as the BoE adopts a slightly tighter policy stance than in the baseline, slowing investment growth.
- **Mild Recession ("S2") Scenario:** This scenario develops as uncertainty about the potential negative effects on the European economy of the U.K.'s departure from the EU increases, causing business sentiment to decline. Brexit negotiations temporarily deteriorate as the U.K. and the EU start to hash out the terms of the trade deal. Additionally, concerns about U.S. trade policy build among investors, causing global bond markets to sell off in early 2019. Capital flows out of emerging markets, causing a moderate correction in global stock markets. Business investment in the U.S. and major European economies starts to falter. The U.S. economy expands more slowly in the near term than in the baseline, though it avoids recession. However, much of Europe, including the U.K., is pushed back into a mild recession in the first half of 2019. Business investment in the U.K. slumps as companies postpone decisions until they have a better idea of how relations between Britain and the EU will play out.
- **Moderate Recession ("S3") Scenario**: In this scenario global equity and risky bond markets sell off over the U.K. government's inability to reach an internally acceptable compromise on Brexit. The U.K. and the EU are unable to agree on a compromise and the U.K. crashes out of the EU. Britain does not succeed in a bespoke bilateral trade agreement, resulting in a hard Brexit at the end of March. Trade arrangements default to WTO rules. Furthermore, protectionist U.S. policy damages global confidence and drags on international trade. Falling global financial markets and heightened volatility precipitate a sharp fall in Chinese property prices, sending shock waves throughout Asia. Business investment in the U.K. slumps as companies postpone decisions until they have a better idea of how relations between Britain and the EU will play out. Furthermore, the recession in Europe and the U.S. and slower Chinese growth knock U.K. industrial output and exports. External weakness swiftly flows through to weaker domestic demand.
- **Protracted Slump ("S4") Scenario:** In this scenario the U.K. falls into a deep recession as a result of multiple shocks that severely restrain liquidity and dislocate financial markets. First, equity markets plunge as the U.K. and the EU are unable to agree on a compromise and the U.K. crashes out of the EU. The risk that the U.K. government would fall increases. Trade arrangements default to World Trade Organization rules, substantially limiting the free movement of goods, services, capital and people, resulting in a significant drop in trade and economic activity in Europe. Furthermore, the Trump administration forges ahead with its plans to increase the tariff rate from 10% to 25% on a wide range of Chinese goods. China imposes a variety of retaliatory measures that reduce U.S. exports and impede the ability of U.S. companies to do business there. China's economy enters a sustained downturn as its property market rapidly unwinds in the face of falling liquidity and declining export receipts. The euro zone drops back into a deep recession, causing populism to expand further, threatening the existence of the euro zone. Close financial and trade links with the euro zone make the U.K. highly vulnerable to rising uncertainty surrounding the future of the single-currency union. The rapidly deteriorating debt crisis badly damages Britain's banking sector, with those financial institutions exposed to the fiscally troubled countries most vulnerable.
- **Below-Trend Long-Term Growth ("S5") Scenario:** In this scenario the U.K. economy avoids recession, but the growth rate is below the baseline pace for an extended period, as elevated risk aversion, a result of heightened concern over the U.K.'s departure from the EU, weighs on asset prices and business and consumer confidence. Though the other downside scenarios feature a subsequent demand-driven recovery back to the baseline trend, supply-side constraints prevent that outcome. Credit markets function effectively, but the supply of

and demand for additional household and corporate credit are restrained by repercussions of Brexit. Furthermore, the growing lack of confidence in the pace of long-run growth combined with Britain's aging demographics leads to a structural shift in household behavior from spending towards saving.

- **Stagflation ("S6") Scenario:** This scenario is based on the assumption that an unanticipated wage-price spiral starts to develop as the U.S. and other major global economies approach full employment. Global oil demand rebounds faster than expected, and as a result oil prices rise faster than in the baseline, peaking around $85 per barrel by mid-2019. Pressures on core consumer prices increase as the higher oil prices push up production costs, prompting many central banks to tighten monetary policy in mid-2019. The sudden monetary tightening sends the U.S. economy into recession by mid-2019 in an environment of high inflation. Higher interest rates and rising inflation cut heavily into discretionary income around the world, and consumer confidence declines significantly, causing global consumer spending to weaken sharply. Firms are squeezed between rising costs and tepid demand, and corporate profitability and stock prices start to fall. Weaker external demand and tighter domestic interest rates cause the U.K. economy to contract by mid-2019.
- **Low Oil Price ("S8") Scenario:** This scenario assumes that oil prices remain low for an extended period. The price of West Texas Intermediate remains around $35 per barrel for four years until 2022 as increases in supply outstrip demand. In contrast, the baseline presumes oil prices hover above $60 per barrel, based on the assumption of strengthening global demand for energy. Asset prices, including equity and property prices, rise in most countries as lower oil prices increase disposable income and business investment in nonenergy-related industries. Sustained low oil prices act like a tax cut in oil-importing countries and boost aggregate demand and world GDP in the next few years because oil importers tend to spend more and save less than oil exporters.
- **Consensus ("CF") Scenario:** This is based on the review of a variety of surveys of baseline forecasts. Moody's Analytics creates consensus targets for GDP and CPI for each country for the first four years of the scenario, since that is the most typical duration in the surveyed results. Forecast sources include the International Monetary Fund, the World Bank, the U.S. Department of Agriculture, central banks, and Focus Economics. For the U.K., consensus targets for GDP, CPI, and the unemployment rate were run through the Moody's Analytics global model to estimate the paths for all other variables.

About the Authors

Petr Zemcik, PhD is a senior director at the Moody's Analytics London office who manages of a team of risk modelers and economists in the London and Prague offices. He frequently serves as an engagement lead and a head modeler for projects across several lines of business in the U.K., continental Europe, the Middle East, and Canada to design and validate PD/LGD/EAD credit risk models for IFRS 9, A-IRB, and stress-testing. He supervises quality control, development, and validation of macroeconomic country models, credit risk products using proprietary data, satellite market risk models, and other forecasting products in Europe and the Middle East. In addition, he is involved in the development and calibration of alternative macroeconomic scenarios. He previously worked at CERGE-EI, a joint workplace of the Center for Economic Research and Graduate Education of Charles University in Prague and the Economics Institute of the Academy of Sciences of the Czech Republic, and in the U.S. at Southern Illinois University in Carbondale IL. He has published numerous articles on econometric methodology and on real estate bubbles in the U.S. and in Europe in peer-reviewed professional journals such as the Journal of Real Estate Economics and Finance, the Journal of Housing Economics, and the Journal of Multivariate Analysis. Petr holds a PhD and MA in Economics from the University of Pittsburgh and MSc in Econometrics and Operations Research from the University of Economics in Prague.

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