Quantitative risk management and stress test
to ensure safety and soundness of financial institutions

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March 21, 2017
Stress test

- In the wake of the financial crisis, U.S. Congress enacted the Dodd-Frank Act
  - Requires the Federal Reserve to conduct an annual stress test
  - Seeks to ensure BHCs have sufficient capital to continue operations throughout times of economic and financial market stress

- Projects balance sheets, RWAs, net income, and resulting post-stress capital over a nine-quarter "planning horizon"
  - BHC stress scenario: internally generated scenarios (Baseline and Adverse) customized to idiosyncratic risk of BHC
  - Supervisory scenario: Baseline, Adverse, Severely Adverse
FRB guidance for quantitative methodologies/models

- Stress test is a forward-looking quantitative evaluation of the impact of stressful economic and financial market conditions on BHC capital

- Specific expectations in terms of quantitative tools/models and their governance:
  - SR15-18: FRB Capital Planning Guidance
    - Use of Models and Other Estimation Approaches
    - Model Overlays
    - Use of Benchmark Models
    - Sensitivity Analysis and Assumptions Management
  - SR11-7: FRB Model Risk Management Guidance
    - Model Development, Implementation and Use
    - Model Validation
    - Model Governance, Policy, and Control
Applications of models

- Economic Scenario Generation
  - Firm-specific scenarios: specific vulnerabilities of the firm’s risk profile
  - Multiple stressful conditions or events can occur simultaneously or in rapid succession

- Loss Estimation
  - Credit risk losses on loans and securities
  - Fair-value losses on loans and securities
  - Market and default risks on trading and counterparty exposures
  - Operational-risk losses
Applications of models (continued)

- **Pre-Provision Net Revenue (PPNR)**
  - Net interest income
  - Non-interest income
  - Non-interest expense

- **Risk Weighted Asset (RWA)**
Model data/input and sources

- **SR15-18 Guidance**
  - Disaggregated levels to capture observed variations in risk characteristics and performance across sub-portfolios/segments under changing conditions
  - Internal data to estimate Losses and PPNR when possible

- **Data quality and relevance**
  - Downturn historical data
  - Suitability for the model and consistent with the modeling framework

- Included/excluded data and proxies for model development population, rationale, and impact on results
- Representative of the bank’s portfolio
- Reconciles with general reporting information (e.g., GL) as applicable
Modeling consideration

- **SR15-18 Guidance**
  - Separately estimate Losses and PPNR for portfolios or business lines that are sensitive to different risk drivers
  - Qualitative Approaches are allowable in limited cases

- Model requires both accuracy and sensitivity; where the later might be more important
  - Loss forecasting: performance both for short- and long-term predictions are important
  - Stress Test: sensitivity is more important than model fit

- Proper granularity and segmentations are critical to deal with changing portfolio composition
Modeling consideration (continued)

- Beware of correlation between dynamic input or “time” dummy variables which can mute the impact of macroeconomic variables

- Treatment dynamic variables which cannot be predicted
  - Time-varying behavioral variables
Modeling framework

- **Credit/PPNR Models**
  - Account level modeling
    - Conditional (i.e., hazard) model/panel regression
    - Credit rating migration model
  - Pool level models: vintage, segment, or behavior pool
  - Time-series regression
  - Choice consideration: granularity to capture portfolio changes, ability to capture important drivers, data availability, resource/timing, and on-going maintenance

- **Market Models**
  - Full revaluation using Front Office pricing model
    - Need to evaluate the model function properly during stress condition: stability, convergence, no arbitrage
  - Approximation (Greek-based) models
  - Need Risk not in Model to deal with limitation
General modeling framework

- Let $T$ a random time of account closing (e.g., due to default or attrition/prepayment), the hazard function is modeled as a regression with $g(.)$ link function and covariates $Z(s)$

$$
\lambda\{t|Z(s)\} = g[\lambda_0(t), Z(s)]
$$

- Where $\lambda_0(t)$ is the baseline hazard to represent the effects of unobserved factors and $s$ is the observation time which can be:
  - Static such as time of origination, $s = 0$
  - Dynamics
    - Last snapshot information without future prediction
    - Including future prediction, i.e. $s = t$ and prediction model $Z(t)$ is available such as PPNR models (e.g., utilization or spend rate) or macro-economic factors

$$
Z\{t|X(s)\} = h[Z_0(t), X(s)]
$$
Dynamic covariates and data stacking

- Dynamic factors that no future prediction are available but they are critical such as refreshed FICO, Utilization, etc., and need to be handled through ‘data stacking’ approach

<table>
<thead>
<tr>
<th>Snapshot Date, s</th>
<th>Snapshot FICO, x1</th>
<th>Snapshot Delinquency, x2</th>
<th>Performance Date, t</th>
<th>MOB, m</th>
<th>Unemployment, x3</th>
<th>Default</th>
<th>Time after snapshot, k</th>
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Dynamic Factor without future predicted values

Performance time, t

<table>
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<th>(s,t)</th>
<th>Performance time, t</th>
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Origination model
- Age (or time-snapshot) model
- 4-Step ahead prediction model
- 2-Step ahead prediction model
- Original data. No predictive capability

Original data. No predictive capability
Model validation depth and scope

- Soundness of modeling approach
  - Methodology, granularity, data quality, and treatment (coverage, proxy, etc.), parameter estimation/calibration
- Model stability under market shock
  - Computational stability, parameter stability, reasonable outcome
- Rigor of model performance evaluation
  - Backtesting to previous stress condition
  - Out-of-sample and out-of-time testing
  - Sensitivity to risk varying risk drivers
    - Separation across different scenarios
    - Consistency with respect to scenarios
- Issues and limitations
  - Risk in model, risk not in model, parameter uncertainty
- Holistic approach
  - Not only focus on the targeted core models, but also include critical upstream and downstream models and tools
- Thorough documentation
Model validation:

Replication

- Independently rerunning/recoding models to confirm and evaluate model outputs

- In-sample backtesting
  - Multiple forecast starting points covering different parts of the economic cycle
  - Model performance for all segments and alternative segments.

- Out-of-sample/out-of-time performance
  - Out-of-development periods test
  - Model performance when “stress-time window” is excluded from parameter estimation
    - Appropriateness for future scenarios where such scenarios do not exist in the development sample
    - Out-of-time forecast performance
    - Parameter stability

- Sensitivity analysis and testing
  - Model sensitivity under distinct economic scenarios
  - Sensitivity to input changes
Model validation:

Benchmarking

- Distinct modeling alternatives
- Evaluate model performance when the true outcomes are unknown (i.e., Stress testing models)
- Diagnose appropriateness of modeling choice
  - Model structure including the simplification choice
  - Segmentation
  - Variable selection, non-linearity, interactions
- Model alternatives used by validators needs to be comprehensive and insightful and are likely to be more complicated and perform better than production models
  - Not constrained by the requirement for model maintenance and operational computation time
Evaluating the dynamics of stress testing models

Dynamics of Horizon Prediction:

\[ \lambda_i(t|s) = \beta_0(k) + x_i^T(s, t)\beta(k) \]

- Prediction of time \( t \) given the ‘snapshot’ information at time \( s \)
- Dynamic covariates:
  - Economic factors\(<-t\)
  - Behavioral covariate\(t<-s\)
- Is there effect from unobserved variables?
  - e.g., baseline hazard in PD model
- Is the sensitivity change over the horizon?
  - e.g., is the effect of FICO at time snapshot decaying over horizon?
Machine learning for variable selections

**Alternative Model: Machine Learning (ML)**

Model importance ranking
- ML embedded method importance measure (e.g. gradient boosting machine (GBM), random forest)
- ML filter methods ranking (univariate and multivariate)

Model interaction selection
- ML H-statistics/ML 2D partial dependent plot
- GLM elastic net with regularization on interactions

Nonlinearity detection
- ML 1D partial dependent plot

Importance ranking using GBM

Nonlinearity and Interaction
Validation platform

Data ingestion
- Teradata
- SAS
- SQL server

Processing
- Hadoop (on disk)
- Spark (in memory)
- SAKE (internal)
- Map reduce

Computation
- Script: Python, R, SAS
- Engine: H2O, Tensor Flow, SystemML
- Infrastructure: GRID, GPU

Model Risk System (MoRS)
Compensating model weakness during usage: Overlays

- Models are often have weakness and limitation due to:
  - Risk in Model:
    - Outstanding issues, limitations, or restriction identified during model validations or performance monitoring
    - Model dependency
      - Weakness of upstream (feeder) models
      - Uncertainty of input assumptions
  - Risk Not in Model: model limitation to capture risk drivers listed in the stress test risk identification process
    - Factors in economic scenario that are not in the models
    - Idiosyncratic factors both external events or business drivers/strategy
Compensating model weakness during usage:
Overlays

- Compensating factors such as model overlays are typically applied for model weakness
  - Quantitative overlay: model benchmark, quantitative analysis, back testing, sensitivity analysis
  - Qualitative overlay: management judgment