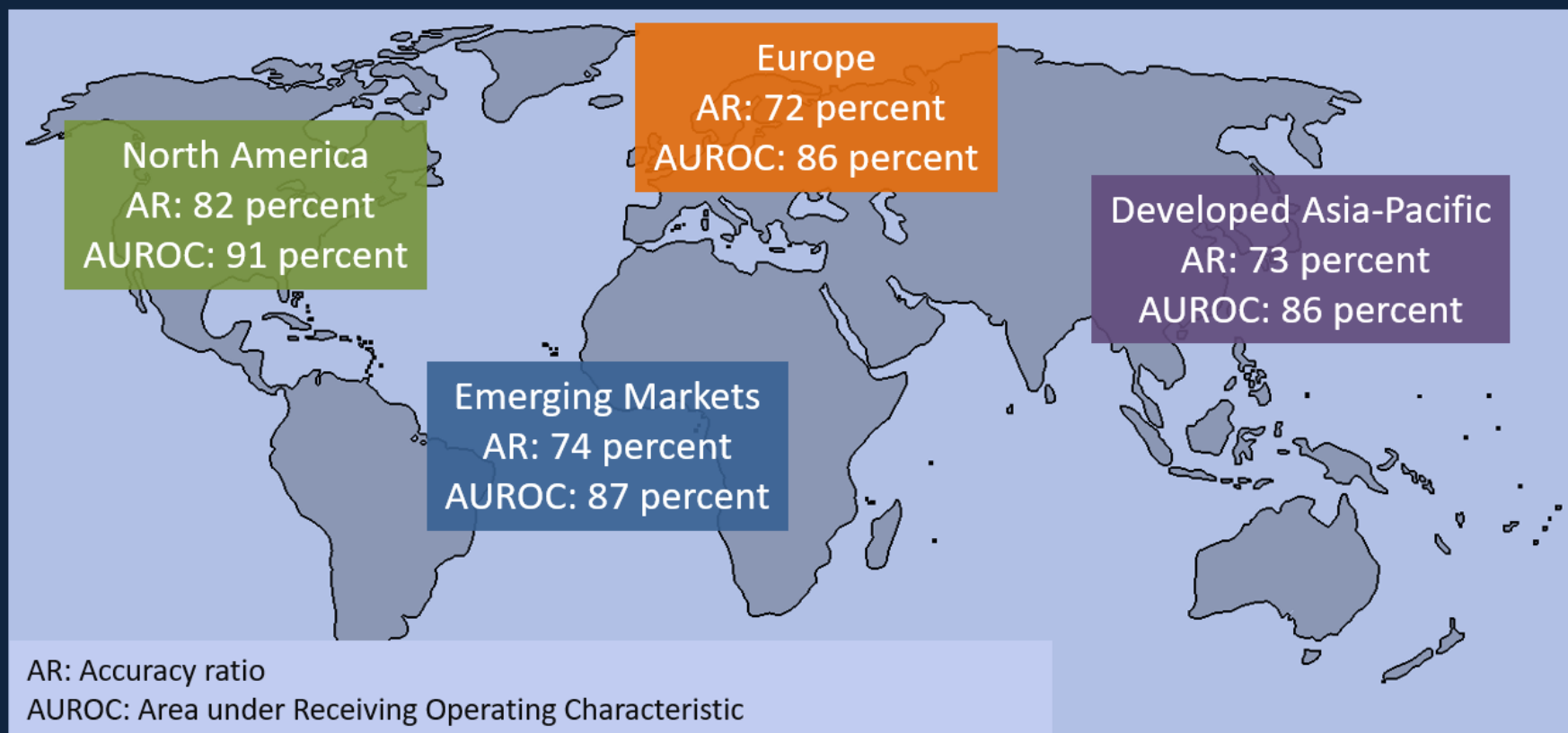


PD Model Accuracy: 1-year ahead default rates



Bottom-up Default Analysis (BuDA)

— Methodology and Applications

Jorge A. Chan-Lau¹ Jin-Chuan Duan² Wei Sun³

¹ Institute for Capacity and Development
International Monetary Fund

² NUS Business School and Credit Research Initiative
National University of Singapore

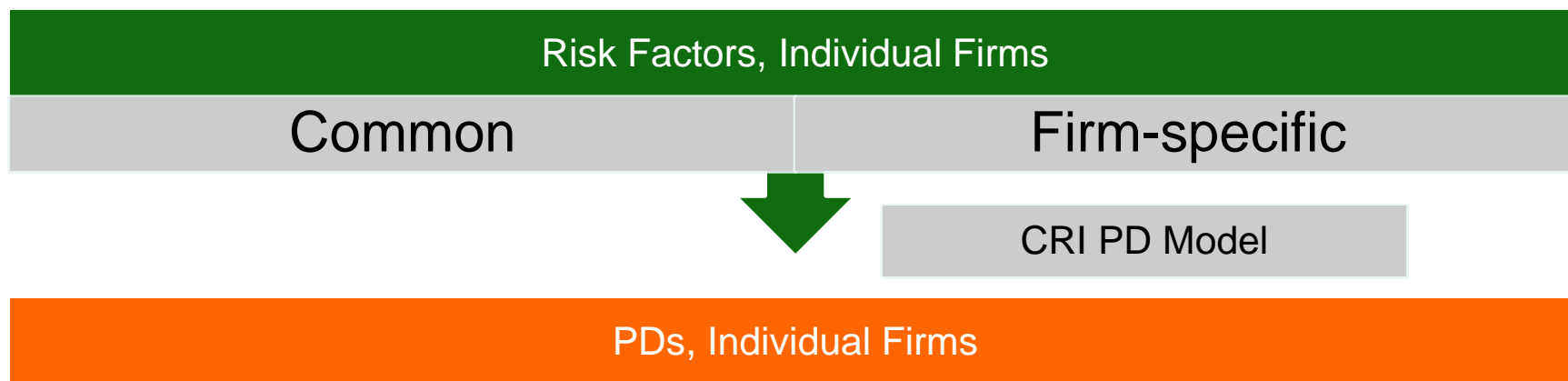
³ Credit Research Initiative
National University of Singapore

International Monetary Fund, Washington DC, July 17-18, 2017

The BuDA Approach

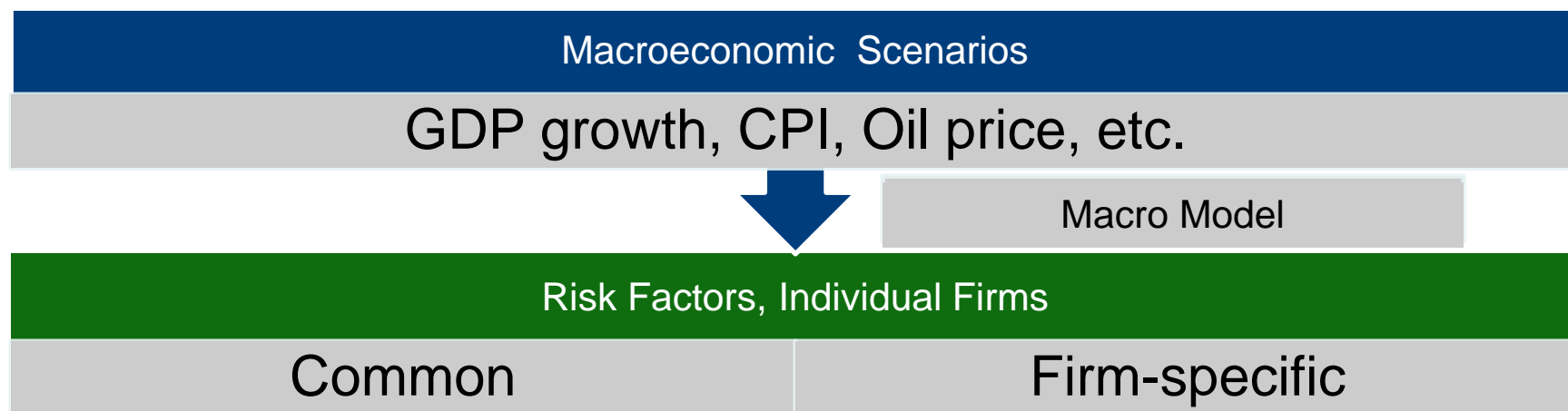
The approach has two components:

- The first is the CRI PD model that links risk factors (e.g. DTD, profitability, etc.) with PD.



The BuDA Approach

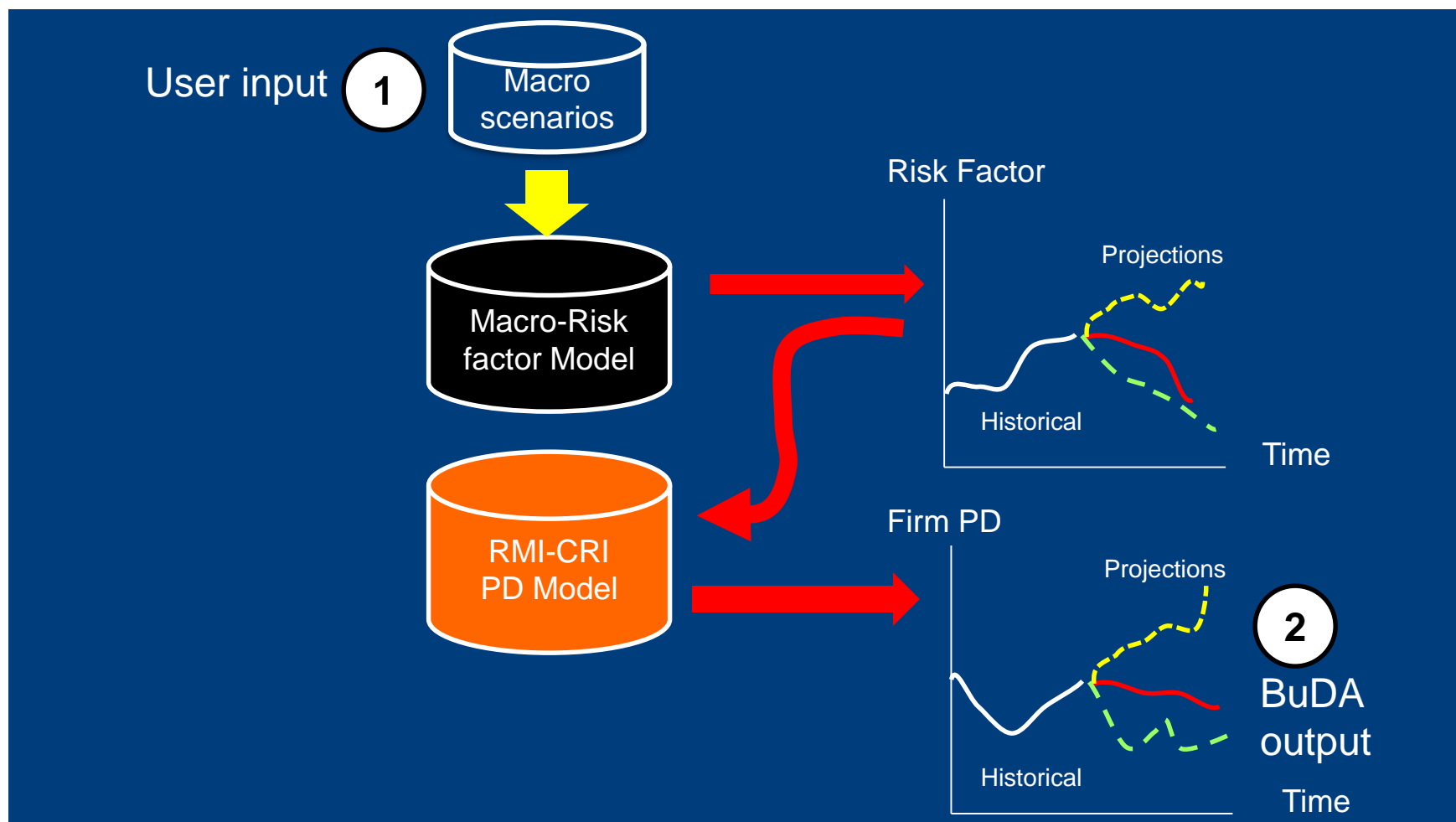
- The second is the macro-risk factor model that links macro-financial factors with PD predictors.



- Model parameters are estimated using historical data.

The BuDA Approach

Under the scenarios characterized by future paths of the stress variables (e.g. world's GDP growth drops to 2% over 2017-2019), BuDA outputs the PD projections for the specified future.



Why Not Link PD and Stress Vars Directly?

- If one has a PD model, it makes sense not to ignore the functional form (maybe non-linear) that links inputs with PD. In this case, one can still use the two-step BuDA approach to do stress testing.
- If one has default frequencies/PDs generated from an unknown model, he has no choice but to directly regress his data on the macro stress variables. In this case, the default data can be quite noisy (e.g. many zeros) or non-stationary for individual series.

The Risk Factors in the CRI PD Model

| Nature | Description | Level/Trend 1,2/ |
|---|---|------------------|
| Economy-wide | Return of domestic stock market index | Current |
| | Short-term domestic interest rate | Current |
| Firm-specific | Financial statements-based factors | |
| | Liquidity (cash + short-term investments/total assets) | Trend and level |
| | Profitability (Net income/total assets) | Trend and level |
| | Market-based factors | |
| | Distance-to-default (volatility adjusted leverage) | Trend and Level |
| | Size (market capitalization relative to median market capitalization) | Trend and Level |
| | Market misvaluation (market cap + total liabilities/ total assets) | Current |
| | Idiosyncratic volatility | Current |
| 1/ The level is computed as the 12-month average value of the factor. | | |
| 2/ The trend is computed as the difference between the current value of the factor and its 12-month average | | |

Macro Model for Predicting Risk Factors

Common risk factors

$$\Delta X_{m,t} = \beta_{m,0}^X + \sum_{k=1}^n \beta_{m,k}^X Z_{k,t} + \gamma_{m,1}^X X_{m,t-1} + \gamma_{m,2}^X X_{m,t-2} + \varepsilon_{m,t}^X,$$

Firm-specific risk factors

$$\Delta \bar{Y}_{i,j,t} = \beta_{i,j,0}^Y + \sum_{k=1}^n \beta_{i,j,k}^Y Z_{k,t} + \gamma_{i,j,1}^Y \bar{Y}_{i,j,t-1} + \gamma_{i,j,2}^Y \bar{Y}_{i,j,t-2} + \varepsilon_{i,j,t}^Y,$$

X_m : common risk factors, $m=1,2$

$\bar{Y}_{i,j}$: i -th country industry average of j -th firm-specific risk factor.

Z_k : k -th macroeconomic variable; may or may not contain X_m .

Why Not Regress on Y Directly?

- Y , e.g. the individual DTD series, might not be stationary (e.g. in absorbing state). It is hard to model its process. The regressional results on Y are quite poor.
- Regressions on Y will result in too many regressors.

Macro Model for Predicting Risk Factors

BuDA can define the macroeconomic scenarios with:

- Any of the 7 default stress variables
- Any of the common risk factors (stock index return and 3-month interest rate) in the CRI PD model
- User-defined stress variables

BuDA — Bottom-up Default Analysis Version 2.0

Testing Region(s)

- United States
- Canada
- China
- India
- Indonesia
- Japan
- Malaysia
- Philippines
- Singapore
- Thailand
- Argentina
- Brazil
- Colombia
- Chile
- Jamaica
- Mexico
- Peru
- Venezuela
- Austria
- User-Supplied Portfolio

Basic Parameters

Testing Time Point: 2016 11

Prediction Horizon: 12 month(s) [Note]

Number of Simulations: 1000 [Note]

Macroeconomic Scenarios

☒ GDP ☒ UNEMP ☒ CPI ☐ NEER ☐ User-Supplied [Note]

☐ IBOR ☐ GSCL ☐ VIX [Note] ☐ Model Macros [Note]

Sample Period

From: 1990 01 To: 2016 11

☒ Sample period up to the testing time point

☐ Whole sample period

☐ User-specified sample period

Other Settings

☐ Actual Realizations ☒ Dynamic Plotting [Note]

Advanced Settings

Testing Industry(s)

☒ All

- ☐ Non-financial
- ☐ Financial
- ☐ Basic material
- ☐ Communications
- ☐ Consumer (cyclical)
- ☐ Consumer (noncyclical)
- ☐ Energy
- ☐ Industrial
- ☐ Technology
- ☐ Utilities

Run

BuDA is developed by Jin-Chuan Duan and Weimin Miao of National University of Singapore (NUS) in collaboration with Jorge Chan-Lau of International Monetary Fund with the active support by NUS Risk Management Institute's Credit Research Initiative team.

Mixed Frequency Regression—Problem

- Mixed data frequency problem:
 X_m (e.g. stock index return) and $\bar{Y}_{i,j}$ (e.g. DTD) are available monthly, while Z_k (e.g. GDP growth rate) is only available quarterly or even yearly.
- The Z_k series displays a choppy pattern with many values being zero.

Mixed Frequency Regression—Treatment

- Step 1: replace zeros with linearly interpolated values within a quarter/year.
- Step 2: regression in time-aggregated manner
 - Rewrite the stress testing function in vector form:

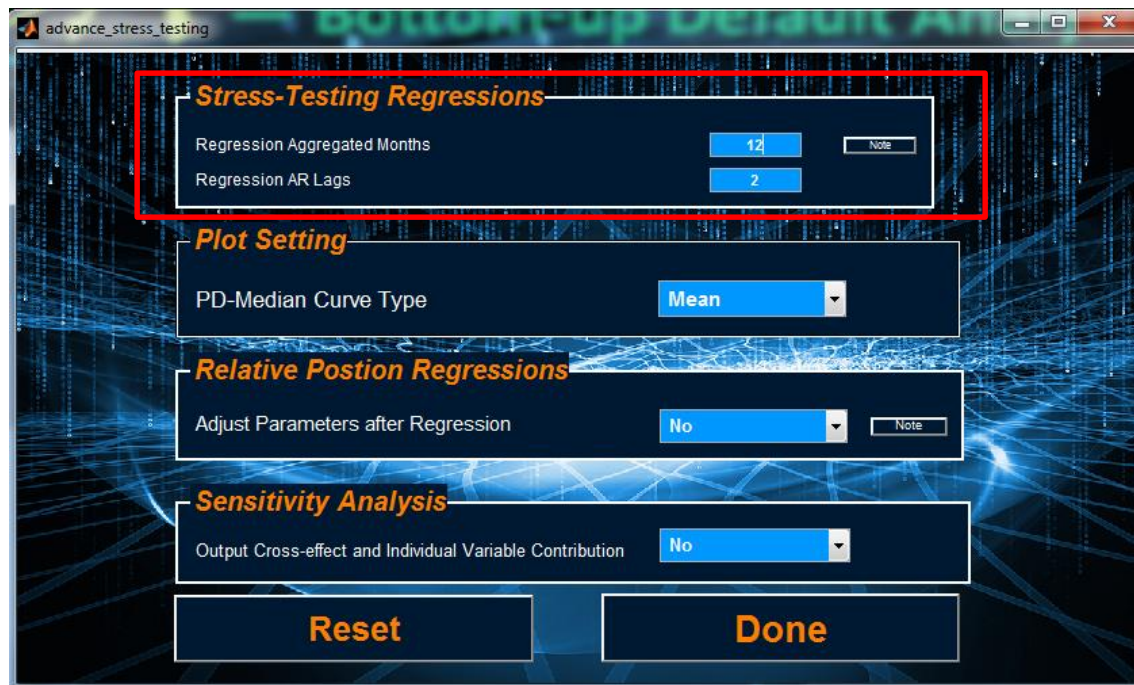
$$\begin{bmatrix} X_t \\ X_{t-1} \end{bmatrix} = \begin{bmatrix} \beta_0 \\ 0 \end{bmatrix} + \sum_{k=1}^n \beta_k \begin{bmatrix} Z_{k,t} \\ 0 \end{bmatrix} + \mathbf{A} \begin{bmatrix} X_{t-1} \\ X_{t-2} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ 0 \end{bmatrix} \quad \text{with } \mathbf{A} = \begin{bmatrix} \gamma_1 + 1 & \gamma_2 \\ 1 & 0 \end{bmatrix}$$

- Substituting for $\begin{bmatrix} X_{t-1} \\ X_{t-2} \end{bmatrix}$ l periods gives rise to:

$$X_t = \beta_0 \sum_{p=0}^{l-1} (\mathbf{A}^p)_{1,1} + \sum_{k=1}^n \boxed{\sum_{p=0}^{l-1}} \beta_k (\mathbf{A}^p)_{1,1} Z_{k,t-p} + (\mathbf{A}^l)_{1,1} X_{t-l} + (\mathbf{A}^l)_{1,2} X_{t-l-1} + \sum_{p=0}^{l-1} (\mathbf{A}^p)_{1,1} \varepsilon_{t-p}$$

Mixed Frequency Regression—Outcome

- Parameter estimation less sensitive to how Z_k is converted to monthly data.

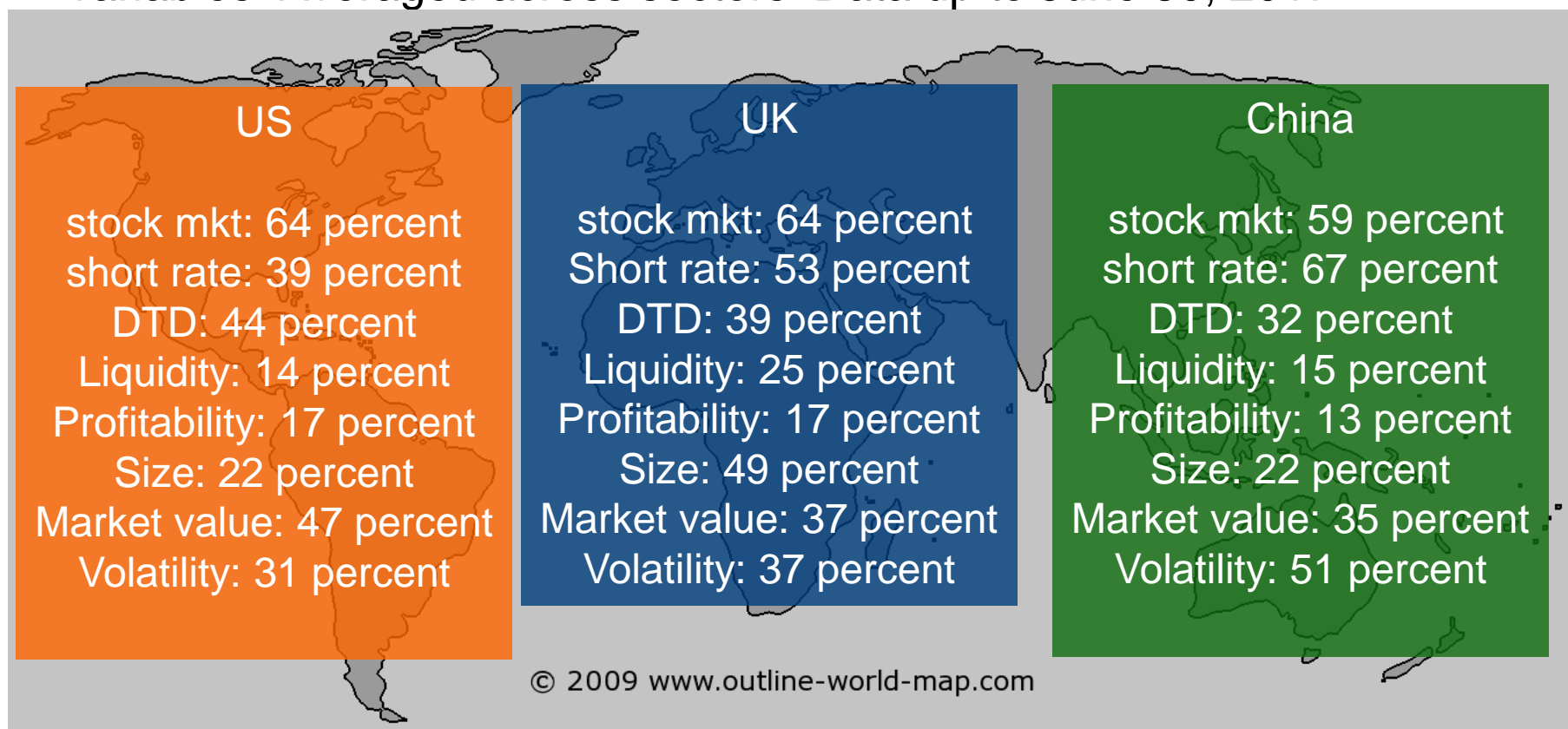


The screenshot displays the 'advance_stress_testing' application window. The interface is divided into several sections, each with a title and a set of controls. The 'Stress-Testing Regressions' section is highlighted with a red rectangle. It contains two input fields: 'Regression Aggregated Months' set to 12 and 'Regression AR Lags' set to 2. Below this is the 'Plot Setting' section with a 'PD-Median Curve Type' dropdown set to 'Mean'. The 'Relative Postion Regressions' section has an 'Adjust Parameters after Regression' dropdown set to 'No'. The 'Sensitivity Analysis' section has an 'Output Cross-effect and Individual Variable Contribution' dropdown set to 'No'. At the bottom are two large buttons: 'Reset' and 'Done'.

| Section | Parameter | Value |
|------------------------------|--|-------|
| Stress-Testing Regressions | Regression Aggregated Months | 12 |
| | Regression AR Lags | 2 |
| Plot Setting | PD-Median Curve Type | Mean |
| Relative Postion Regressions | Adjust Parameters after Regression | No |
| Sensitivity Analysis | Output Cross-effect and Individual Variable Contribution | No |

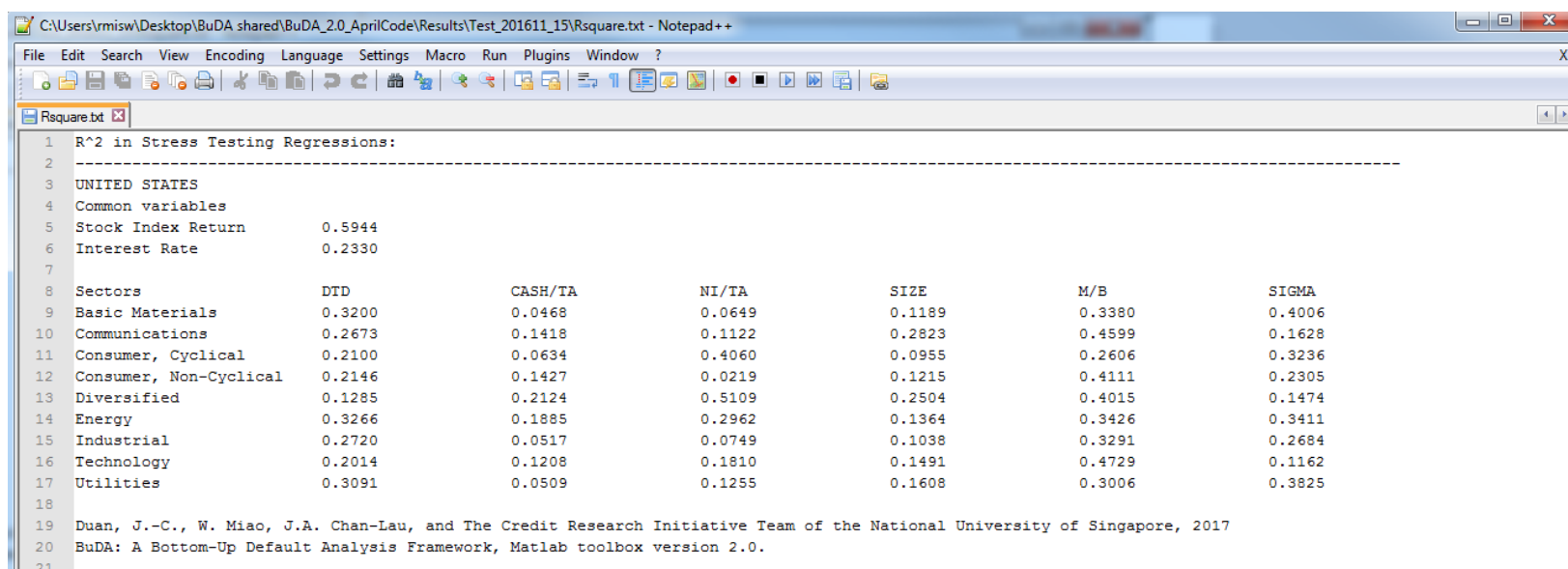
R^2 of Macro-Risk Factor Regressions

R^2 of the stress testing regression with all 7 pre-defined stress variables. Averaged across sectors. Data up to June 30, 2017.



R^2 of Macro-Risk Factor Regressions

“Rsquare.txt” in the “Results” folder displays the goodness-of-fit for the stress testing regressions.



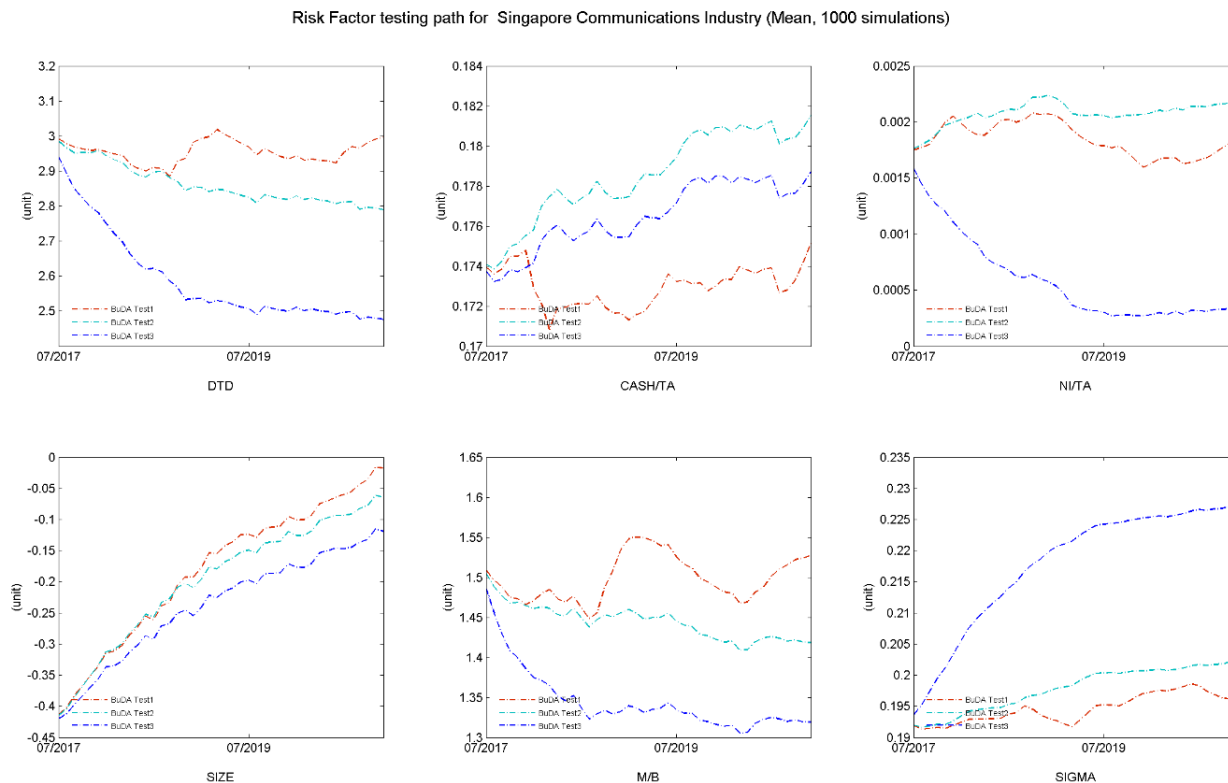
C:\Users\rmisw\Desktop\BuDA shared\BuDA_2.0_AprilCode\Results\Test_201611_15\Rsquare.txt - Notepad++

Rsquare.txt

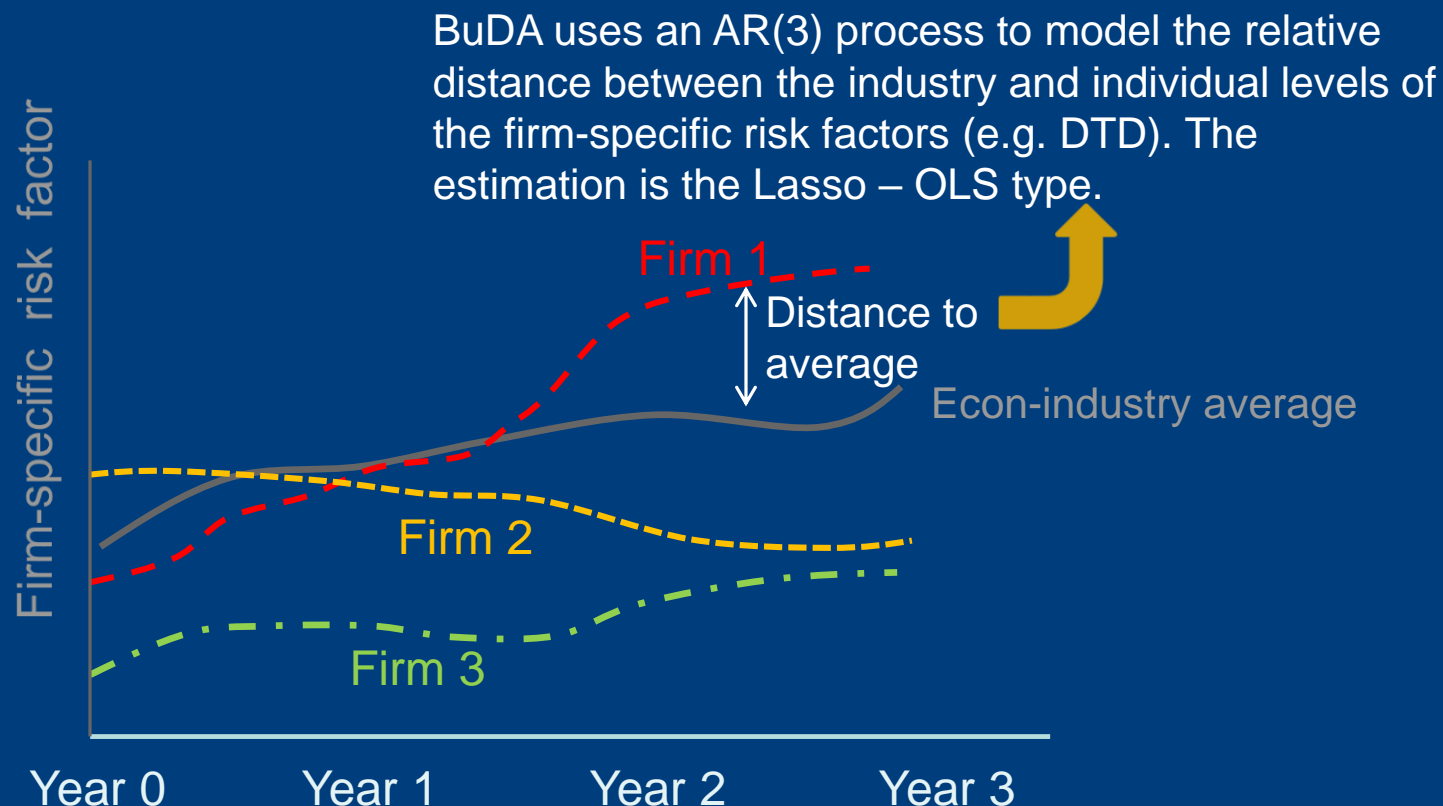
```
1 R^2 in Stress Testing Regressions:
2 -----
3 UNITED STATES
4 Common variables
5 Stock Index Return      0.5944
6 Interest Rate           0.2330
7
8 Sectors                 DTD          CASH/TA      NI/TA         SIZE          M/B          SIGMA
9 Basic Materials         0.3200      0.0468      0.0649      0.1189      0.3380      0.4006
10 Communications          0.2673      0.1418      0.1122      0.2823      0.4599      0.1628
11 Consumer, Cyclical      0.2100      0.0634      0.4060      0.0955      0.2606      0.3236
12 Consumer, Non-Cyclical  0.2146      0.1427      0.0219      0.1215      0.4111      0.2305
13 Diversified             0.1285      0.2124      0.5109      0.2504      0.4015      0.1474
14 Energy                  0.3266      0.1885      0.2962      0.1364      0.3426      0.3411
15 Industrial              0.2720      0.0517      0.0749      0.1038      0.3291      0.2684
16 Technology              0.2014      0.1208      0.1810      0.1491      0.4729      0.1162
17 Utilities               0.3091      0.0509      0.1255      0.1608      0.3006      0.3825
18
19 Duan, J.-C., W. Miao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2017
20 BuDA: A Bottom-Up Default Analysis Framework, Matlab toolbox version 2.0.
21
```

Risk Factor Analysis

The BuDA can also export the evolution of the default covariates under various scenarios.

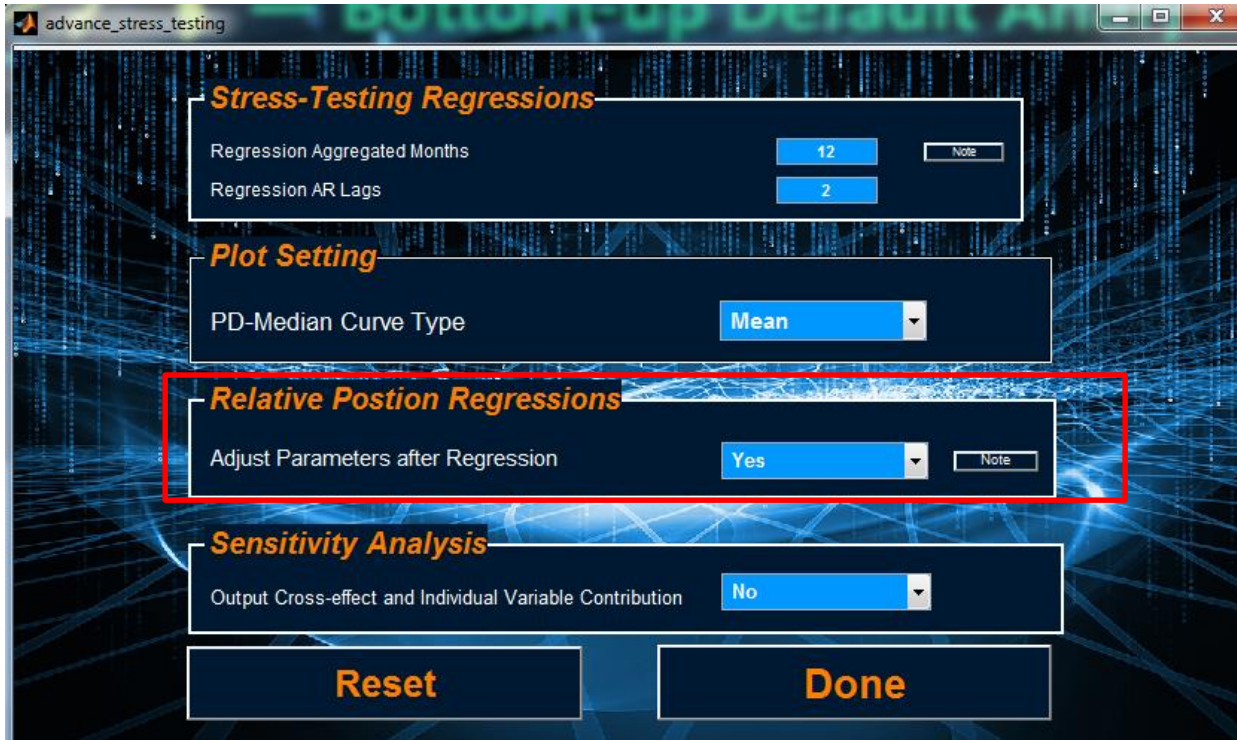


From \bar{Y} to Y : An AR(3) Process



From \bar{Y} to Y : An AR(3) Process

If 'Yes' is chosen in the "Relative Position Regressions" panel, the regression will run twice. User can adjust the coefficients in the second run if she has a better specification for the parameters.



The screenshot displays the 'advance_stress_testing' application window. It features a dark blue background with a network-like pattern. The interface is organized into several panels, each with a title in orange text:

- Stress-Testing Regressions**: Contains two input fields. 'Regression Aggregated Months' is set to 12, and 'Regression AR Lags' is set to 2. A 'Note' button is located to the right of the second field.
- Plot Setting**: Contains a dropdown menu for 'PD-Median Curve Type' set to 'Mean'.
- Relative Position Regressions**: This panel is highlighted with a red rectangular border. It contains a dropdown menu for 'Adjust Parameters after Regression' set to 'Yes', with a 'Note' button to its right.
- Sensitivity Analysis**: Contains a dropdown menu for 'Output Cross-effect and Individual Variable Contribution' set to 'No'.

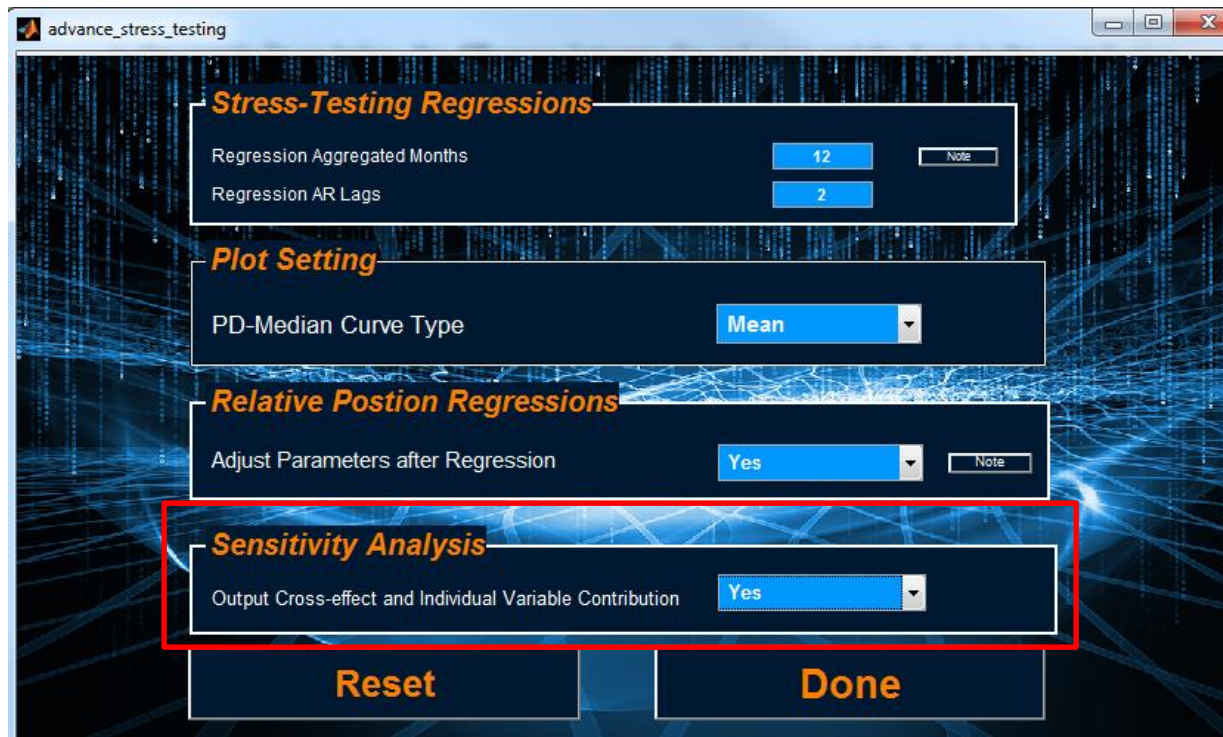
At the bottom of the window, there are two large buttons: 'Reset' and 'Done'.

Prescribing Macro Scenarios

- It is crucial that the multiple stress variables defining a scenario are internally consistent.
- It is a good idea to rely on a macroeconomic model or structural vector autoregression to produce future paths of the stress variables.

Sensitivity Analysis

User can select “Yes” in the “Sensitivity Analysis” panel in order to assess the individual contribution to the PD of each stress variable.



The screenshot displays the 'advance_stress_testing' application window. It features four main configuration panels on a dark blue background with a network-like pattern:

- Stress-Testing Regressions:** Includes 'Regression Aggregated Months' set to 12 and 'Regression AR Lags' set to 2. A 'Note' button is present.
- Plot Setting:** Includes 'PD-Median Curve Type' set to 'Mean'.
- Relative Postion Regressions:** Includes 'Adjust Parameters after Regression' set to 'Yes'. A 'Note' button is present.
- Sensitivity Analysis:** This panel is highlighted with a red rectangular border. It includes 'Output Cross-effect and Individual Variable Contribution' set to 'Yes'.

At the bottom of the interface are two large buttons: 'Reset' and 'Done'.

Sensitivity Analysis

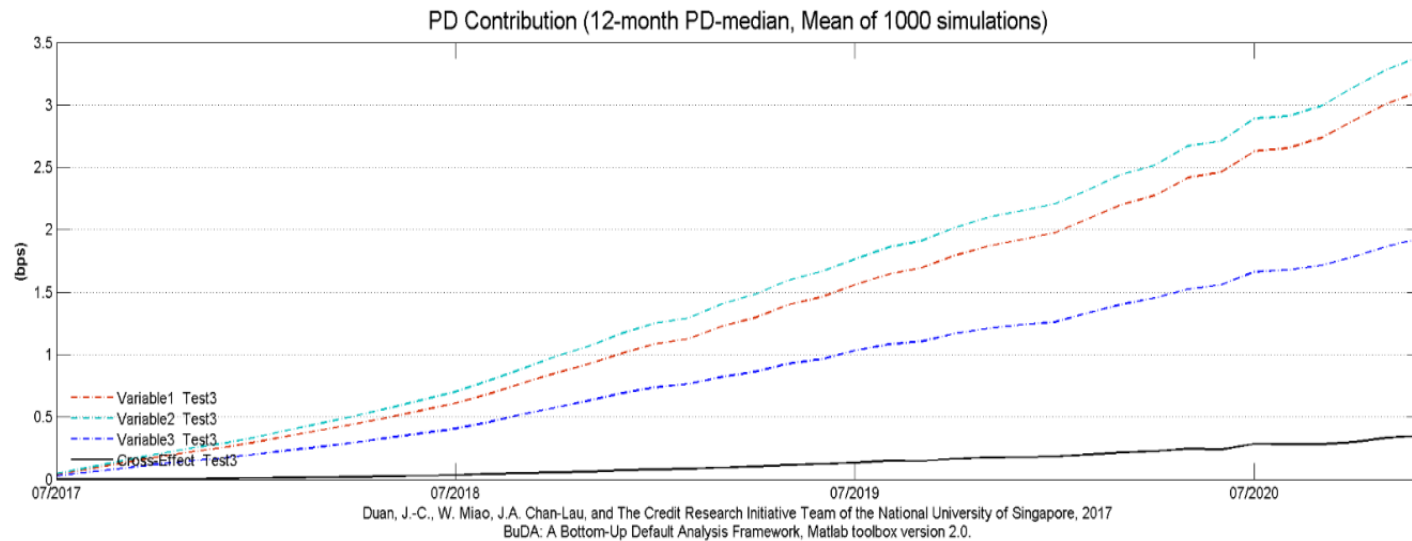
PD_{flat} : PD in the “zero-change” scenario, where the state of economy stays the same for the years to come, e.g. the GDP is fixed for the next five years.

PD_i : the stressed PD when only the i -th variable (among many) follows the presumed trajectory into the future, while others stay constant. $i=1, 2, \dots, n$.

PD_{All} : the stressed PD when all stress variables are considered simultaneously.

Sensitivity Analysis

- Distance between red curve and X-axis: $PD_1 - PD_{flat}$
- Distance between green curve and X-axis: $PD_1 + PD_2 - 2PD_{flat}$
- Distance between blue curve and X-axis: $PD_1 + PD_2 + PD_3 - 3PD_{flat}$
- Cross effect: $PD_1 + PD_2 + PD_3 - 2PD_{flat} - PD_{All}$



Some Useful Datasets in the 'Results' folder

Testing_Firm_Information.xlsx

Profile information for all testing firms.

| | A | B | C | D | E | F | G | H |
|----|---------------------------------------|--------|----------------|-----------------------|------------------|------------------|-------------------------|-----------------------|
| 1 | Company Name | IDBB | CRI Company ID | Exchange Country Code | Exchange Country | Domicile Country | Bloomberg Industry Code | Bloomberg Industry |
| 2 | Creative Technology Ltd/Singapore | 103117 | 18 | 9 | Singapore | Singapore | 10013 | Technology |
| 3 | GL Ltd | 113174 | 426 | 9 | Singapore | Singapore | 10004 | Consumer Cyclical |
| 4 | DBS Group Holdings Ltd | 115709 | 2350 | 9 | Singapore | Singapore | 10008 | Financial |
| 5 | Dairy Farm International Holdings Ltd | 115780 | 2354 | 9 | Singapore | Hong Kong | 10005 | Consumer Non-cyclical |
| 6 | Mandarin Oriental International Ltd | 115796 | 2359 | 9 | Singapore | Hong Kong | 10004 | Consumer Cyclical |
| 7 | Jardine Strategic Holdings Ltd | 115798 | 2361 | 9 | Singapore | Hong Kong | 10006 | Diversified |
| 8 | Hongkong Land Holdings Ltd | 115801 | 2364 | 9 | Singapore | Hong Kong | 10008 | Financial |
| 9 | Singapore Airlines Ltd | 115808 | 2368 | 9 | Singapore | Singapore | 10004 | Consumer Cyclical |
| 10 | Oversea-Chinese Banking Corp Ltd | 115810 | 2370 | 9 | Singapore | Singapore | 10008 | Financial |
| 11 | UOL Group Ltd | 115819 | 2373 | 9 | Singapore | Singapore | 10008 | Financial |
| 12 | Haw Par Corp Ltd | 116382 | 2491 | 9 | Singapore | Singapore | 10006 | Diversified |
| 13 | Jardine Matheson Holdings Ltd | 116423 | 2532 | 9 | Singapore | Hong Kong | 10006 | Diversified |
| 14 | United Overseas Bank Ltd | 116588 | 2689 | 9 | Singapore | Singapore | 10008 | Financial |
| 15 | Kennel Corp Ltd | 116617 | 2735 | 9 | Singapore | Singapore | 10006 | Diversified |

Some Useful Datasets in the 'Results' folder

Testing_firm_PDs_**mth.xlsx

Historical month-end PDs for all testing firms in “Historical” tab and projected PDs under various scenarios in “BuDA Test*” tabs.

Testing_firm_PDs_12mth.xlsx - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer Acrobat

Clipboard Font Alignment Number Styles Cells

08 0.0641539799827481

1 This file reports the stress PDs for individual firms.
2 Unit of PD measure: Basis points.
3 Duan, J.-C., W. Miao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2017. BuDA: A Bottom-Up Default Analysis Framework, Matlab toolbox version 2.0.

| 4 Company | IDBB | CRI Comp | Exchange | Exchange | Domicile | Bloomberg | Bloomberg | Jun-17 | Jul-17 | Aug-17 | Sep-17 | Oct-17 | Nov-17 | Dec-17 | Jan-18 | Feb-18 | Mar-18 | Apr-18 | May-18 | Jun-18 |
|----------------|--------|----------|----------|-----------|-----------|-----------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 5 DBS Group | 115709 | 2350 | 9 | Singapore | Singapore | 10008 | Financial | 12.88112 | 13.48609 | 14.94066 | 15.79992 | 17.79834 | 19.69783 | 20.66959 | 21.92647 | 23.76994 | 25.47516 | 28.44049 | 28.92537 | 32.34759 |
| 6 Hongkong | 115801 | 2364 | 9 | Singapore | Hong Kong | 10008 | Financial | 0.364494 | 0.485261 | 0.535256 | 0.564162 | 0.596032 | 0.642156 | 0.672326 | 0.721522 | 0.78612 | 0.818643 | 0.881829 | 0.923783 | 0.963729 |
| 7 Oversea-C | 115810 | 2370 | 9 | Singapore | Singapore | 10008 | Financial | 1.757956 | 2.220045 | 2.962579 | 2.991515 | 3.081883 | 3.460097 | 3.684605 | 3.951754 | 4.245552 | 4.664076 | 5.088972 | 5.345889 | 5.702318 |
| 8 UOL Group | 115819 | 2373 | 9 | Singapore | Singapore | 10008 | Financial | 0.053236 | 0.064931 | 0.068709 | 0.066029 | 0.064952 | 0.066051 | 0.064154 | 0.06437 | 0.066126 | 0.068951 | 0.070128 | 0.069063 | 0.072822 |
| 9 United Ov | 116588 | 2689 | 9 | Singapore | Singapore | 10008 | Financial | 3.794549 | 5.135506 | 5.686209 | 5.67213 | 5.731142 | 6.012448 | 6.031266 | 6.08396 | 6.344944 | 6.637536 | 6.765072 | 6.917079 | 7.318108 |
| 10 GuocoLan | 117501 | 2874 | 9 | Singapore | Singapore | 10008 | Financial | 25.37108 | 35.49575 | 40.96178 | 41.43693 | 41.14296 | 44.93988 | 48.03288 | 50.6555 | 52.9287 | 54.7791 | 58.24418 | 60.32211 | 63.41441 |
| 11 HL Global | 117738 | 2993 | 9 | Singapore | Singapore | 10008 | Financial | 29.55014 | 178.5567 | 218.9434 | 223.3399 | 231.2948 | 276.6805 | 277.2293 | 301.354 | 294.434 | 291.3806 | 277.568 | 301.6389 | 288.9085 |
| 12 OUE Ltd | 117839 | 3039 | 9 | Singapore | Singapore | 10008 | Financial | 2.116722 | 3.278029 | 4.432073 | 5.464606 | 5.928806 | 6.552023 | 7.292434 | 8.267435 | 9.486672 | 10.41338 | 11.20259 | 12.31684 | 13.29935 |
| 13 Singapore | 117988 | 3122 | 9 | Singapore | Singapore | 10003 | Communi | 0.005126 | 0.008658 | 0.011228 | 0.012813 | 0.014423 | 0.01526 | 0.015649 | 0.018082 | 0.019841 | 0.021073 | 0.021391 | 0.023671 | 0.026978 |
| 14 Straits Tra | 118024 | 3135 | 9 | Singapore | Singapore | 10008 | Financial | 1.293103 | 2.005071 | 2.349235 | 2.878506 | 3.369754 | 3.867681 | 4.183848 | 4.390219 | 4.570921 | 4.647142 | 4.813312 | 4.946951 | 5.141286 |

BuDA Test1 BuDA Test2 BuDA Test3 Historical

** denotes the prediction horizon for the output PD, e.g. 12 month (1 year).