

Bottom-up Default Analysis (BuDA v3.3.3) The user manual of BuDA Toolkit

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ABSTRACT

Bottom-up Default Analysis (BuDA) is a credit stress testing and scenario analysis toolkit developed by the Credit Research Initiative (CRI) team of National University of Singapore (NUS) in a collaboration with the International Monetary Fund (IMF). This toolkit is operated and supported by CRI (<u>https://www.nuscri.org</u>). This document provides stepby-step instructions with illustrated examples for the BuDA web application. Regulatory authorities, central banks, and commercial/investment banks may use the BuDA toolkit to conduct credit stress testing and scenario analysis and, more generally, to examine macroeconomic and financial risks. Users are recommended to understand the key concept underpinning BuDA by reading its white paper^{*}.

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BuDA (v1.0) was developed by Jin-Chuan Duan of the NUS-CRI team and Weimin Miao of CriAT, a former NUS-CRI team member, in collaboration with Jorge Chan-Lau of IMF. The NUS-CRI team provides the continual development and support of the BuDA platform.

^{*}The Credit Research Initiative team (2021), Bottom-up Default Analysis (BuDA v3.3.3) White Paper, Accessible via https://nuscri.org/en/white_paper/.



I. Overview

There is a growing demand for practical models and tools used for analyzing the dynamics of credit risk under different macroeconomic scenarios. The Bottom-up Default Analysis (BuDA) was conceived to meet this demand. The BuDA toolkit provides an easy-to-use interactive platform for analyzing the credit risk of individual firms/sectors/economies, or user-defined portfolios under different scenarios, stressed or otherwise. BuDA has been implemented with the API (Application Programming Interface) web application which only requires users to access an internet browser. Users need not install any other programming software as the BuDA executions will use the CRI cloud-based computing resources. With this hassle-free toolkit, users can focus on scenario design and risk analysis.

The application's structure is shown in Figure 1, where users are required to specify/provide three main inputs: (1) target portfolio, (2) testing scenarios, and (3) simulation settings. BuDA allows users to build their own portfolios from any of over 80,000 listed companies in 133 economies in the CRI database. The testing scenario of interest is specified/uploaded by users, which is based on a single or multiple macroeconomic and/or financial stress variable(s).

To meet varying needs of analysts, BuDA offers several flexibilities, including a customized portfolio, user's supplied stress variables & scenarios, as well as advanced settings to modify some simulation parameters. In addition, BuDA has an inbuilt stress-variables recommender which assists users to identify a set of stress variables that are most apt for their target portfolio out of a list of close to 3000 potential stress variables. This recommender will choose a desired number of stress variables, say, 5 out of the user-specified set of potential stress variables which can be drawn from a list of close to 3000 global and economy/sector variables. This manual focuses on how to utilize the BuDA toolkit. Examples with a brief discussion of the results are provided to assist users to gain a better appreciation.





Figure 1: An overview of BuDA implementation

II. Step-by-step instructions

There are three main steps in BuDA to perform stress testing and scenario analysis. Users will be asked to specify a target portfolio, macroeconomic and financial scenarios, and simulation parameter settings, as depicted in Figure 1. The detail of each step is given in this section.

Step 1: Target Portfolio

The first step is to specify the portfolio of interest, on which the bottom-up default analysis will be conducted by aggregating the credit risks of individual firms to the portfolio level. To form the target portfolio, users may add the economies and industries from the drop-down lists. Alternatively, users may customize their own target portfolio by submitting a file.



			2	3 S BASIC SETTINGS
ILSTING FORTIOLIO			TESTING SCENARIO	
			TESTING PORT	FOLIO
	Select from	the listed econon	nies/regions and industrie	es, or construct your own target portfolio
	Econom	nies		Industries
United Kingdom ×	United Sta	tes of America ×	China ×	Financial\Banks ×
				Banks
Asia Pacific	•	China	•	Add 💼 Clear
Ad	ld	💼 Clear		
			or choose	
			📛 User's target po	ortfolio
			Next	

Figure 2: Testing Portfolio

For the first option, the requirements are to add both "*Economies*" and "*Industries*". These are choices based on six main geographic regions, from which users can consider to either add a specific country or simply select all economies. Users can also enter multiple economies. To complete this step, users need to add the industries of interest. Then, the target portfolio will be formed using all companies classified under the selected industries in the specified economies. BuDA groups companies into 12 industries, covering nine non-financial industries and three financial sub-sectors (banks, insurance, and other financial firms).

For users with their own target portfolios in mind, selecting "User's target portfolio" presents a way to customize the portfolio. To form a customized portfolio, users must provide an Excel file specifying the company IDs. Importantly, the list should follow the Excel template below:

	Α
1	IDBB
2	305999
3	117809
4	117400
5	162324

The Excel file should contain only Bloomberg IDs (IDBBs) and the file must be saved as *.csv (Comma delimited). Once the file is successfully



uploaded, BuDA will correctly identify their economies and industries and upload the data for the selected firms. The full list of the available companies with their IDBBs in the BuDA database and the template can be downloaded (optional) after clicking *"User's target portfolio"* as in Figure 2.

Step 2: Testing Scenarios

This step focuses on building the stress scenarios of interest. Users need to specify the scenarios, the testing and training data period, and the stress variable(s). The selected stress variables are common for every firm in the target portfolio regardless of their industries and economies. The users are required to upload Excel file(s) if they consider a user supplied stress testing scenario (see step 2.1) and/or stress variable(s) (see step 2.4).

Step 2.1: Stress testing scenarios

Users need to specify the nature of scenario analysis. Selecting "*Backtesting*" requires no additional file. On the other hand, opting for "User-specified scenarios" will require uploading an Excel file for their testing scenarios after finishing step 2.4 (the final step before proceeding to Other Settings).

Step 2.2 & 2.3: Testing time point & training sample period

Users are required to fill in "Testing Time Point", "Training Sample Period", see Figure 3.

 "Testing Time Point" is defined as an initial month prior to the testing scenario starting month. In other words, if the testing time point is denoted by t, t+1 will be the first period of the testing scenario. To put it simply, this is the time point from which users want to begin their scenario analysis.

2	Select testing time point						
		2018-06				ĺ	₩
3	Select training sample period						
		Till testing	tim	e poi	int	~	0
		1990-01	曲	to	2018-06		曲

Figure 3: Fill testing time point and training sample period

Two observations are in order:

 With the testing time point being set in Step 2.2, BuDA will automatically adjust, upon confirming the stress variables, the testing time point by checking data availability.



- Although users may select any month in the given period, the choice should be made with data availability in mind. For example, the testing time point in Figure 3 is 201806. Users need to ensure that their uploaded testing data is available from 201807 onward.
- *"Training Sample Period"* is the period that BuDA uses to estimate the stress testing regressions. There are three choices:
 - "Till testing time point" the training period is defined as the period up to the specified testing time point.
 - "Whole sample period" all available training data will be used as the training data.
 - "User-specified sample period" users can specify any range within the available sample period.

Step 2.4: Stress variables selection

BuDA provides historical data for a list of close to 3000 potential stress variables, including the country specific macroeconomic variables, *common risk factors* (CRI-PD predictors¹ for country and industry levels), commodity prices, and other stress variables of interest. Users can select from this list by checking "*Choose from economy/variable list*" or upload their own stress variables (optional) by checking the "*User Supplied Stress-testing Variables*". Combining the provided and user's supplied variables is possible.

Users can also let BuDA recommend a desired number of stress variables, up to 10, from the provided list of potential variables that are most apt for the target portfolio. Doing so requires of checking *"Stress Variables Recommender"* and following three simple steps. These steps for using the recommender will be covered with a concrete example later in section III of this guide.

4	Choose stress-testing variables	
	□ Choose from economy/variable list	
	□ User Supplied Stress-testing Variables ()	
	Stress Variables Recommender 1 New!	
	The chosen variables are:	
		💼 Clear

Figure 4: The selection of stress variables

¹ The CRI-PD model has multiple predictors, including firm specifics and common risk factors. User can also use those common risk factors as the stress variables. Readers can find concrete discussions of the CRI-PD model's inputs in the BuDA White Paper.



Choose from Economy/Variable List

The categories of the provided variables are shown in

. Users can easily sort the macroeconomic variables and common risk factors by economy, see **Error! Reference source not found.**5. If a group of economies is selected, e.g., Eurozone, the variables for its individual members will be included. Updated details of these variables, including the data sources, can be downloaded upon clicking the information sign. After confirming the selected variables, BuDA will summarize the variable selected, see Figure 10 later.

ountry/Econom	y specific macro va	ariables 🚯					
Eurozone		∽ Gr	eece	~	GDP	~	Add
her stress vari	ables of interest						
VIX	~	bbA					
VIA	•	Add					
he chosen varia	ables are:						
France\GDP ×	Germany\GDP ×	Germany\Stock	Index Return × Greed	ce\GDP ×			n Clear

Figure 5: The selection of stress variables



Table 1: List of provided stress variables

Туре	Variables	Brief Description		
Country specific	GDP	Real Gross Domestic Product growth rate		
variables	UNEMP	Difference of Unemployment rate		
	CPI	Percentage change of consumer price index		
	NEER	Percentage change of Nominal Effective Exchange Rate		
	INT	Difference of 3-month interbank rate		
	HPI	House Price Index growth rate		
	PPI	Percentage change of producer price index		
	САВ	Difference of Current account balance		
Country specific Common	Stock return	Monthly stock return		
PD predictors)	Interest rate	3-month interbank rate (level)		
	Aggregate DTD	Aggregate distance-to- default for financial and/or non- financial industry		
Other key stress variables	Commodity Prices	Percentage change of Standard and Poor's Goldman Sachs Commodity Index and over 20 individual commodities		
	VIX	Percentage change of the Chicago Board Options Exchange Vol atility Index		
	FFI	St. Louis Federal Reserve Financial Stress Index (level)		
Credit Cycle Index	CCI	Credit Cycle Index is provided by using aggregated CRI-PD. User can select the data from country to industry levels.		

User-supplied Stress Testing Variables

For a user's supplied variables, it is important to provide their historical time series in an Excel file (*.csv) using the template as shown in Figure . The overall length of the data should be at least **five** years, although using ten years or more is recommended. Apart from the historical data, users need to specify the frequency and type of each variable using the following definitions:

- "Frequency" (row 6), specify the value of:
 - \circ "1" for monthly data
 - $\circ~$ "0" for quarter-end data and fill the data in month 3, 6, 9, and 12 only
 - $\circ~$ "-1" for year-end data and fill data in month 12 only
- "Macro Type" (row 10), specify the value of:
 - "1" indicates growth rate % or percentage change (e.g. GDP growth)
 - o "0" indicates change in different (e.g. difference of unemployment rate)



• "-1" indicates the level value (e.g. interest rate).

	Α	В	с	D	Е	F	G	н	I	J	к
1	This Frequ	ency prov	ides the informati	on whether the t	raining ma	cro-econo	mic scenar	ios used ar	re reported	l on a mon	thly basis c
2	The value	"1" means	"Monthly"; "0" m	eans "Quarterly";	and the v	alue "-1" n	neans "Yea	rly".			
З	If it is on a quarterly basis; the data should be reported in Month 3 6 9 12 while blank need be reported in other months.							is.			
4	If it is on a yearly basis; the data should be reported in Month 12 while blank need be reported in Month 1-11										
5	Growth ra	te on a mo	onthly basis should	be MoM growth	rate (non-	annualize	d); on a qu	arterly basi	is should b	e QoQ gro	wth rate (n
6	Frequency	/	1	1							
7											
8	This Macro	o Type pro	vides the informa	tion that for each	country w	hether the	e training n	nacroecono	omic scena	rio is the c	hange (grov
9	The value	"1" means	Change (Growth	Rate %)"; the va	lue "0" me	ans "Chan	ge (Differe	nce)"; the	value "-1"	means "Le	vel".
10	Macro Typ	e	-1	1							
11											
12	year	month	FED Stress Index	Oil price return							
13	1993	12	0.198								
14	1994	1	0.179								
15	1994	2	0.365								
16	1994	3	0.509								
17	1994	4	0.643								
18	1994	5	0.745	4.73							
19	1994	6	0.781	6.30							
20	1994	7	0.704	5.93							
21	1994	8	0.672	-12.78							
22	1994	9	0.872	4.72							
23	1994	10	0.923	-1.35							
24	1994	11	0.951	1.12							
25	1994	12	0.979	-3.63							
26	1995	1	0.898	1.80							
27	1992	2	0.796	0.42							

Figure 6: User's supplied training data template

Stress Variables Recommender

This new feature helps users select a set of stress testing variables that are most apt for the target portfolio. The algorithm recommends a desired number of stress variables out of a list of close to 3000 global and economy/sector-specific variables by utilizing a cutting-edge zero-norm variable selection technique. To use this recommender, simply check "*Stress Variables Recommender*" in Figure , and follow the three simple steps.

In the first step, users are required to define a pool of variables from which the recommendation algorithm can choose. By default, the algorithm will select variables from the economies in the target portfolio. The categories of stress variables available are the same as in Table 1. Users can click "+" to expand each category and select/unselect the variables in that category. The total number of variables in the pool will also be displayed, see Figure 77.



	50		
		Scientific reference	
0		2	3
STEP	1	STEP 2	STEP 3
To begin please	define the nool of variables that	the recommendation algorithm can	choose from
i bigin, picabe		i die recommendation algoriani our	
Select economies for c	country/economy specific macro	o variables* :	
Singapore ×			
All regions	✓ All economies	✓ Add	Clear
⊟ Country/Economy s	pecific macro variables		
🕂 🗹 Macro-econom	ic variables (8 sub-groups)		
🕂 🗹 Common facto:	rs (4 sub-groups)		
🕇 🗆 Credit Cycle In	dices (14 sub-groups)		
Select other variables	of interest:		
□ VIX			
□ FFSI			
+☑ Commodities (2	21 variables)		
	Total number of	variables for the algorithm to choose	e from: 33
		2	
		Mout	
		INEXC	

Figure 7: Definition of stress variable pool in recommender

Click "Next" to proceed to the second step, users can then fill in the desired number of stress variables that the algorithm should recommend (from 1 to 10 variables), see Figure 8.

	0	2	3
	STEP 1	STEP 2	STEP 3
2	Please choose the exact number	of variables that you want the algorithm to select (between 1-10) 4	
		Previous Next	

Figure 8: Choice of the number of variables to be recommended

In the third step, users can review the choices made in the previous two steps and revise the variable(s) by going back to the previous step. Users may have in mind some "mustinclude" stress variable(s) that are deemed critical to the task. These variables can only be entered from within the subset of stress variables defined in step 1. The "must-



include" stress variable(s), if chosen, will be forced into the recommended set of stress variables and crowd out other variables even if they do not deliver at the same level of explanatory power, see

Figure 9. Of course, this option may also be left blank. Finally, click "*Start Recommendation Algorithm*" to begin the selection. The resulting recommended variables will automatically be filled in the stress variables box in Figure .

			01111 U
lease review the information	n you have entered		
	The poo	l of stress-testing variables	
Regions	Singapore		
	Macro-economic variables	GDP, UNEMP, CPI, NEER, INT, HF	PI, PPI, CAB
	Common factors	Stock Index Return , Interest Rate , (Non-Financial)	Aggregate DTD (Financial) , Aggregate DTD
Potential variables	Other stress variables	GSCI , Cushing OK WTI Oil , BFO Cru Oil , ARA Gasoil 0.2%, US PIP Natur LME Lead , LME Nickel , LME Zinc, Wheat No 2 , YC Illinois Corn No.2 , ISA Raw Sugar , ICO Coffee Compos	ade Oil, NYH Gasoline, NYH No 2 Heating al Gas, LME Aluminium, LME Copper, JCE Gold Bullion, H&H Silver, Soft Red Yellow Soybean No 1, Memphis Cotton, ite, ICCO Cocoa
# Potential variables	33		
# Variables to be chosen	4		
tional Please select any sp	ecific variables that you th	ink are vital ('must-include') for yo	our portfolio of interest
ngapore\GDP ×			-
ntry/Economy specific macr	o variables		
ngapore 🗸	GDP	~ Add	
r stress variables of interest			
Select V	Add		

Figure 9: Selection of 'must-include' variables (optional)



After confirming the stress variables, BuDA will automatically check and report the data availability, see Figure 10. BuDA can proceed only when the overlapping period among the selected variables are larger than 5 years. Therefore, users are recommended to select a long enough training sample period to avoid model estimation difficulties.

The available data periods are : Stress-testing variables : December, 1993 to September, 2018. CRI PD Data : up to September 2018.					
Stress-testing variable	Available Start Date	Available End Date			
France GDP	1990-04	2018-09			
China GDP	1990-04	2018-09			
Germany GDP	1990-04	2018-09			
VIX	1990-02	2018-09			
FED Stress Index	1993-12	2018-09			
Oil price return	1993-12	2018-09			

Figure 10: Available periods of the training period checking

Uploading user specified scenarios

When "user specified scenarios" is checked, users may select "Generate scenario file" to confirm their selection, where an Excel file will be generated and downloaded. The file will be automatically customized to the selected stress variables in Step 2.4, in which users can fill in the scenarios. The variables in the provided file should match those stress variables.

Figure 11 is a generated Excel file using the stress variables previously selected. The following information should be filled in to complete the stress testing scenarios:

- "Frequency" (row 6) specifies the value of:
 - o "1" for monthly data
 - \circ "0" for quarter-end data and fill the data in month 3, 6, 9, and 12 only
 - $\circ~$ "-1" for year-end data and fill data in month 12 only
 - $\circ~$ The frequency does not need to be the same as that of the training data
- Ensure the same data type of each variable as in the training data, which is defined in Table 1 for the provided stress variables and/or the user's uploaded stress variables.
- Do not modify the generated Excel file for testing scenario, except for providing the data.
- The coverage of the provided scenario should be from the first month or the most recent quarter-end or year-end months depending on the data frequency. The unused rows can be left blank.



- Multiple scenarios can be tested simultaneously by adding more sheets into the file.
- The uploaded Excel file should be in *.xlsx format.

	Α	в	с	D	E	F	G	н	1	L	к	L	м
1	(i) Please	specify the	frequency of	f each selec	ted stress variak	le, where	'1' for monthly da	ata(MoM), '0' for q	uarter-en	d data(Qo	Q), '-1' for	year-end da	ata(YoY)
2	(ii) Please	fill the tim	e series of th	e selected s	stress variables.	The quart	er-end data will b	e filled in month	5 3 <mark>,6,9</mark> ,12,	and month	12 for the	e year-end o	data
3	(iii) Please	e refer to Ta	ble 7 in BuD	A White Pap	per for informati	on on des	cription of the Pro	ovided Macroecon	omic Vari	iables			
4													
5			France GDP	China GDP	Germany GDP	VIX	FED Stress Index	Oil price return					
6		frequency	0	0	0	1	1	1					
7													
8	year	month	France GDP	China GDP	Germany GDP	VIX	FED Stress Index	Oil price return					
9	2018	10											
10	2018	11											
11	2018	12	0.00	0.50	0.30	1.0	0.0	5.0					
12	2019	1				1.0	0.0	5.0					
13	2019	2				1.0	0.0	5.0					
14	2019	3	-0.25	0.25	0.30	1.0	0.0	5.0					
15	2019	4				2.0	0.1	4.0					
16	2019	5				2.0	0.2	4.0					
17	2019	6	-0.50	0.00	0.30	2.0	0.3	4.0					
18	2019	7				3.0	0.4	3.0					
19	2019	8				3.0	0.5	3.0					
20	2019	9	-0.50	0.00	0.30	3.0	0.5	3.0					
21	2019	10				4.0	0.5	2.0					
22	2019	11				4.0	0.5	2.0					
23	2019	12	-1.00	0.00	0.30	4.0	0.5	2.0					

Figure 11: The automatically generated testing scenario template

There is an additional requirement if users select to provide stock index return as one of the stress variables. Instead of providing returns, users must provide stock index values, then BuDA will calculate the returns.

Step 3: Basic Parameters and Advanced Setting

Basic Parameters

For the basic parameters, users are required to fill in "PD Horizon", "Simulation Settings", "Probability of Default Implied Rating" and "Portfolio Aggregation Setting", (See Figure 12):

- Users can specify the PD's forward horizon, which is available from 1-month PD to 60-month PD. The information concerning the forward horizon can be found in the BuDA white paper.
- "Number of simulations" determines the precision of the BuDA estimate. BuDA generates simulated possible outcomes under the given scenario and compute the average of the simulated quantity of interest (e.g., the target portfolio's median PD). The number of simulations can be specified by users. A larger number of simulations will require more computing time, but the result is more accurate.



- For "Probability of Default implied Rating" (PDiR2.0), BuDA provides a graph which depicts the overall stress testing results with reference to a letter-based rating scale. These labels indicate the PD boundaries for different letter ratings. These boundaries are generated with the CRI PDiR2.0 methodology by referencing the credit migration history of a credit rating agency. Default is set to referencing the S&P ratings. Users can opt for Moody's ratings using the dropdown menu.
- Users can also specify the aggregation method used on individual companies stressed PD, which aggregates all the simulated PD on the selected portfolio's company number level. The default setting is choosing the mean and median. In addition, users can also aggregate by multiple quantile levels should they prefer, which may cater for a more nuanced analysis of distribution of risk in the industry under different stressed scenarios.

Set basic parameters	s for your simulation	
Predicti	on Horizon	
PD Horizon	12	month(s) 🚺
Simulat	ion Settings	
Number of Simulations	10	0
Probabi	lity of Default Implied Rating	(PDiR2.0)
Systematically map the implied rating referencing to rating migration experience from	S&P v	
Portfolio	o Aggregation Settings	
Other than portfolio mean/median, please specify the additional quantiles of interest	0.12, 0.25, 0.36, 0.78, 0.99	quantile 🕄
📽 Show Adva	anced Settings	
Figure 12: Ba	sic Parameters	

OTHER SETTINGS



Advanced Setting

Users can modify some simulation parameters as shown in Figure 3, "Show Advanced Settings" (optional).



Stress Testing Regressions

6

Regression Aggregated Months	12
Lags allowed for autoregressive variables	2
Relative Po	sition Regressions
Adjust Parameters after Regression	No 🗸
Sensitivity	Analysis
Output Cross-effect and Individual Variable Contribution	No 🗸
Res	set

Figure 13: Advanced setting

The first option is "*Regression Aggregated Months*". Some stress variables, for example, GDP, are typically available on a quarterly frequency whereas others may be available monthly or even daily. Implementing the stress testing regressions faces a challenge of having to deal with mixed-frequency data. To address this issue, BuDA deduces the stress testing regressions to a time-aggregated form (see the BuDA White Paper for the detail). Users can specify the number of the time-aggregated months, where 12-month is the default option.

"Lags allowed for autoregressive variables" lets users adjust the number of lag terms deployed in the stress testing regressions, and the default is two lag terms.

"Adjust parameter after regression" is an option for relative-position autoregression, which is based on AR(3). Recall that the stress testing regressions are performed on the industry-averaged firm-specific variables. The relative position (individual value minus industry average) is applied to translate from the simulated future industry level to individual level (see the BuDA White Paper for the detail). This function allows users, if they see fit, to modify the estimated AR(3) parameters. If this option is selected, the Excel file, FirmParainEcon, will be automatically downloaded after the stage III estimation is



completed, see **Error! Reference source not found.**. The file will report the parameter estimates for each variable in the firms' relative-position autoregression. Users can modify the estimates in a way they see fit, before uploading the file as shown in Figure 14. This is useful when users have a strong intuition on the autoregression parameters².

ADJUST PARAMETERS AFTER REGRESSION	
You can modify the values in the files that will be downloaded now and upload all the files back here to continue with the calculation	
Please append the economy code to each of your files in case you are testing for multiple economies. For example filename_11.csv for Taiwan. You can download the mapping list of regions and econom IDs from here	list of regions and economy
Choose Files No file chosen Upload files	
Submit	

Figure 14: Adjust parameter after regression

By selecting "Yes" in the drop-down menu in the "Sensitivity Analysis" panel, users can assess the contribution of each stress variables to the stressed portfolio PD by holding other stress variables constant. The user can also see the difference between the sum of the individual effects and the gross effect when all variables are accounted for simultaneously. This difference is viewed as the cross effect.

After submitting, BuDA immediately starts the estimation where the estimation time in total and for different subcomponents will be estimated and shown, see Figure 15. Once the estimation is complete, the BuDA outputs will be automatically download as *.zip file. Users should turn off any pop-up blocker if the zip file cannot be downloaded. The discussion on the BuDA results is provided later in Section IV.

				Terminate the job
		0	7	
	Estimated time	Re-estimated time	Percentage of estimated time	Actual time
Overall progress	2 min, 13 sec	2 min, 13 sec	20 %	
O Data preparation	55 sec	n.a.	✓ Complete	13 sec
• Stress testing regression	23 sec	23 sec	🗘 Running	
• Firm specific residual dynamic	25 sec		Pending	
• Scenario simulation	30 sec		Pending	

Figure 15: Estimated running time



² As an example, the estimation result may suggest a quick decay rate for some individual-level risk factor (measured as a relative position) and decides that more persistence is called for. The AR(3) parameters can then be revised to generate a higher level of persistence.

III. Stress-Variables Recommender: an example

This section provides an example of using BuDA's recommender function to select stress variables. This example uses the financial industry of the ASEAN-5 countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand) and perform a backtesting from 2008-01 onward.

Three-step Instruction

Step 1:

To begin, define a pool of potential stress variables from which the recommendation algorithm can choose. Select economy/sector-specific stress variables and other variables of interest to define this pool. By default, the algorithm will select variables from the economies in the target portfolio, which is the ASEAN-5 financial industry in this example. Users can add or remove economies to reflect their needs. The economy/sector-specific variables are categorized into three groups. Users can click "+" to expand each category and select/unselect variables in that category. In this example, all categories are fully included. For other variables of interest, VIX and FFSI are also added to the pool, see Figure 16. In total, 132 variables are in the pool for the algorithm to choose from.



1) To begin, please define the pool of variables that the recommendation algorithm can choose from

Select economies for country/economy specific macro variables* :

Indonesia × Malay	sia × Philippines ×	Singapore ×	Thailand \times		
All regions	∽ All e	conomies	~	Add	💼 Clear
✓ Country/Economy sp	ecific macro variabl	es			
🕂 🗹 Macro-economi	c variables (8 sub-gi	oups)			
🕂 🗹 Common factor	s (4 sub-groups)				
🕂 🗹 Credit Cycle Ind	ices (14 sub-groups)				
Select other variables o	f interest:				
VIX					
FFSI					
+□Commodities (2	1 variables)				
	Total	number of varia	ables for the algor	rithm to choose f	rom: 132
			Next		
* By default, the recomme	endation algorithm wil	select variables	from the economies	s in the testing port	folio.
	Figure 16: [Defining the	pool of stres	s variables	

Step 2:

Specify the number of desired stress variables for the algorithm to select. In this example it is set to 5 variables (see Figure 17). The algorithm is set to choose up to 10 variables.



Figure 17: Specifying number of variables

Step 3:

In the final step, users can review the variables in the defined pool and the desired number of stress variables to be recommended. Additionally, users have the option to put one or more variables in the defined pool as the 'must-include' stress variables so that they will always appear in the final recommended set. In this example, Singapore GDP is the "must-include" variable. Select Singapore GDP using the selection box and click "Add". As such, the final 5 variables chosen by the algorithm will comprise Singapore GDP and 4 other stress variables to deliver the highest explanatory power, see Figure 18.



3 Please review the information you have entered

Regions	Indonesia, Malaysia, Phi	lippines, Singapore, Thailand
	Macro-economic variables	GDP, UNEMP, CPI, NEER, INT, HPI, PPI, CAB
	Common factors	Stock Index Return , Interest Rate , Aggregate DTD (Financial) , Aggregate DTD (Non-Financial)
Potential variables	Credit Cycle Indices	Country/Economy CCI, Basic materials, Communications, Consumer (cyclical), Consumer (non-cyclical), Diversified, Energy, Industrial, Technology, Utilities, Financial, Financial/Banks, Financial/Insurers, Financial/Others
	Other stress variables	VIX, FFSI
# Potential variables	132	
# Variables to be chosen	5	
ional Please select any	specific variables that you th	nink are vital ('must-include') for your portfolio of interest
ional Please select any ngapore\GDP ×	specific variables that you th	nink are vital (must-include') for your portfolio of interest
ional Please select any ngapore\GDP ×	r specific variables that you th acro variables	nink are vital ('must-include') for your portfolio of interest
ional Please select any ngapore\GDP × htty/Economy specific mangapore	acro variables	nink are vital (must-include) for your portfolio of interest
ional Please select any ngapore\GDP × ntry/Economy specific mangapore r stress variables of inter	acro variables GDP est	nink are vital ('must-include') for your portfolio of interest
ional Please select any ngapore\GDP × htty/Economy specific mangapore r stress variables of inter Select	acro variables GDP est Add	nink are vital ('must-include') for your portfolio of interest

Figure 18: Reviewing the information and selecting 'must-include' variables

Now, click "Start Recommendation Algorithm" and wait for the results to be generated. During the computation, a summary about the variable selection task will be displayed for users' reference.

Results

The recommended 5 variables are automatically filled in the stress variables box in Step 2.4 (see Figure 19), namely, the "must-include" Singapore GDP, Indonesia Aggregate DTD (Financial), Malaysia Interest Rate, Thailand Interest Rate, and Thailand Aggregate DTD (Financial).



4	Choose stress	s-testing variable	S			
	□ Choose fro	om economy/va	riable list			
	🗆 User Suppl	lied Stress-testi	ng Variables 🚯			
	☑ Stress Vari	iables Recomm	ender 🕄 🔨 New!			
	The chosen	variables are:				
	S	ingapore\GDP ×	Indonesia\Aggregate DTD (Financial) ×	Malaysia\Interest Rate ×	Thailand\Interest Rate ×	🟛 Clear
		Thailan	d\Aggregate DTD (Financial) ×			

Figure 19: Recommended variables

Next, click "*Confirm*" to check the sample period for each variable and then click "*Next*" to go to the final step. This example uses all default values for other settings. So, click "*Submit*" to start the analysis. Download the results when they are ready.

The file *12mthPDMedian_PDiR2.0 (Mean).png* shows that using the 5 recommended stress variables yields a good result in terms of matching the stressed portfolio PDs with the actual PDs from 2018-01 onward, see Figure 20.



Figure 20: Backtesting result of ASEAN-5 financial industry



IV. BuDA Implementation: an example

This section explains from start to finish the BuDA stress testing analysis as well as the interpretation of the BuDA results. The example is the Energy Industry of the United States of America and deploys two stress variables: (1) Cushing OK WTI Oil spot price (WTI Crude) provided in the BuDA database and (2) the US GDP on a quarterly basis. The second variable in this example is purposely treated as a user-supplied stress variable and its time series is extracted from the US Federal Reserve Database even though the US GDP series is also available in the BuDA database.

Figure 21 shows the backtesting results where the testing time point is 2010-01 and the training data is the whole sample period. This section first provides a guidance for specifying the user inputs and then turns to the description of the BuDA results.



Figure 21: Backtesting result of US energy industry

Three-step Instruction

Step 1:

Rather than selecting the country and industry, the target portfolio for this illustration purpose comprises all energy firms in the US identified by their IDBBs (Bloomberg IDs) in an Excel file. When "User's target portfolio" is selected, a window, "Upload portfolio", pops up. The Excel file in Figure 22 contains the IDBBs of these firms and the file is saved as *.csv before uploaded.



1	A IDBB	Upload portfolio ×
2	67049998	
3	18618975	Please provide a list of the IDBBs (Bloomberg IDs) of
4	69392722	the target firms following the format of this template
5	7744560	The complete company information list can be
6	7773909	
7	7699118	downloaded from here.
8	7589626	Chasse Files No file shasen
9	7287344	
10	1755986	
		🔁 Upload

Figure 22: Case Study Step 1

Once the provided portfolio is successfully uploaded, the Economies and Industries boxes are updated as "United States of America" and "Energy", see Figure 23.

			TESTING PORTFOL	IO				
		Select from the listed e	economies/regions and industries, or co	nstruct your own target portfolic)			
	Ec	conomies			Industries			
	United States of America ×				Energy ×			
Asia Pacific	v	✓ All economies	~	All i	ndustries	~		
	Add	Clear			Add	🛅 Clear		
			or choose					
			🖿 User's target portfolio					
			Next					

Figure 23: Provided portfolio is successfully updated

Step 2:

Select 'User-specified scenarios'. Furthermore, choose the testing time point as 2021-02 and the training period to be "*Till testing time point*". Since WTI Crude spot price is provided by BuDA, click "*Choose from economy/variable list*" to select it from "*Other stress variables of Interest*". In addition, US GDP is intended for inclusion through "*User Supplied Stress Variable*". To upload the US GDP data, users follow the instructions for preparing the training and testing data.

Training data preparation for user's supplied stress variables

• To upload the US GDP data, simply tick the *"User Supplied Stress Variable"* check box to upload the data set.



- For monthly US GDP data, "Frequency" is specified as "1", and "Macro Type" as "1", in C8 and C12 in Figure 24, respectively.
- In this example, data are assigned for each month from 1993-01 to 2021-04.

	A	В	C	D	E	F	G	Н		J	K	L	M	N	0	P	Q	R	5
1	US																		
2																			
3	This Frequ	iency prov	ides the in	formation	whether	the training	z macro-ec	onomic sc	enarios use	ed are repo	rted on a	monthly ba	sis or a qu	arterly bas	is or a vea	rly basis.			
4	The value	"1" means	s "Monthly	": "0" mea	ins "Quart	erly": and th	, ne value "-	1" means '	'Yearly".	· · ·		· '		· '	· '	1			
5	If it is on a	quarterly	basis;the	, data shoul	ld be repo	rted in Mon	th 3 6 9 12	while blar	, nk need be	reported i	n other mo	onths.							
6	If it is on a	a vearly ba	sis; the dat	ta should b	, be reporte	d in Month	12 while b	lank need	be reporte	d in Montl	n 1-11								
7	Growth ra	ite on a mo	onthly basi	s should b	e MoM gr	owth rate (r	non-annua	lized); on a	a quarterly	basis shou	ld be QoQ	growth rat	te (non-an	nualized);	on a yearly	/ basis shou	uld be YoY g	growth rate	e.
8	Frequency	y	1						l. i			Ī							
9																			
10	This Macro	o Type pro	vides the i	nformatio	n that for	each counti	y whethe	r the traini	ng macroe	conomic sc	enario is t	he change	(growth ra	te/differer	nce) or the	level.			
11	The value	"1" means	s "Change	Growth R	ate %)"; t	he value "0'	' means "C	hange (Dif	ference)";	the value	"-1" mean	s "Level".							
12	Macro Typ	e	1																
13																			
14	year	month	US_GDP																
15	1993	1	0.055962																
16	1993	2	0.055962																
17	1993	3	0.055962																
18	1993	4	0.193447																
19	1993	5	0.193447																
20	1993	6	0.193447																
21	1993	7	0.158941																
22	1993	8	0.158941																
23	1993	9	0.158941																
24	1993	10	0.451306																
25	1993	11	0.451306																
26	1993	12	0.451306																
27	1994	1	0.322678																
28	1994	2	0.322678																
29	1994	3	0.322678																
30	1994	4	0.449444																
31	1994	5	0.449444																
32	1994	6	0.449444																
33	1994	7	0.194579																
34	1994	8	0.194579						-										
35	1994	9	0.194579																
36	1994	10	0.380424																
37	1994	11	0.380424																
38	1994	12	0.380424																
30	1995	macro	train tem	nlate	4			1	1	1			1	1	1	1		: 4	
		macro	_aam_eem		0														_

Figure 24: US GDP Historic growth rate

Figure 25 shows the available training sample period for the selected stress variables: WTI Crude spot price and US GDP.



			TEST	TING SCEN	IARIOS			
		Choose and upload t	he required f	iles, if needed, for	the macroec	onomic variables to use.		
1	Specify scenarios							
	User-specified	l scenarios 🚯				🗆 Backtesting 🚯		
2	Select testing time point							
			2021-02		# 0			
3	Select training sample period							
			Till testin	g time point	~ (
			1993-01	苗 to 2021-0	2 🗰			
	Choose from economy/variable	e list						
	Choose from economy/wariable	list.						
	☑ User Supplied Stress-testing V	'ariables 🚯						
	🗆 Stress Variables Recommende	er 🔁 🧹 New!						
	The chosen variables are:	_						
	Cushing OK WTI Oil ×	US_GDP (User-Supplied) ×						🛅 Clear
			The a	vailable data pe	riods are		Г	
		Stress	s-testing va	riables : January	y 1993 to Ma	arch 2021		
			CRI PD Data	a : January 1991	to March 2	021		
		Stress-testing variable	1	Available Start Dat	e	Available End Date	_	
		Cushing OK WTI Oil	1	990-02		2021-03		
		US GDP (User-Supplied)	1	993-01		2021-05		

Figure 25: Available training period of uploaded training data

Testing data preparation

After confirming the stress variables, select "*Generate testing scenario file*". A customized template corresponding to the user's chosen variables will be downloaded. Do not modify or re-use the template as it might create inconsistency and cause an error.

In this example, there are three scenarios of interest (adverse, current and improving), which are determined by the WTI Crude spot price and US GDP growth rate as shown in Figure 26. Each scenario should be specified in separate sheets of a single Excel file. By default, the provided template accommodates two scenarios. Users can add a new sheet by copying "*Scenario 2*" and creating "*Scenario 3*".

It is important to specify the correct data frequency in the first sheet. "1" is filled in for this example as monthly data are used (see cell C6 in adverse scenario 1, Figure 26).

Upload the filled template to BuDA and click "confirm".



Note: that the frequency of the testing data does not need to be the same as the training data. All three of the sheets must have the identical length and variable names.

												A	В	C	D	
											1	year	month	WTI_Crude_0	US_GDP	
											2	2021	2	5	0.2	
	A	В	С	D	E						3	2021	3	5	0.21	
1	(i) Please sp	ecify the frequ	ency of each sel	lected stress va	riable,						4	2021	4	5	0.22	
2	(ii) Please fil	l the time seri	ies of the selecte	ed stress variab	les. The 🔄	A	В	С	D	E	5	2021	5	5	0.23	
3	(iii) Please re	efer to Table 6	in BuDA White I	Paper for inforr	nation c 1	year	month	WTI_Crude_	CUS_GDP		6	2021	6	5	0.24	-
4					2	2021	2		s 0.	2	7	2021	7	5	0.24	
5			WTI_Crude_Oil	US_GDP	4	2021	4		3 0.1	>	/	2021	/	5	0.25	-
6		frequency	1	. 1	5	2021	5	3	3 0.1	2	8	2021	8	5	0.26	-
7					6	2021	6	3	0.:	2	9	2021	9	5	0.27	
8	year	month	WTI_Crude_Oil	US_GDP	7	2021	7	8	B 0.1	2	10	2021	10	5	0.28	
9	2021	2	-3	-0.1	8	2021	8	3	B 0.:	2	11	2021	11	5	0.29	1
10	2021	3	-3	-0.11	9	2021	9	3	B 0.1	2	12	2021	12	5	0.3	
11	2021	4	-3	-0.12	10	2021	10	3	3 O.:	2	13	2022	1			1
12	2021	5	-3	-0.13	11	2021	11		0	2	14	2022	1			
13	2021	6	-3	-0.14	13	2021	12		o 0	2	14	2022	2			-
14	2021	7	-3	-0.15	14	2022	2				15	2022	3			
15	2021	8	-3	-0.16	15	2022	3				16	2022	4			
16	2021	9	-3	-0.17	10	5 2022	4				17	2022	5			
17	2021	10	-3	-0.18	17	7 2022	5				18	2022	6			
18	2021	11	-3	-0.19	18	3 2022	6				19	2022	7			
19	2021	12	-3	-0.2	19	2022	7				20	2022	8			+
20	2022	_1			20	2022	sonario 1	conorio 2	Sconorio 2	æ	20		Scenario 1	cenario 2	cenario 3	
	< > _	Scenario 1	Scenario 2 Scer	nario 3 🛛 🕀)	a du		cenario 2	Scenario 5	æ					rechard 5	

Figure 26: Stress Scenarios on WTI Crude and US GDP

Step 3:

The default setting of BuDA is to use 1-year PD values, thus the PD horizon is set for 12 months. PD Horizon can be set anywhere between 1 and 60 months. Users can also set the PDiR2.0 ratings to be mapped to S&P or Moody's.

Click "Submit". It may take several minutes to half-an-hour to complete the various BuDA computation tasks. The estimated times for different BuDA steps will be shown and the overall progress will also be reported on the screen.



OTHER SETTINGS

Set basic parameters for your simulation

Prediction Horizon

PD Horizon	12	month(s)
Simulatio	on Settings	
Number of Simulations	10	0
Probabili	ty of Default Implied Rating (PDiR2.0)
Systematically map the implied rating referencing to rating migration experience from	S&P ~	
Portfolio	Aggregation Settings	
Other than portfolio mean/median, please specify the additional quantiles of interest		quantile 🕄

Figure 27: Case Study Step 3'

Results

Once the computation is complete, BuDA will automatically download the outputs in a *.zip file. The following section will cover the detail of the BuDA results, as seen in Figure 28.



RickFactor Analysis			File folder	
			The folder	
Sensitivity_Analysis			File folder	
12mthPDMedian_PDiR2.0 (Mean).png	65,535	58,594	PNG File	17/5/2021 11:4
12mthPDMedian_PDiRold (Mean).png	65,931	59,167	PNG File	17/5/2021 11:4
Coefficients.txt	16,069	2,793	Text Document	17/5/2021 11:4
🕼 Firm_HistoricalPD.csv	965,251	343,884	Microsoft Excel Co	17/5/2021 11:4
🕼 Firm_stressedPD_Scenario 1.csv	85,859	35,936	Microsoft Excel Co	17/5/2021 11:4
🕼 Firm_stressedPD_Scenario 2.csv	86,719	36,132	Microsoft Excel Co	17/5/2021 11:4
🕼 Firm_stressedPD_Scenario 3.csv	87,039	36,248	Microsoft Excel Co	17/5/2021 11:4
Parameter_Selection_Record.txt	772	422	Text Document	17/5/2021 11:4
PDmedian_Mean&Multiplies_12mth.xlsx	250,500	50,701	Microsoft Excel W	17/5/2021 11:4
PDmedian_Mean&Quantiles_12mth.xlsx	253,062	52,675	Microsoft Excel W	17/5/2021 11:4
Rsquare.txt	3,698	789	Text Document	17/5/2021 11:4
Testing_Firm_Information.csv	28,476	5,442	Microsoft Excel Co	17/5/2021 11:4

Figure 28: BuDA results

(i) Parameter_Selection_Record.txt

This file provides a summary of the user's request, including the selected economies, industry, and stress variables. It also indicates the testing time point and training period. Users may keep this file as a reference.

This file records the basic parameters you have selected for this test. Testing Regions: United States of America Testing Industries: Diversified, Energy Macro Variables: WTI_Crude_Oil, US_GDP Scenarios: Scenario 1, Scenario 2, Scenario 3 Testing Time Point: 202102 Training Sample Period: 199301 to 202102 PD Horizon: 12 Number of Simulations: 1000

Figure 29: Parameters Selection Record

(ii) Testing_Firm_information.csv, Testing_Firm_information_Historical.csv

These two files report the information on individual firms included in the portfolio. "Testing_Firm_information_Historical.csv" also reports the historical PDs of each firm in the sample. Users may notice several missing PDs, as those companies may not exist in that data period. They may have already defaulted, exited the market for reasons other than default, or have not been listed in a stock exchange yet.



A A	8	C D	E	F	G	H	1	J	K	L	M	N	0	P	Q	R	S	T	U	V	W	Х	Y	Z	AA	AB	AC	
1 This file n	ports the l	historical PDs for i	ndividal firms	i.,																								
2 Unit of PD	measure:	Basis points.																										
3 Company	IDBB	CRI Comp. Exchan	ge Domicile	Bloomber	Bloombe	r Jan-91	Feb-91	Mar-91	Apr-91	May-91	Jun-91	Jul-91	Aug-91	Sep-91	Oct-91	Nov-93	1 Dec-91	Jan-92	2 Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	
4 Fremont I	10802741	23605 Austral	ia United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Nŧ
5 FutureFue	10004206	27014 United	Sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Né
6 Energy Tra	10005604	27026 United	Sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Nę
7 Hess Corp	100078	27044 United	Sta United Sta	10007	Energy	16.24025	12.17328	13.77033	4.548836	3.906413	4.806178	3 2.970552	2.069833	2.04617	1.549248	3.571045	5 4.238824	6.320156	5 11.64355	17.35354	6.903173	5.934667	6.057492	2.556685	2.296702	2.906826	2.977613	8.
8 Apache C	100104	27064 United	Sta United Sta	10007	Energy	19.29652	14.98187	20.55743	14.23145	10.72099	12.97268	7.395307	5.743944	2.82909	1.942198	3.67183	8 48.57902	74.91638	84.16288	57.01098	25.00635	22.51131	29.72483	18.37581	13.72272	11.82978	11.73734	1
9 REX Amer	100133	27085 United	Sta United Sta	10007	Energy	311.7197	266.3215	275.6095	5 195.2684	191.0922	244.7993	90.34563	83.55964	48.25699	38.92564	53.2463	3 80.99564	80.19173	99.36364	109.968	60.79089	52.91725	78.99518	71.76006	51.40923	51.87532	35.8014	2
10 DCP Mids	10021078	27151 United	Sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Ne
11 BP Prudhe	100220	27160 United	Sti United Sti	10007	Energy	0	0	0	0 0	0	0	0 0	0	0	0 0		0 0	0	0 0	0	0	0 0	0	0	0	0	0	
12 Cabot Oil	100253	27184 United	Sta United Sta	10007	Energy	0.057748	0.060295	0.136843	0.212717	0.184493	0.280758	0.215892	0.182031	0.23947	0.417632	0.9540	7 2.257707	4.532982	2 5.400017	4.583967	3.460983	2.971222	5.003747	2.017548	1.757578	1.244708	1.708367	3
13 Chevron G	100315	27239 United	Sti United Sti	10007	Energy	0.230474	0.225472	0.188793	0.195846	0.258981	0.295045	0.189607	0.144098	0.099852	0.073561	0.150275	5 0.160981	0.303932	0.401418	0.241763	0.203563	0.236035	0.282394	0.218364	0.18173	0.181541	0.213477	0
14 EOG Reso	100529	27403 United	Sta United Sta	10007	Energy	3.804087	3.739271	3.936225	5.08306	3.708196	5.869979	4.532527	3.10134	2.566907	2.986621	3.32847.	4.109502	5.815816	4.142914	1.880523	1.209952	1.04269	0.724172	0.41158	0.417976	0.370172	0.523297	0
15 EQT Corp	100539	27409 United	Sta United Sta	10007	Energy	0.270414	0.419832	0.333481	0.32261	0.323868	0.488216	5 0.237795	0.204507	0.144458	0.07005	0.06677	8 0.136453	0.138954	0.413163	0.404894	0.241975	0.168382	0.080377	0.040835	0.020457	0.028305	0.02213	0
16 Exxon Mo	100546	27416 United	Sta United Sta	10007	Energy	0.262819	0.257868	0.155752	0.143358	0.187777	0.175211	0.120502	0.116417	0.087848	0.094692	0.13531	1 0.137806	0.197925	5 0.179983	0.197174	0.13572	0.172019	0.13423	0.150392	0.150415	0.152649	0.163055	0
17 Halliburto	100698	27547 United	Sta United Sta	10007	Energy	1.323541	1.228056	2.036661	3.524042	2.645307	5.410338	5.884665	6.565507	10.40243	10.14252	12.8739	7 20.00053	26,45967	7 19.43589	28.13342	22.53522	14.65495	13.53992	7.034336	4.719963	9.239296	12.67317	1
18 Calumet S	10071540	27566 United	Sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Na
19 Helmerick	100729	27579 United	Sta United Sta	10007	Energy	0.093355	0.097471	0.177254	0.108619	0.082855	0.120965	0.076266	0.07271	0.044751	0.042811	0.07524	3 0.091458	0.070156	5 0.074196	0.051335	0.030829	0.034632	0.031599	0.024295	0.017871	0.015033	0.021031	0
20 Murphy C	101024	27821 United	Sta United Sta	10007	Energy	0.614114	0.693043	1.08409	0.919939	1.092313	1.194304	1.954994	2.311405	3.214279	3.616456	4.62445	1 4.423271	3.904352	4.853884	4.879197	2.697535	2.888015	0.566651	0.417598	0.302953	0.249247	0.198098	0
21 NACCO In	101029	27829 United	Sta United Sta	10007	Energy	45.04634	42.90964	47.79756	64.59164	61.46829	41.18584	24.51854	22.99835	19.17195	19.12982	38.708	3 24.34808	23.66827	7 11.1796	10.65262	6.856546	4.559443	22.73964	18.97528	28.72795	28.30633	24.85236	2
22 Occidenta	101106	27899 United	Sta United Sta	10007	Energy	31.0078	24.15356	34.27297	81.52992	63.0866	60.68439	47.26897	48.17435	53.40808	62.1994	93.5915	8 86.33786	65.46501	61.04045	22.94846	19.12782	15.12115	15.98046	12.28041	11.18077	14.9799	18.39999	
23 Oceaneer	101107	27900 United	Sta United Sta	10007	Energy	7.100388	5.885924	8.502405	5 11.40399	6.830675	8.745344	8.1264	8.509225	12.94696	9.41809	12.9090	7 17.78899	11.81975	6.320891	7.924494	3.836161	3.818131	3.050788	3.272694	2.098676	1.986019	1.686172	3
24 ONEOK In	101122	27913 United	Sta United Sta	10007	Energy	5.789688	10.10351	14.72249	10.43327	9.375181	10.46448	3 12.16385	10.42175	5.933399	6.758664	4.599333	3 4.071559	6.873443	8.272588	6.057028	8.657398	8.523013	7.543312	5.685914	5.187652	4.785437	3.341248	4
25 Goodrich	101150	27940 United	Sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Né
26 Permian B	101161	27951 United	Sta United Sta	10007	Energy	0.000475	0.000526	0.000571	0.023394	0.026606	0.027842	0.017121	0.015697	0.01255	0.011813	0.01045	2 0.008928	0.009152	0.012406	0.003846	0.003568	0.002447	0.000879	0.000942	0.000642	0.000247	0.000389	0
27 ConocoPf	101174	27959 United	Sta United Sta	10007	Energy	3.931683	3.931358	3,420709	4.262078	4.713367	6.255903	3.975992	3.525085	3.992039	3.665908	5.91918	9 5.140442	4.380707	4.52891	3.646125	3.581924	2.684079	3.331189	1.872913	1.780149	1.511015	2.798622	3
28 RPC Inc	101284	28039 United	Sta United Sta	10007	Energy	0.072291	0.039389	0.128409	0.175261	0.30462	0.317864	0.486098	0.524704	0.384281	0.66473	0.95227	6 1.025572	2.575375	0.9599	0.610095	0.500239	0.32078	0.298517	0.435055	0.440158	0.575183	0.696728	0
29 Sabine Ro	101296	28051 United	Sta United Sta	10007	Energy	6.56E-08	7.78E-08	1.39E-07	3.14E-07	2.61E-07	2.28E-07	7 9.39E-08	3.93E-08	3.01E-09	7.73E-10	4.77E-10	0 1.91E-09	4.55E-10	1.71E-10	9.47E-10	6.52E-10	4.73E-10	1.85E-11	9.80E-12	1.63E-11	2.29E-11	1.09E-11	- 2
30 San Juan I	101305	28061 United	Sta United Sta	10007	Energy	9.83E-10	1.16E-09	1.54E-09	2.12E-06	3.45E-06	5.00E-06	5 0.000161	0.000294	0.008694	0.00922	0.010394	4 1.29E-06	1.20E-06	5 9.39E-07	5.27E-05	3.39E-05	2.05E-05	0.000182	0.000117	0.000135	0.005769	0.008005	0
31 Schlumbe	101318	28069 United	Sta United Sta	10007	Energy	0.170475	0.157917	0.27302	0.356619	0.279952	0.390716	5 0.222984	0.22652	0.304601	0.248116	0.30814	4 0.367489	0.416795	0.35003	0.37822	0.245686	0.224472	0.259801	0.199143	0.144712	0.126914	0.134169	0
32 Southwes	101377	28126 United	Sta United Sta	10007	Energy	0.0378	0.044536	0.054689	0.226315	0.176143	0.25428	8 0.286612	0.354676	0.415634	0.498758	0.48147.	2 0.720991	0.694921	1.184992	0.628512	0.435483	0.298573	0.334174	0.163868	0.105044	0.067596	0.033956	0
33 Marathon	101581	28293 United	Sta United Sta	10007	Energy	1.213736	1.580068	1.44813	3 2.152479	10.87938	17.40984	11.2794	5.97758	8.260391	10.94382	16.2763	3 25.266	33.68199	34.2592	49.46446	11.18227	10.56383	13.57636	13.63361	17.46166	17.15495	27.44589	2
34 Williams	101661	28356 United	Sti United Sti	10007	Energy	24.70847	15.20946	12.01743	8.82208	7.143613	10.54652	2 7.559912	7.064513	5.040661	4.107429	3.92508	9 2.979104	3.42755	2.399449	3.487836	6.502337	6.766047	6.927033	7.183249	6.23048	5.188475	4.716517	4
35 Adams Re	101901	28530 United	sta United Sta	10007	Energy	159.1451	127.3578	113.1952	77.55084	88.66956	102.2791	91.65619	120,4782	87.0203	96.787	114.048	9 94.63002	86.67695	76.62358	/9.02878	81.20107	56.60424	55.52575	40.83105	91.56289	59.28143	68,45542	1
36 Trecora R	102193	28705 United	sta United Sta	10007	Energy	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	N
37 Enservco	102228	28725 United	sta united Sta	10007	Energy	NaN	NaN	NaN	NaN	New	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Né
	Firm H	istoricalPD	(+)														4											

Figure 30: Testing Firm Information

(iii) Coefficients.txt and Rsquare.txt

"*Coefficients.txt*" reports the parameter estimates, along with their standard errors. The results in Figure 31 show that the WTI Crude spot price has positive effects on the stock index return and aggregate DTD values, which are in line with the intuition.

UNITEDSTATESOFAME	RICA			
Common variables				
	Stock Index Return	Interest Rate	Aggregate DTD Fin	Aggregate DTD nonFin
Intercept	4.47e-03	-1.34e-02	5.95e-02	1.06e-01
	(3.81e-03)	(4.71e-03)	(2.14e-02)	(2.27e-02)
WTI Crude Oil	1.45e-03	1.66e-03	4.65e-03	5.39e-03
	(3.04e-04)	(3.99e-04)	(8.78e-04)	(7.30e-04)
US GDP	1.83e-02	2.73e-02	5.06e-02	3.93e-02
_	(7.78e-03)	(9.93e-03)	(2.27e-02)	(1.85e-02)
Lag l	-4.03e-02	5.57e-02	4.62e-02	1.51e-01
	(5.31e-02)	(2.60e-02)	(4.68e-02)	(4.58e-02)
Lag 2	-6.14e-02	-7.00e-02	-7.11e-02	-1.84e-01
	(5.39e-02)	(2.90e-02)	(4.93e-02)	(4.89e-02)

Figure 31: Coefficients.txt

In addition, the R-squares³ of all stress testing regressions are reported in "Rsquare.txt". Results in Figure 32 show that WTI Crude spot price and US GDP growth rate together have the highest explanatory power for Stock Index Return among the common risk



 $^{^3}$ The R-squares are calculated in the normal way instead of that in Duan et al (2012). In addition, when there are insufficient data (less than 5 firms or less than 3 years of data) in the specific economy-sector, the aggregation group-sector mean is used as a substitution. For details, please refer to BuDA White Paper v3.3.2 page 27.

factors. For the sector-average firm-specific variables, the R-square for M/B is the highest for Energy sector.

0.5058				
0.2316				
0.1620				
0.2596				
Sector mean)				
DTD	CA/CL	NI/TA	SIZE	M/B
0.2575	0.1806	-0.0773	0.1606	0.3146
average as not enou	gh data in the secto:	r)		
0.4520	0.3021	0.2763	0.3981	0.4562
	0.5058 0.2316 0.1620 0.2596 Sector mean) DTD 0.2575 average as not enou 0.4520	0.5058 0.2316 0.1620 0.2596 Sector mean) DTD CA/CL 0.2575 0.1806 average as not enough data in the sector 0.4520 0.3021	0.5058 0.2316 0.1620 0.2596 Sector mean) DTD CA/CL NI/TA 0.2575 0.1806 -0.0773 average as not enough data in the sector) 0.4520 0.3021 0.2763	0.5058 0.2316 0.1620 0.2596 Sector mean) DTD CA/CL NI/TA SIZE 0.2575 0.1806 -0.0773 0.1606 average as not enough data in the sector) 0.4520 0.3021 0.2763 0.3981

Figure 32: Rsquare.txt

(iv) Firm_stressedPD_Scenario 1, Scenario 2, and Scenario 3.csv

These files report the 12-month stressed PDs of each firm (individual level) for each stressed scenario. Please refer to the BuDA white paper for further details on how the stressed PDs are computed. *"Firm_stressedPD_Scenario 1.csv"* contains the BuDA results which are the stressed PDs under Scenario 1 (Adverse WTI Crude Oil spot price and US GDP growth rate) and displayed in Figure 33.

Tims ine reports the stress pub for individial rims. Unit of PD measure: Basis pub for individial rims. Please cite the BuDA results in the following way: Duan, JC., W. Mao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2021. BuDA: A Bottom-Up Default Analysis Framework, version 3.3.0. Company IDB8 CRI Compi.Exchange Domicile (Bloomber Bloomber Feb-21 Mar-21 Apr-21 Jun-21 Jul-21 Aug-21 Sep-21 Oct-21 Nov-21 Dec-21 Fremont 1 0802741 23605 Australia United St 10007 Energy 122.8611 158.0925 190.6477 2.82071 4.58169 97.2562 200.542 Nov-21 Dec-21 FutureFue Loopode 27040 United St United St 10007 Energy 138.6721 127.8492 174.3888 127.256 28.1438 245.7368 27.83559 31.6431 32.2857 334.6031 354.273 28.698 37.2383 34.57368 138.11202 86.27947 FutureFue Looport 27026 United St United St 10007 Energy 118.6762 152.9492 14.3888 55.5977 28.143 24.57385 31.6341 34.2784 14.57808 23.2323 54.6348 56.6434 54.77844
Unit of YD measure: lasis points. Please cite the BUDA results in the following way: Duan, JC., W. Miao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2021. BuDA: A Bottom-Up Default Analysis Framework, version 3.3.0. Company IDBB CRI Complexinge Domicile (Bloomber Beb-21 Mar-21 Apr-21 Mar-21 Jul-21 Aug-21 Sep-21 Oct-21 Nov-21 Dec-21 Per-21 Per-21 Per-21 Distribution 2004206 2014 United Stat United Stat 10007 Energy 12.2811 158.0925 100477 02.2277 22.2627 255.0128 287.8689 27.2666 29.06477 29.26899 FutureFue 10004206 27014 United Stu United Stat 10007 Energy 11.783623 2.740675 3.772684 4.475175 4.820871 4.581873 4.761068 5.045903 5.388272 5.517491 5.775184 Energy Tri 10005694 2.7026 United Stu United Stat 10007 Energy 118.6762 152.9492 174.3888 1955997 228.1243 245.7368 274.3555 310.7431 322.3857 334.6031 334.7211 Hess Com Diory78 2.7044 United Stu United Stat 10007 Energy 4.475708 5.106073 5.32923 5.4232323 554.286484 74.55788 8.311202 8.827947
Please cite the BuDA results in the following way: Duran, JC., W. Miao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2021. BuDA: A Bottom-Up Default Analysis Framework, version 3.3.0. Company IDB8 CRI Complexhange Domicile (Bioomber Bioomber Feb-21 Mar-21 Apr-21 Mary-21 Jun-21 Aug-21 Sep-21 Oct-21 Nov-21 Dec.21 Femory Jun-21 Jun-21 Aug-21 Sep-21 Oct-21 Nov-21 Dec.21 Dec.21 Nov-21 Dec.21 N
Duan, JC., W. Miao, J.A. Chan-Lau, and The Credit Research Initiative Team of the National University of Singapore, 2021. BuDA: A Bottom-Up Detault Analysis Framework, version 3.3.0. Company IDBB CRI Complexchange Domicile (Bloomber Bloomber Bloomber Feb-21 Mar-21 May-21 Jun-21 Jul-21 Lul-21 Sep-21 Oct-21 Nov-21 Dec-21 Fremont F 10802741 23605 Australia United Stit 10007 Energy 12.8611 158.0925 190.6477 20.2277 25.20128 287.8698 297.2366 290.6492 286.173 292.6699 FutureFue 10004206 27014 United Stit United Stit 10007 Energy 11.86692 2.740675 3.772684 4.475175 4.820871 4.551873 4.761065 5.045903 5.388272 5.517491 5.775184 Energy Tri 10005604 27026 United Stit United Stit 10007 Energy 118.6762 152.9492 174.3888 95597 28.1243 4.57365 5.017431 322.3857 334.6031 34.77514 Energy Tri 10005604 27026 United Stit United Stit 10007 Energy 118.6762 152.9492 167.85597 28.1243 457.358 31.04
Company IDB8 CRI CompLExchange Domicile (Bloomber Feb-21 Mar-21 Apr-21 Mar-21 Jul-21 Jul-21 Age-21 Sep-21 Oct-21 Nov-21 Dec-21 Fremont F 1004206 2014 United Sti Incore Freery 122.811 156.092 109.6477 202.2577 255.0128 287.868 270.256 250.042 288.173 292.669 FutureFut 10004206 27014 United Sti United Sti 10007 Energy 1.783623 2.740675 3.772684 4.475175 4.820871 4.581873 4.761068 5.045903 5.382672 5.511491 5.775184 Energy Tr4 10005644 27026 United Sti United Sti 10007 Energy 118.6762 152.9492 174.3888 59597 28.1243 245.7368 74.3555 31.6431 32.23857 334.6031 34.1202 86.27947
FremontF 10802741 23605 Australia United Stic 10007 Energy 122.8611 158.925 190.6477 202.277 222.6275 255.0128 287.8698 297.2366 290.0542 288.173 292.6699 FutureFue 10004206 27014 United Stic 10007 Energy 1.783623 2.740675 3.772684 4.475175 4.802071 4.551873 4.761068 5.045903 5.388272 5.517491 5.77714 Energy Tri 10005604 27026 United Stic United Stic 10007 Energy 118.6762 152.9492 174.3888 195.9597 282.1243 245.7368 274.3555 310.741 322.3857 334.6031 34.7214 Hess Corn 100075 Energy 43.64163 49.41764 47.67508 51.06073 52.3223 56.42221 59.64386 65.6484 74.5758 83.11020 86.27947
FuturePie 1000/206 27014 United Stubilities 10007 Energy 1.738562 2.740675 3.772664 4.75175 4.820871 4.581873 4.761068 5.045903 5.338272 5.517491 5.775184 Energy Tri 10005604 27026 United Stubilities 10007 Energy 118.6762 152.9492 174.3888 195.9597 28.21243 245.7368 274.3555 310.741 322.3857 33.46031 324.931 354.7368 324.7368 274.3555 310.741 322.3857 33.46031 324.931 354.7315 4.80147 4.57878 8.10102 86.27947
Energy Tr 10005604 27026 United 5ti United 5ti 10007 Energy 118.6762 152.9492 174.388 195.9597 228.1243 245.7368 274.3555 310.7431 322.3857 334.6031 354.7217 Hesc Corp 10078 27044 United 5ti United 5ti 10007 Energy 43.64163 49.41768 47.6758 51.60677 52.32923 65.4221 59.64226 65.8428 46.745.578 83.11202 85.27947
Hess Corp 100078 27044 United Sta United Sta 10007 Energy 43.64163 49.41768 47.67508 51.06073 52.32923 56.42221 59.64386 66.8048 74.55788 83.11202 86.27947
REX Amer 100133 27085 United Sta United Sta 10007 Energy 7.542284 12.00427 17.35716 23.32444 32.18888 43.38055 56.21932 81.17503 88.39172 109.1897 134.3316
DCP Midst 10021078 27151 United Sta United Sta 10007 Energy 86.79962 97.19196 107.0486 120.0941 139.6103 158.0194 172.5097 187.4678 206.479 219.5129 235.5402
BP Prudhc 100220 27160 United Stc United Stc 10007 Energy 2.393531 1.600349 1.285467 1.483039 1.985415 2.210228 2.089163 2.01408 2.21298 1.963503 1.775257
Cabot Oil 100253 27184 United Sta United Sta 10007 Energy 6.602343 6.71779 6.052518 5.690866 5.845816 5.950327 6.281221 7.124905 7.767722 8.406605 8.707624
Chevron C 100315 27239 United Sta United Sta 10007 Energy 24.95404 37.86579 75.80555 117.5004 162.2655 209.6402 277.5381 348.1382 361.3147 454.7769 499.7736
EOG Resol 100529 27403 United Sta United Sta 10007 Energy 31.63771 36.37159 39.52311 43.72233 48.13735 52.43326 58.20429 68.87399 79.5599 94.79434 110.0192
EQT Corp 100539 27409 United Sta United Sta 10007 Energy 68.90571 89.34453 105.2091 109.2242 113.925 119.296 125.1413 148.4281 159.8213 163.027 165.188
Exxon Mo 100546 27416 United Sta United Sta 10007 Energy 22.1269 24.43382 35.02087 50.60882 65.52885 83.8052 108.4959 144.4539 179.2362 219.481 272.3099
Halliburto 100698 27547 United Sta United Sta 10007 Energy 55.11362 50.6325 57.38073 67.6983 76.07609 80.60649 87.70337 98.16227 106.3744 112.6044 118.5511
Calumet S 10071540 27566 United Sta United Sta 10007 Energy 80.02655 74.11446 78.95053 92.95904 109.6391 120.0061 128.6662 142.5917 151.9819 166.2633 178.0239
Helmerict 100729 27579 United Sta United Sta 10007 Energy 39.85655 48.91403 61.11287 70.03287 80.66621 95.79209 111.4403 125.3544 139.9541 155.6855 169.2528
Murphy O 101024 27821 United Sta United Sta 10007 Energy 150.2499 170.2359 160.7212 166.2717 163.2531 174.505 176.0627 191.316 205.4951 216.1369 229.748
NACCO In 101029 27829 United Sta United Sta 10007 Energy 31.12977 38.97503 45.0098 52.48098 62.20729 71.49052 84.37981 100.5315 119.1575 140.2195 163.5537
Occidenta 101106 27899 United Sta United Sta 10007 Energy 215.1188 327.6193 411.188 485.9467 556.0662 586.8673 673.1134 767.344 918.3785 934.2331 1013.278
Oceaneer 101107 27900 United Sta United Sta 10007 Energy 73.88017 89.73585 104.701 116.1512 132.5065 145.4379 160.8247 184.0052 207.2844 224.5771 235.5438
ONEOK In 101122 27913 United Sta United Sta 10007 Energy 90.25203 207.7665 432.1028 643.2683 830.9583 1015.951 1098.32 1174.969 1200.438 1272.271 1334.509
Goodrich 101150 27940 United Str 10007 Energy 74,84823 65,06254 48,76308 45,03629 53,13501 63,27709 69,33399 73,2644 76,04172 79,04066 82,0198
Permian E 101161 27951 United Str United Str 10007 Energy 0.338402 0.315824 0.267446 0.24273 0.219931 0.212314 0.223776 0.248784 0.269943 0.292275 0.3157
ConoroPb 101174 27959 United Str 10007 Energy 25 52673 24 45428 27 9509 33 21203 39 67875 49 07248 59 18456 74 1548 92 85883 113 3641 136 876
BC Inc 101284 28039 United Str United Str 10007 Energy 8,975341 12,10374 16,03621 18,09141 19,83629 21,91511 24,09204 27,21695 30,25508 32,10497 34,11286
Sabine Bo 101296 28051 United Sta United Sta 10007 Energy 0.002047 0.002827 0.003556 0.0044 0.005626 0.005479 0.006425 0.004965 0.006966 0.005867 0.008498
San Juan E 101305 28061 United Sta Inon7 Energy 0.027626 0.064368 0.073439 0.078272 0.083372 0.08559 0.096662 0.10859 0.112945 0.123216 0.126794
Schlumbe 101318 28069 United Statilitied Stat 1007 Energy 68 71239 89 71554 106 5554 123 1815 145 2318 163 5409 184 4801 215 8327 243 751 261 3708 277 921
Southwas 101377 28126 [Jointed stripting stripting stripting] 55 9877 223 7756 275 955 309 0002 337 1308 365 0621 347 5017 445 1557 475 588 494 2666 530 3697
Marshhon 101561 2209 United St: 10007 Energy 100725 21504 63 70477 72 051004 92 100225 118 (217 12) 2510 142 6622 147 085
Williams 101661 28356 [United st: [United st: [United st:] 107 Energy 34 / 819 / 47 / 583 / 68 / 866 / 59 / 885 / 53 / 333 / 57 / 788 / 57 / 789 / 53 / 783 / 57 / 788 / 75 / 788 / 78 / 7
Adams Ro 101901 20530 (Inited Strilling St. 10007 Energy J 40733 72.2014 20.30620 33.3053 32.27687 32.0007 36.200 01.22003 01.3016 34.2900 01.2010
Teners 1 (1019) 2770 [Initial Science 31] 2007 [Initial Science 31] 20
Teconomic 102105 E0100 UTILES CONTRES DE DITECTOR 1000 LINES E 20007 LE 20007 LE 20007 LE 20007 LINES DE DITECTOR 2000 LINES DE DITECTOR
EIGENVUY 10/226/20 20/20 VIIITEU 3/CU VIIITEU 3/C 10/07/20 10/20 2
Firm_stressedPD_Scenario 1

Figure 33: Testing_firm_PDs_12mth_Test1.csv



(v) 12mthPDmedian_PDiR2.0(Mean).png

"12mthPDmedian_PDiR2.0(Mean).png" reports the bottom-up aggregated portfolio PDs (medians) for both the historical data (training data) and the user-specified scenarios.

For computing the stressed portfolio PD, the median PD for all individual firm in the target portfolio is computed under each simulation run. Since 1000 simulation is chosen in this example, the stressed portfolio PD, BuDA generates 1000 stressed median PDs and average them to obtain the final stressed portfolio PD. Their values for different time points are displayed in Figure 34.

The blue solid line in this figure is the actual CRI-PD of the portfolio, whereas the three dotted lines are the stressed portfolio PDs corresponding to the three given scenarios (adverse, current and improved scenarios, denoted as Scenario 1, 2 and 3). As expected, the results show the highest stressed portfolio PD under the adverse scenario.

Since v3.3.3, we add a new function that caters for user-specified aggregation method. Therefore, some additional results figures, named as "12mthPD(aggregated_method) _PDiR2.0(Mean).png", may be generated.



Figure 34: 12-Month PD of the bottom-up portfolio

(vi) PDmedian_Mean&Quantiles_12mth.xlsx

PDmedian_Mean&Quantiles_12mth.xlsx displayed in Figure 35 below shows the results produced under Scenario 1 (Adverse case). While the plot discussed in (iii) uses the stressed portfolio PD computed as the mean of the 1000 simulated median firm PDs,



users can apply other statistics. For example, users may consider using mean or other quantiles, instead of median, of the individual PDs in the target portfolio.

Since v3.3.3, we add a new function that caters for user-specified aggregation method. Therefore, some additional results figures, named as "PD(aggregation_method) _Mean&Quantiles_12mth.xlsx", may be generated.

Jnit of PD me	asure: Unit.												
lease cite th	e BuDA resul	ts in the follo	wing way:										
Juan, JC., W	/. Miao, J.A. (Chan-Lau, and	The Credit Re	search Initiat	ive Team of th	ne National Ur	iversity of Sir	ngapore, 2021	BuDA: A Bo	ttom-Up Def	ault Analysis F	ramework, ver	sion 3.3.0.
/ear	Month	CRI	Mean	Median	95%-quantile	75%-quantile	25%-quantile	5%-quantile					
2020	10	0.00706183											
2020	11	0.00527056											
2020	12	0.00352474											
2021	1	0.00312472											
2021	2	0.00255267											
2021	3	0.00238234	0.003065	0.00298528	0.00417254	0.00344595	0.00263893	0.00215377					
2021	4		0.00324344	0.00312671	0.00485919	0.00373853	0.00262476	0.00205387					
2021	5		0.00350513	0.0033287	0.00562752	0.00416889	0.00264885	0.00193388					
2021	6		0.00397676	0.00369696	0.00709805	0.00477564	0.0028565	0.00196367					
2021	7		0.00443216	0.00405111	0.00857006	0.0053718	0.00303641	0.00196857					
2021	8		0.004943	0.00443023	0.0097767	0.00607413	0.00319398	0.00207006					
2021	9		0.00536759	0.00471141	0.01124957	0.00664865	0.00324932	0.00203391					
2021	10		0.00587484	0.00501675	0.01258617	0.00721264	0.00344748	0.00209258					
2021	11		0.00610217	0.00507558	0.01335531	0.00773185	0.00354367	0.00204833					
2021	12		0.0063895	0.00538521	0.01385043	0.00809945	0.00363405	0.00204249					

Figure 35: Median, Mean, and Quantiles of simulated PD-median

(vii) PDmedian_Mean&Multiplies_12mth.xlsx

Additional results pertaining to portfolio median PD simulations are also available to users. Columns E to I of "*PDmedian_Mean&Multiplies_12mth.xlsx*" as seen in Figure 36 provide the probabilities for the portfolio's stressed PD at time t+1, t+2, etc. to exceed the portfolio PD at the testing time point, t. The fact that 90%, 52.9%, and 27.7%, etc. of the simulated stressed portfolio PDs in December 2021 (last row) under the adverse scenario are higher than the portfolio median PD in February 2021 (testing time point) is in line with expectations.

Since v3.3.3, we add a new function that caters for user-specified aggregation method. Therefore, some additional results figures, named as PD(aggregation_method) _Mean&Multiplies_12mth.xlsx", may be generated.



it of PD m	easure: Unit.													
ease cite t	ne BuDA result	ts in the follo	wing way:											
uan, JC., V	V. Miao, J.A. C	han-Lau, and	The Credit Re	search Initiat	ive Team of t	ne National U	niversity of Si	ngapore, 2021	BuDA: A B	ottom-Up De	ault Analysis	Framework, v	ersion 3.3.0.	
ear	Month	CRI	Mean	1-time proba	2-time proba	3-time proba	4-time proba	5-time proba	oility		,			
2020	7	0.00633383												
2020	8	0.00613829												
2020	9	0.00686662												
2020	10	0.00706183												
2020	11	0.00527056												
2020	12	0.00352474												
2021	1	0.00312472												
2021	2	0.00255267												
2021	3	0.00238234	0.003065	0.802	0.004	0	0	0						
2021	4		0.00324344	0.782	0.036	0.002	0	0						
2021	5		0.00350513	0.78	0.094	0.008	0.001	0						
2021	6		0.00397676	0.829	0.191	0.033	0.004	0.001						
2021	7		0.00443216	0.849	0.281	0.07	0.019	0.004						
2021	8		0.004943	0.891	0.379	0.135	0.04	0.009						
2021	9		0.00536759	0.872	0.432	0.167	0.07	0.029						
2021	10		0.00587484	0.892	0.491	0.219	0.096	0.046						
2021	11		0.00610217	0.89	0.494	0.259	0.123	0.06						
2021	12		0.0063895	0.9	0.529	0.277	0.142	0.07						

Figure 36:PDmedian_Mean&Multiplies_12mth.xlsx

(viii) RiskFactor_analysis folder

This folder provides details of the shock to the PD predictors based on the specified stress scenario. The image file in the folder illustrates the simulated paths of the stressed PD predictors. Those Excel files provide the historical data of the PD predictors along with their stressed values.

United States of America Energy.png	18/5/2021 5:54 AM	PNG File
ы United States of America Energy_Scenari	18/5/2021 5:54 AM	Microsoft Excel C
🔊 United States of America Energy_Scenari	18/5/2021 5:54 AM	Microsoft Excel C
🔊 United States of America Energy_Scenari	18/5/2021 5:54 AM	Microsoft Excel C

Figure 37: Risk Factor Analysis Folder

Figure 38 below shows how DTD responds under the specified scenarios. The blue line represents the stressed PD under the adverse scenario, suggesting that DTD is expected to decline which will in turn cause an increase in the stressed PD value. In contrast, DTD increases significantly under the improving scenario (green line) and increases, though relatively less, if the current operating climate continues (red line). The raw data to generate this plot can be found in United States of America Energy_ Scenario 1, _ Scenario 2, and _ Scenario 3.csv.





Figure 38: Simulated Paths of the Stressed Predictor using DTD as an example

(ix) Sensitivity_analysis folder

BuDA also has an optional function, "Output Cross-effect and Individual Variable Contribution", which can be selected in the advance settings in Step 3. If this option is selected, an additional "Sensitivity_Analysis" folder will be provided. This folder contains the files representing the contribution of the stressed variables to the stressed portfolio PD.

The main result is illustrated as an image file for each scenario. Figure 39 shows the contribution of WTI Crude spot price, US GDP growth rate, and cross-effect of these two variables to the stressed portfolio PD under the adverse scenario. Table 2 below provides additional notations for understanding this plot.

Notation	Description
PD _{GDP}	The stressed portfolio PD that is estimated when only US GDP has moved as specified,
	while WTI Crude spot price stays flat
PD _{WTI}	The stressed portfolio PD that is estimated when only WTI Crude spot price has
	changed as specified, and US GDP remains constant
PD _{flat}	The portfolio PD when both variables remain constant in the years to come
PD _{all}	The original stressed portfolio PD when both variables have moved as specified in the
	testing scenario

As we have two stress variables, we assume that there are three partial contributions to the change in the stress PD for each scenario. These contributions are derived from WTI Crude spot price, US GDP growth rate, and interaction between these two variables. Define the total contribution of these three terms as $PD_{all} - PD_{flat}$. The partial contribution of WTI Crude to the stressed portfolio PD can be seen as $PD_{WTI} - PD_{flat}$, while that of US GDP will then be $PD_{GDP} - PD_{flat}$. The



contribution of the cross-effect is the difference between the sum of partial contributions of WTI Crude and US GDP and the total contribution, i.e. $(PD_{GDP} + PD_{WTI} - 2PD_{flat}) - (PD_{all} - PD_{flat})$.

The partial contribution of WTI Crude is the blue line in Figure 38. As the blue line is much greater than zero, it means that the change in WTI Crude in the adverse scenario significantly raises the stressed portfolio PD. The sum of partial contributions of WTI Crude and US GDP is displayed by the red dotted line. As the red dotted line is above the blue line but not substantially, it implies that the increase in PD for the adverse scenario is mainly contributed by WTI Crude followed by US GDP. The cross-effect, the black line, appears to be mildly negative.



Figure 39: Cross-effect and Individual Variable Contribution

The remaining files in the "Sensitivity_Analysis" folder have similar descriptions as those of the main results. However, these files show the effect of movement in only one variable *ceteris paribus*. As there are three scenarios and two stressed variables in this example, the sensitivity analysis will provide six different scenario plots in total.



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