Musings on Long Run Climate Risk Modelling for Banks

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Scott D. Aguais, Ph.D.
Managing Director, Z-Risk Engine
saguais@Z-RiskEngine.com

Notes:

- This ‘Climate Musings’ Draft discussion was presented at the ESG Europe conference on April 27, 2022:
  - We summarize key aspects of current research on developing climate risk stress testing approaches for quantifying ‘transition risk’ for banks (physical risks to be added later)
  - The Z-Risk Engine solution is a multi-factor solution which assesses PIT/TTC ratings using region and industry sector systematic credit risk cycles
  - Our plan is to develop ‘Climate Z’ systematic risk factors to add long-run climate risk to the ZRE short-run credit cycle framework
  - ZRE is used currently to support more accurate IFRS9 and Stress Test projections for corporate and commercial bank portfolios
  - The expanded ZRE Climate Z module will be designed to support internal bank, portfolio-wide climate stress tests using a variety of external, regulatory and internal scenarios applied to bank portfolios leveraging bank’s IRB credit models
  - The next step will be to publish a more detailed methodology paper for the proposed approach

Presentation Overview

- ## Climate Change Risk Modelling Overview:
  - Climate is Complicated
  - Uncertainty & Downside Risks
  - ‘Paradigm Shift’ is Required
  - Climate Risk Horizons Vary
  - Structural Change – sunrise industries vs sunset industries

- ## A General Climate Risk Modelling Framework:
  - Unexpected Carbon Policy (Tax/Price) Shocks Drives Transition Risks
  - Sector Differentiation by Carbon Footprint
  - Integrating Technology/Demand Elasticity/Consumer Preferences Etc Using a ‘Structured Mixed Model

- ## Adapting PIT/TTC Ratings to Model Climate Credit Risks for Banks:
  - PIT/TTC Credit Risk Approach Review - adding predictions of systematic factors to individual ratings
  - Integrating Systematic Climate Zs
  - Adapting the Z-Risk Engine Platform

- ## Appendices, Bibliography, Our Credit Risk Publications Bibliography

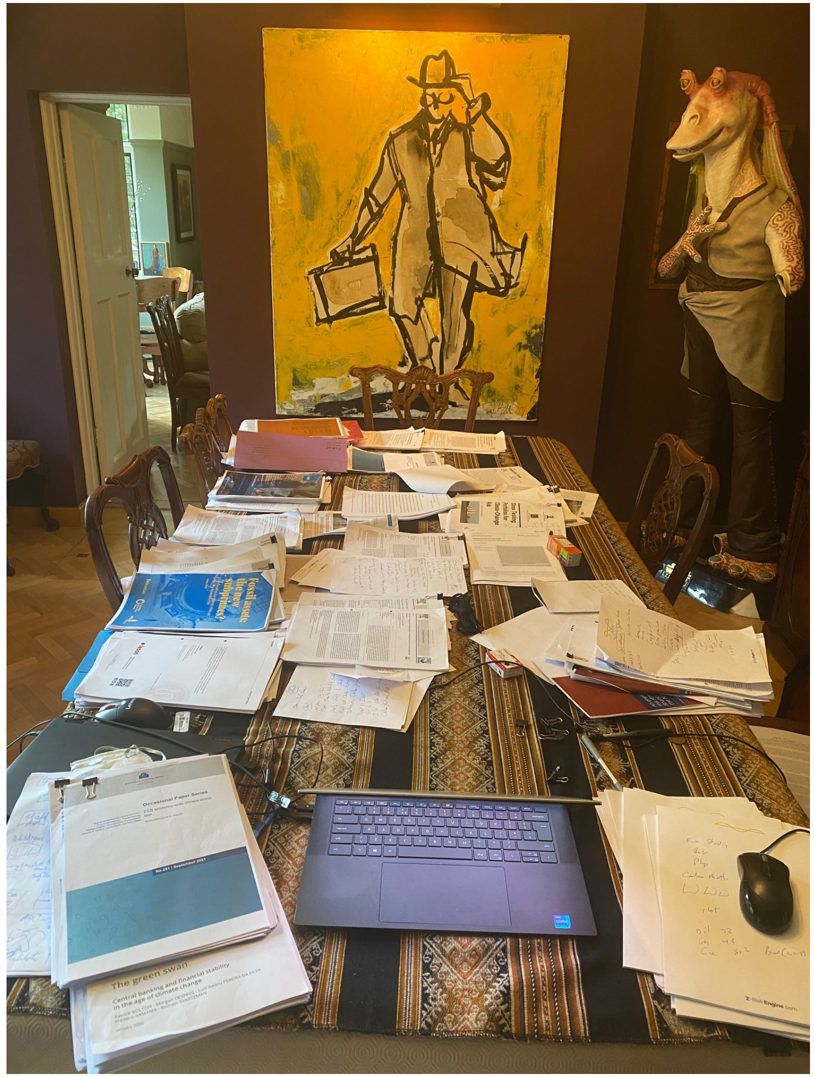
Key ‘Musing’ Presentation Points

- **Focus on Transition Risk** - credit risk metric for corporate/commercial firms
- Physical Climate Risk may be easier to incorporate in company-specific risk ratings (detailed knowledge of firm plus insurance helps some)
- Modeling long-run climate-driven credit risks requires models with **multiple systematic factors**
- **Unexpected carbon policy shocks** drives future LR climate credit risks - short-run economic shocks drives large credit losses (see ‘Great Recession’)
- Climate risk modelling is in it’s **INFANCY** – historical data is extremely limited
- ‘Jury’ is out on whether climate driven credit risks in the future are ‘**bigger or smaller than a breadbox**’
- Modelling climate credit risks can be integrated into **PIT/TTC ratings frameworks** that utilize **systematic risk factors**

Climate Change/Risk – Global Issue – Complex Topic – V Early Days

- **'Climate Change is Complicated ('CCIC'):**
  - IPCC – PARIS 2015 – BIS – ECB – EBA – BoE – ESG – TCFD – UNFCCC – CO2 – GHG – LtG – ACPR – BdF – NiGEM
  - NGFS – GtCO2e/year – CDR – Scope 1 2 3 – NACE – COP21 – US$/tCO2
  - AnaCredit – Four Twenty Seven Data – Orbis – Urgentum
  - WIOD – ExioBase – CPRS – CDP – TruCost - LIMITS
  - 'Sunrise – Sunset' Industries – IAM – CGE – ECM – EMK – EABM
  - 'Paradigm Shift' – 'Stranded Assets' – 'Green Swan'
  - 1 degree 1.5 degrees 2 degrees 2.5 degrees 3 degrees 3.5 degrees….

Scott's 'Climate Research' Dining Room – Jar Jar Binks as a Climate Research Observer



200 Years of 'Carbon Addiction' Requires Substantial Carbon Policy Intervention 'Green Swans' Are Extremely Complex – With Substantial Uncertainty/'Fat Tails'

Climate risks stem from classic market-failure 'writ planetary':

'the aim is to correct [a 200-year] externality using <u>deliberate policy intervention</u> rather than let a more or less evolutionary trajectory guide the transition'.

See Semieniuk et al, (2020), p 5, 'Low-carbon transition risks for finance'.

Bolton et. al., (2020) has characterised climate change as a 'Green Swan':

'our framing of the problem is that climate change represents a <u>green swan</u>, it is a new type of systemic risk that involves interacting, nonlinear, fundamentally unpredictable, environmental, social, economic and geopolitical dynamics….climate risks are not just black swans, i.e.., tail risk events,….climate change represents a colossal and potentially irreversible risk of staggering complexity'.

See P. Bolton et. al., (2020), page 6, 'The Green Swan', (BIS/Banque de France)

Climate 'Fat Tails' Continued…..

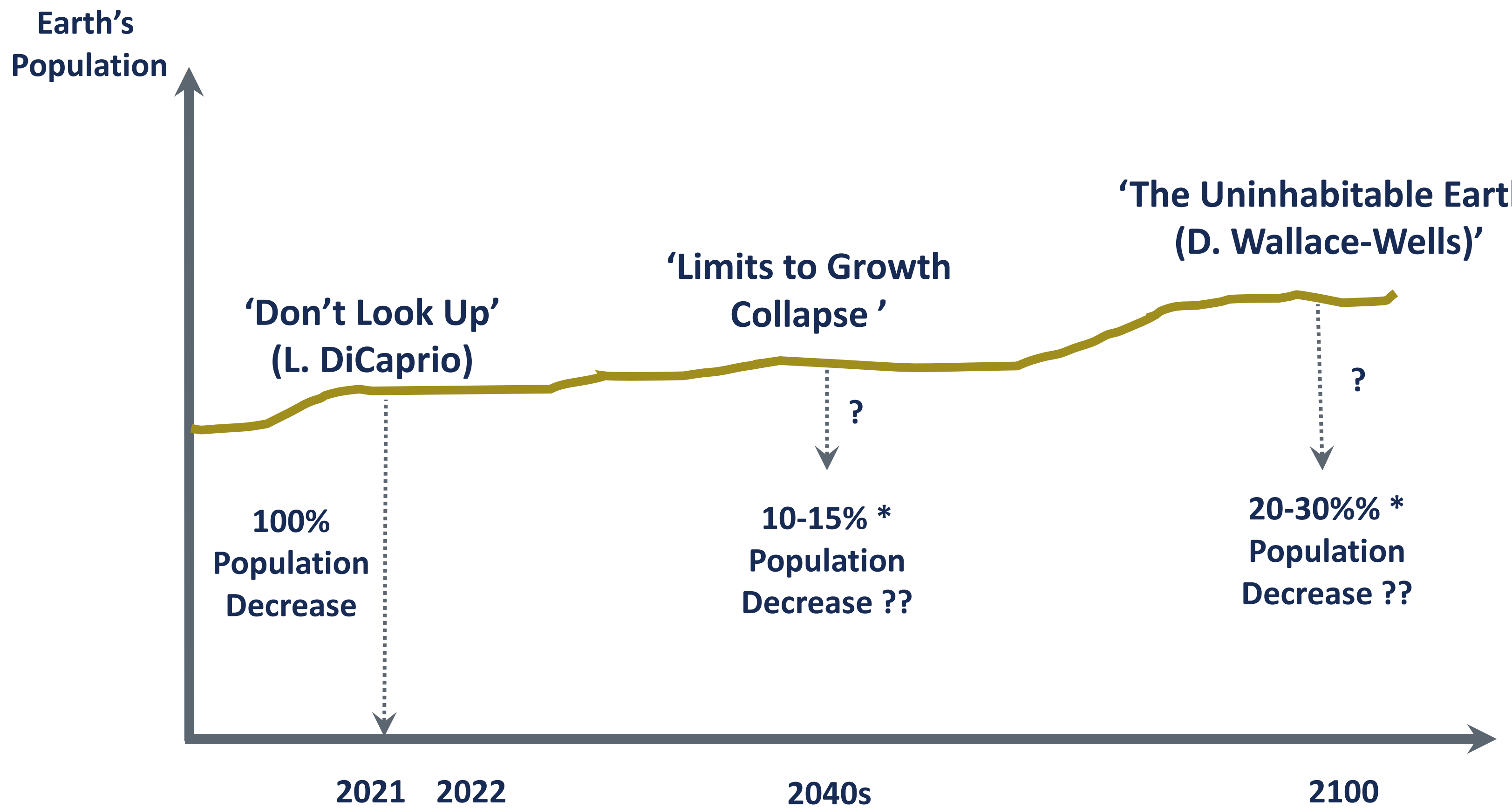
Estimates of Climate 'Fat Tails' from Wagner/Weitzman reach 10% for the possibility of major temperature increases:

'here's what you get: about a 10 percent chance of eventual temperatures exceeding 6C (11F) unless the world acts much more decisively than it has'.

G. Wagner & M Weitzman, 'Climate Shock', page 53.

Climate Change Uncertainty is Massive – How Bad is the ‘Downside Risk’

Climate Change Risk ‘One Way Street’

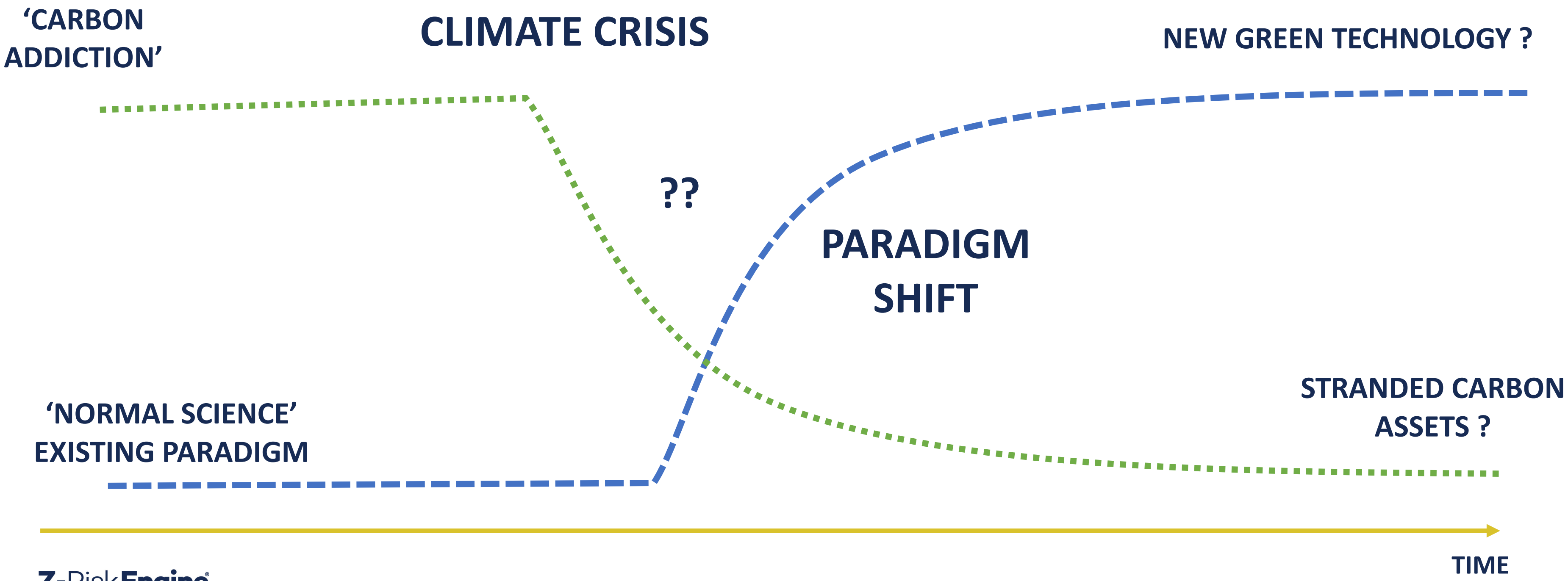


* ‘100%Guesstimates’

Thomas Kuhn, 'The Structure of Scientific Revolutions' (1962)
Science Doesn't Evolve in a Continuous Cycle of Smaller Improvements

'Epistemological Break'

- *'Scientific progress requires radical breaks from previous ideological conceptions'*
- Forward not Backward Looking
- Minimal Historical Data for model estimation
- 'Structured mixed model'
- Vey long run horizons to 2100 ?



Climate Risk Stakeholder/Research Map

REGULATORS	MISC ORGANISATIONS	ACADEMICS		ASSET MANAGEMENT	
		MERTON DD	BOND VAL	EQUITIES	BONDS

REGULATORS

STRESS TESTING

(1) ECB

(2) BANC de FRANCE

(3) DUTCH

(4) BoE

Vermuelen et al DNB (2019)
Vermuelen et al DNB (2021)

Baldassarri et al S&P (2020)

Allen et al BdF (2020)

Carbone et al ECB (2020)

Krogstrup/Oman IMF, IMF (2019)

Jung et al FRBNY (2021)

MISC ORGANISATIONS

STRESS TESTING

(1) NGFS

(2) BIS

(3) I4CE

(4) CEP

ACADEMICS

MERTON DD

Capasso et al (2020)

Reinders et al (2020)

Monasterolo et al (2019)

Battiston et al (2021)

Cahan-Fouret et al (2021)
Capital Stranding Multipliers

BOND VAL

Agliardi & Agliardi (2021)

ASSET MANAGEMENT

EQUITIES

Battiston et al (2017)

Bouchet et al (2020)

Monasterolo (2020)

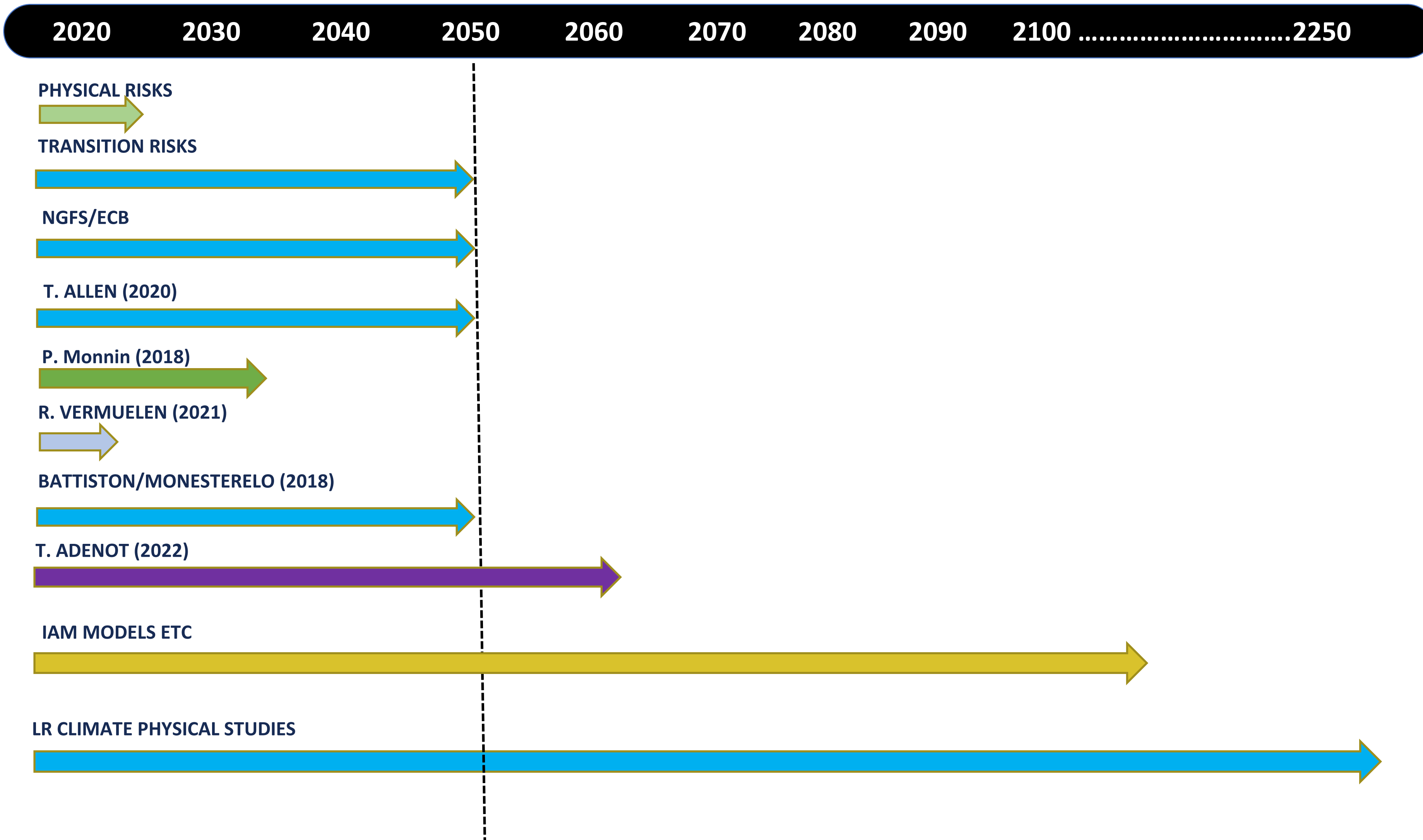
Bolton et al (2021)
Carbon Risk Premiums

BONDS

Capasso et al (2021)

Battiston et al (2019)

Climate Risk Modelling Horizons Vary Across the Research
2100 Probably Preferred To Get Beyond 'Net Zero'



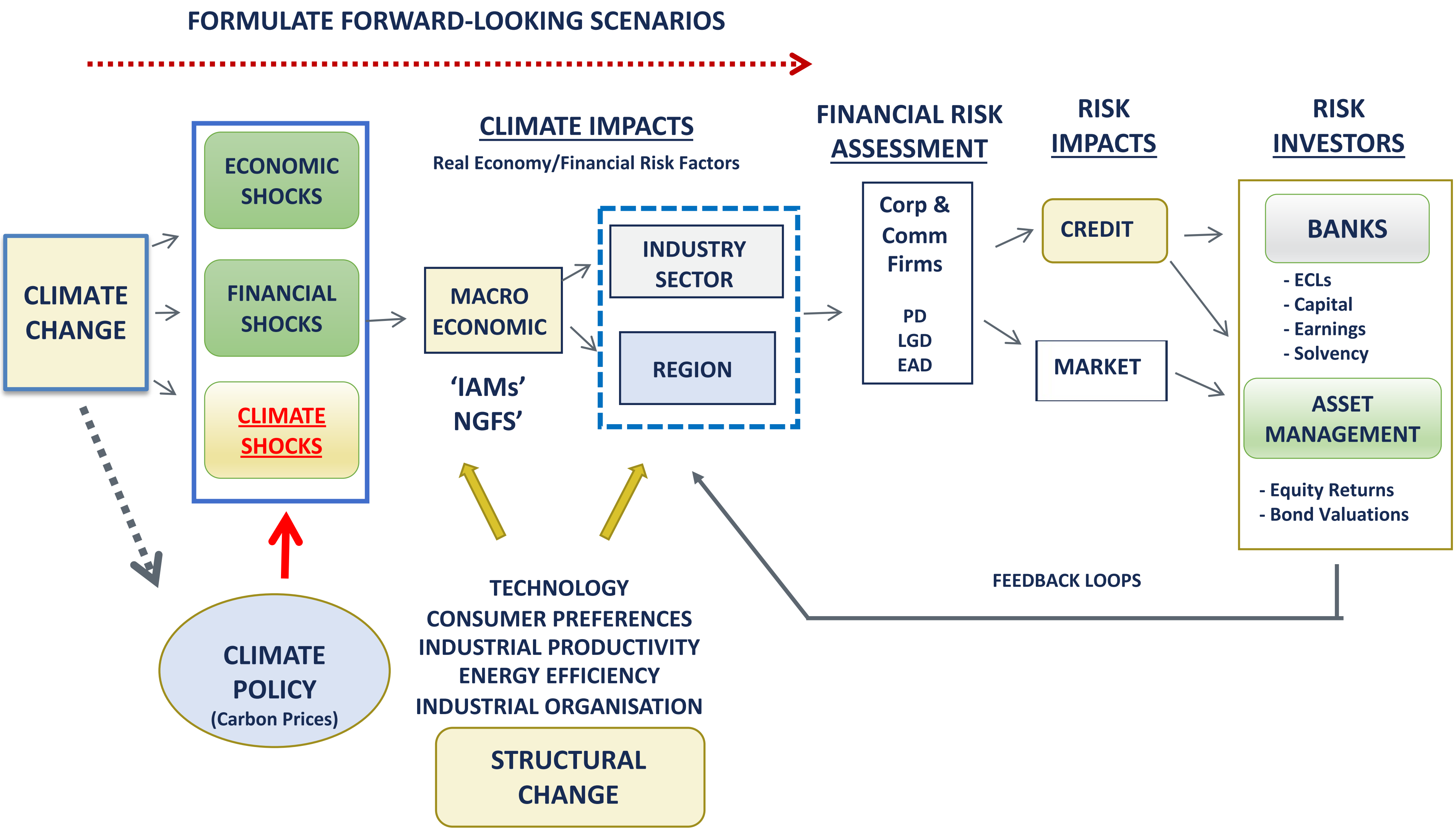
200 Years of ‘Wrong-Way Carbon’ Structural Change Suggests Different Structural Change is a Key Part of Modelling Climate Risk Going Forward

- Key Paper:
  - *G. Semieniuk et al, (2020) ‘Low-carbon transition risks for finance’*
  - Low-carbon transition ‘entails large-scale’ structural change – asset revaluation shocks, debt default, and the creation of ‘bubbles’ in rising ‘sunrise industries’
  - Rapid, large-scale change (real economy) could substantially impact financial side of the economy
  - Traditional financial ‘bubbles/manias’ (1929 Crash, radio, airplanes, electricity etc.) usually in sunrise industries
  - Aggressive low-carbon policy shocks to ‘sunset industries’ would be a new risk phenomenon
  - Substantial stranding of carbon assets, carbon capital equipment can create substantial ‘sunset’ financial risks

- Other key academic papers:
  - *T. Ciarli & M. Savona, (2019) ‘Modelling the Evolution of Structure and Climate Change: A Review’*
  - Review of various developing models for Climate Risk and interrelationships between the environment & the economy

- Projected Carbon Asset Stranding (general estimates):
  - **33% of oil reserves**
  - **50% of natural gas reserves**
  - **80% of coal reserves**

Modelling Climate Risk – Stress Tests With Forward-Looking Scenarios – Volatile Climate Change POLICY Produces Unexpected Shocks



Modelling Climate Credit Risks – Key Carbon Building Blocks

GDP/NGFS SCENARIOS → CARBON PRICES (taxes) → CARBON INTENSTY GHG/CO2/TURNOVER

Example of Industry Sector Segmentation
(Alphabetic not arrayed by Emissions)

- Aerospace & Defence
- Banking
- Chemicals & Plastic Products
- Construction
- Consumer Products
- Oil & Gas
- Finance, Real Estate & Insurance
- Hotels & Leisure
- Basic Industries
- Machinery & Equipment
- Media
- Medical
- Steel & Metal Products
- Mining
- Motor Vehicle & Parts
- Retail & Wholesale Trade
- Business & Consumer Services
- Technology
- Transportation
- Utilities

FINANCIAL RISK ASSESSMENT

Corp & Comm Firms

PD
LGD
EAD

↑

↔ INPUT-OUTPUT PRODUCTION RELATIONSHIPS

↔ CARBON EMISSIONS SCOPE 1 2 3

↔ DEMAND ELASTICITY (COST PASS-THROUGH)

Summarizing Examples from Climate Modelling Literature

- **Examples of climate 'shocks' in literature:**
  - **2015 Paris Agreement as 'policy shock'**
  - **100% fossil fuel Equity value drop**
  - **Bond value shocks – difference between adverse and very adverse climate scenarios**
  - **Various deterministic carbon price shocks**

- Price Elasticity of Demand – Influences Ability to Pass-Through Climate Costs (Baldassarri et al (2020) industry examples):
  - Highly inelastic – food, staples, household & personal products, utilities
  - Inelastic – energy, capital good, retailing
  - Elastic – transportation, professional services, apparel
  - Highly elastic – consumer services, media & entertainment, automobiles

- Various Modelling Metrics:
  - 'Transition Vulnerability Factor' – TVF – 'Climate Beta' (Cost increase sensitivity)
  - Carbon Footprint – CO_2 and GHG emission data by sector, firm etc. – absolute measure
  - Carbon Price Elasticity – Expressed in % Response (Delta)
  - Carbon Intensity – CO_2/GHG emissions/Firm Turnover – relative measure

Summarizing Climate/Credit Risk Modelling Literature - 'Infancy'

CLIMATE RISK MODELLING 'BUILDING BLOCKS'

MACRO SCENARIOS	CARBON PRICE SCENARIOS	DEFINITION OF POLICY SHOCKS	EMISSION DATA	REGION/SECTOR DETAILS	DEMAND ELASTICITY I/O
• Multiple IAMs • NGFS Growing as a Standard	• Aggregate Global (Weighted) • Some Individual Regions/Countries	• Limited by nature of Uncertainty being large • Heterogeneous • Non-Standardized	• Multiple Sources (7?) • Non-Standardized	• Non-standardized	• Non-Standardized

- Lots **more work** to extend and integrate macro models & **sector/region models**
- Most modelling focused on corporate credit risk uses Merton Model Approach (Default Distance) - 'Homegrown' default distance research on limited firm samples usually less than 1000
- Unexpected Carbon Policy Shocks – Range of Assumptions in their **infancy**
- Short-Run Systematic Credit Cycle Risk (PIT) **NOT Integrated** With Long-Run Systematic Climate Risk

Z-RiskEngine

Extending PIT/TTC Systematic Factors to Predict LR Climate Risk for Corp/Commercial Portfolios

- PIT/TTC Credit Risk Approach is a Solid Foundation - integrates predictions of systematic credit cycle industry/region systematic factors to individual ratings
- Next Step: Integrating Systematic Climate Zs
- Adapting the Z-Risk Engine Platform
- ‘Green RWA’ (www.greenrwa.org) also using this multi-factor credit risk approach we developed over the last 20 years at BarCap, RBS, ZRE for PIT/TTC Ratings for their climate risk modelling - https://www.greenrwa.org/the-cerm
- *Garnier, J., J. Baptiste-Gaudemet & A. Gruz, ‘The Climate Extended Risk Model (CERM)’ April 12, 2022, https://arxiv.org/abs/2103.03275*

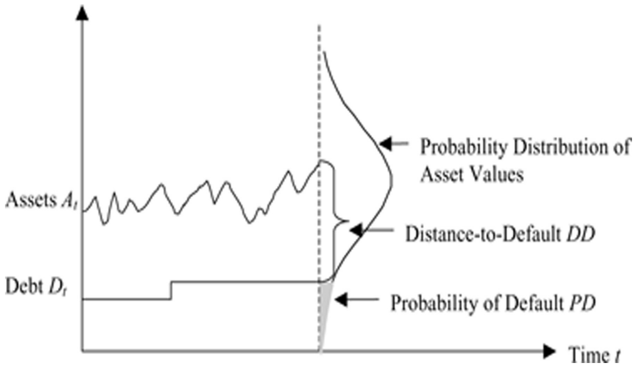
Determinants of Integrated Corporate/Commercial Credit Risks

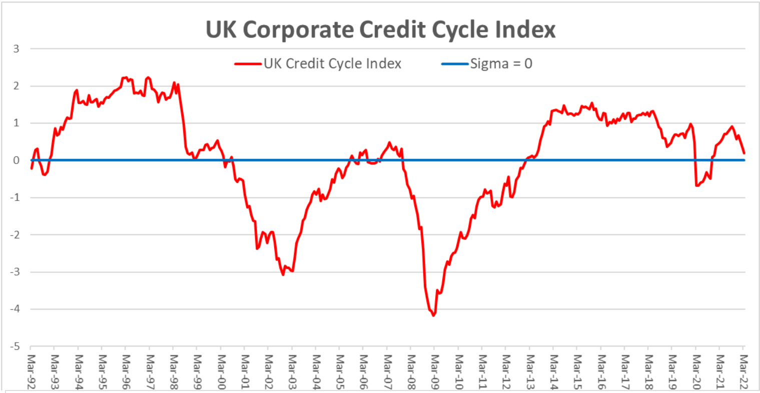
COMPANY CREDIT RISK = **IDIOSYNCRATIC COMPANY-SPECIFIC** + **PIT REGION/SECTOR NEAR-TERM SYSTEMATIC CYCLE RISK** + **LONG-RUN SYSTEMATIC CLIMATE RISK**

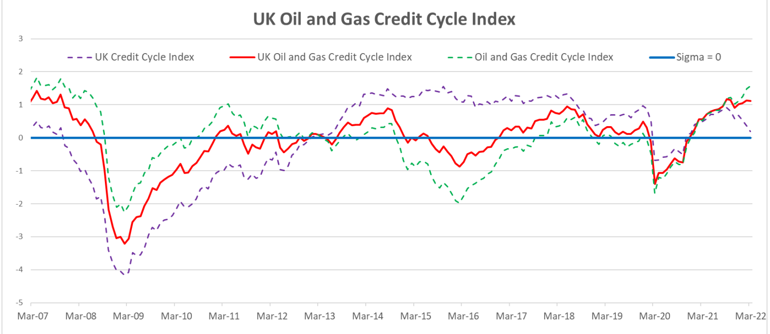
Z Region/Industry Credit Cycles

EXTENSIONS

Company Default Distance Credit Risk Model



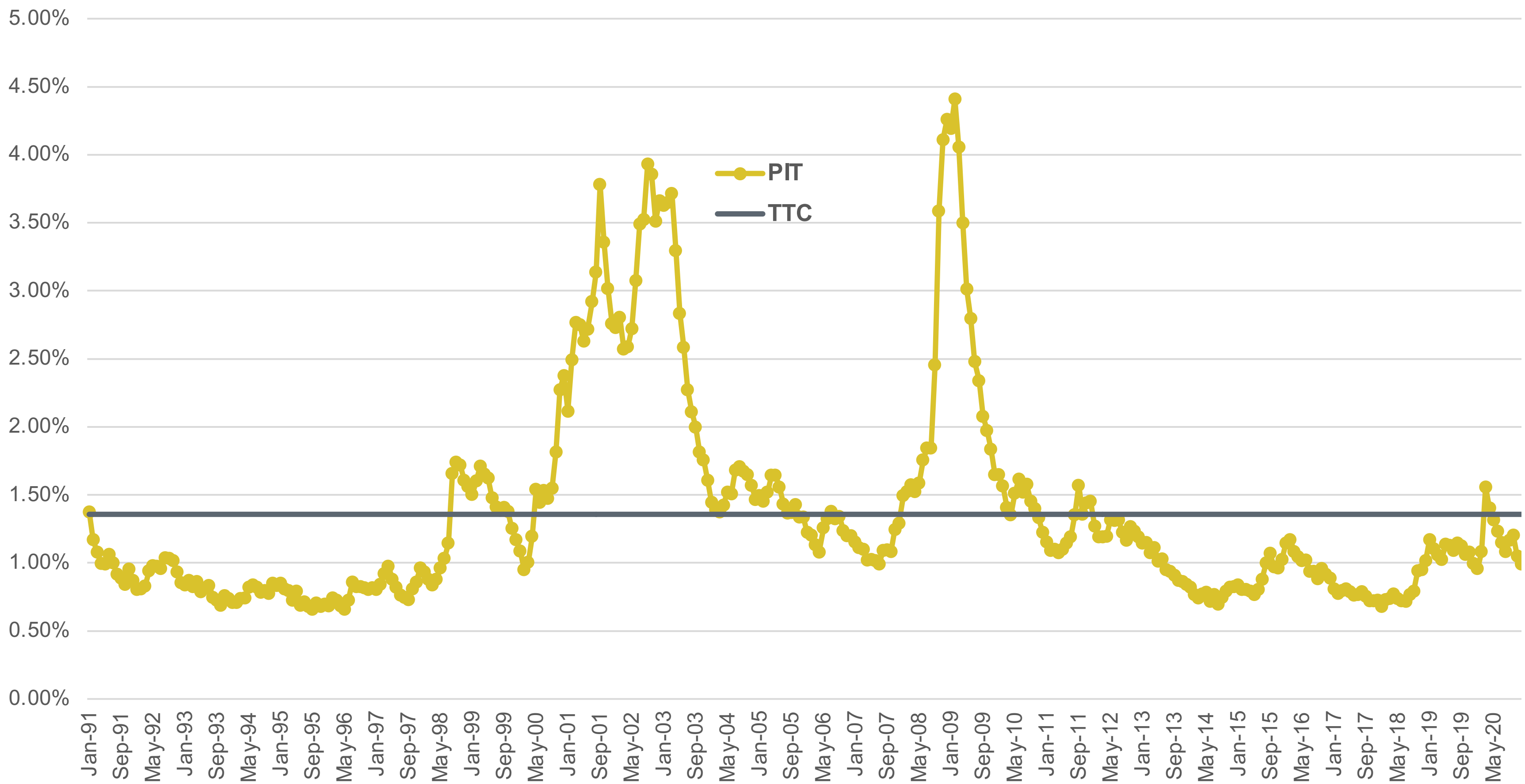




Source: Moody's EDFs & Z-Risk Engine

Z Adjusted NA Corporate PIT PDs Varied 3X From TTC Credit Conditions During Last 2 Recessions

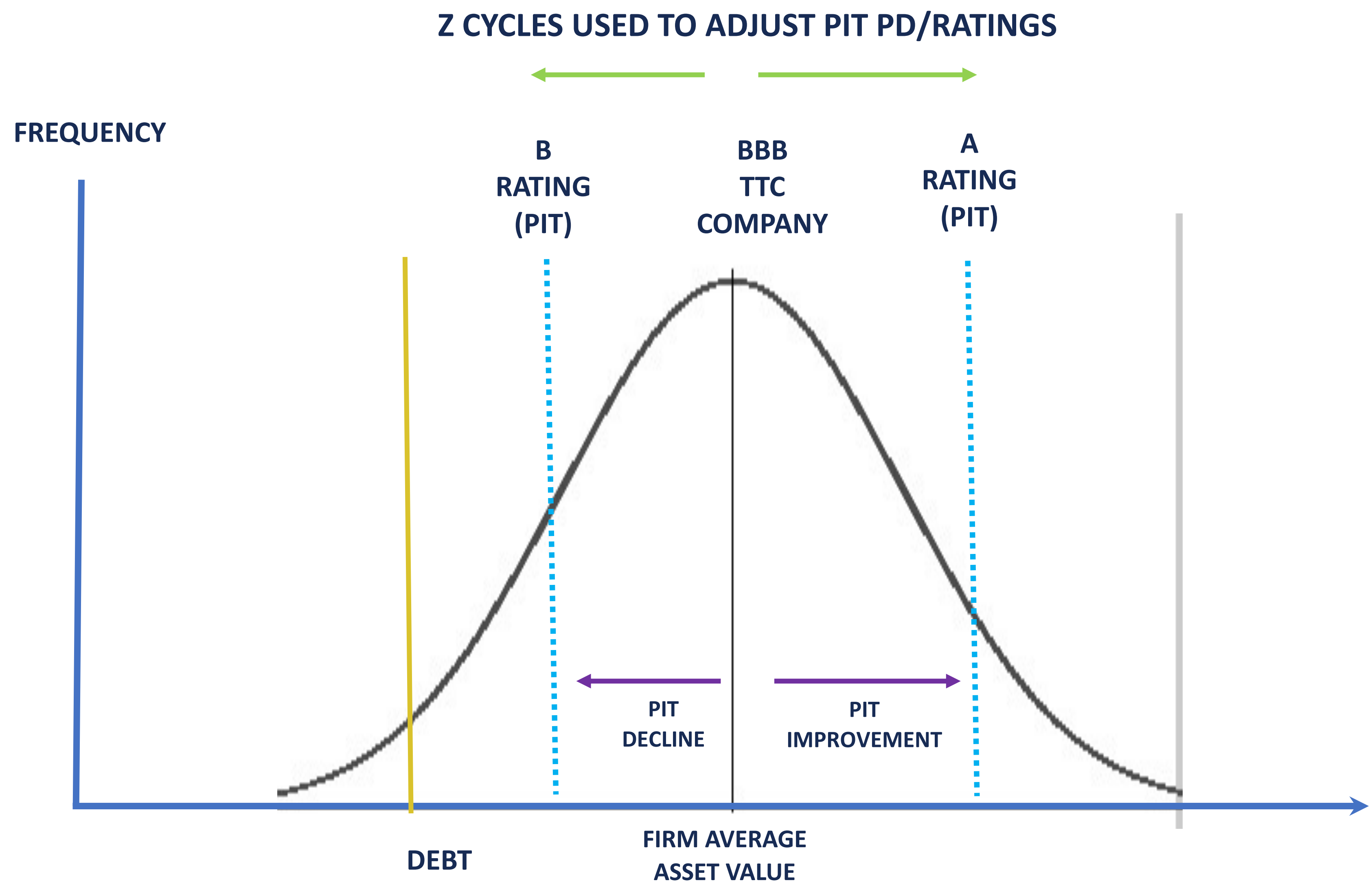
TTC As An Average of PIT Calculated PDs – NA Corporates



Source: Moody's EDFs & Z-Risk Engine Research

Z-Risk Engine

Z Cycle Factors Used to Adjust TTC Starting BBB Rating to Higher & Lower PIT Credit Ratings/PDs At Different Points in the Cycle



European Corporates Credit Cycle Example – Estimated From Moody's EDFs

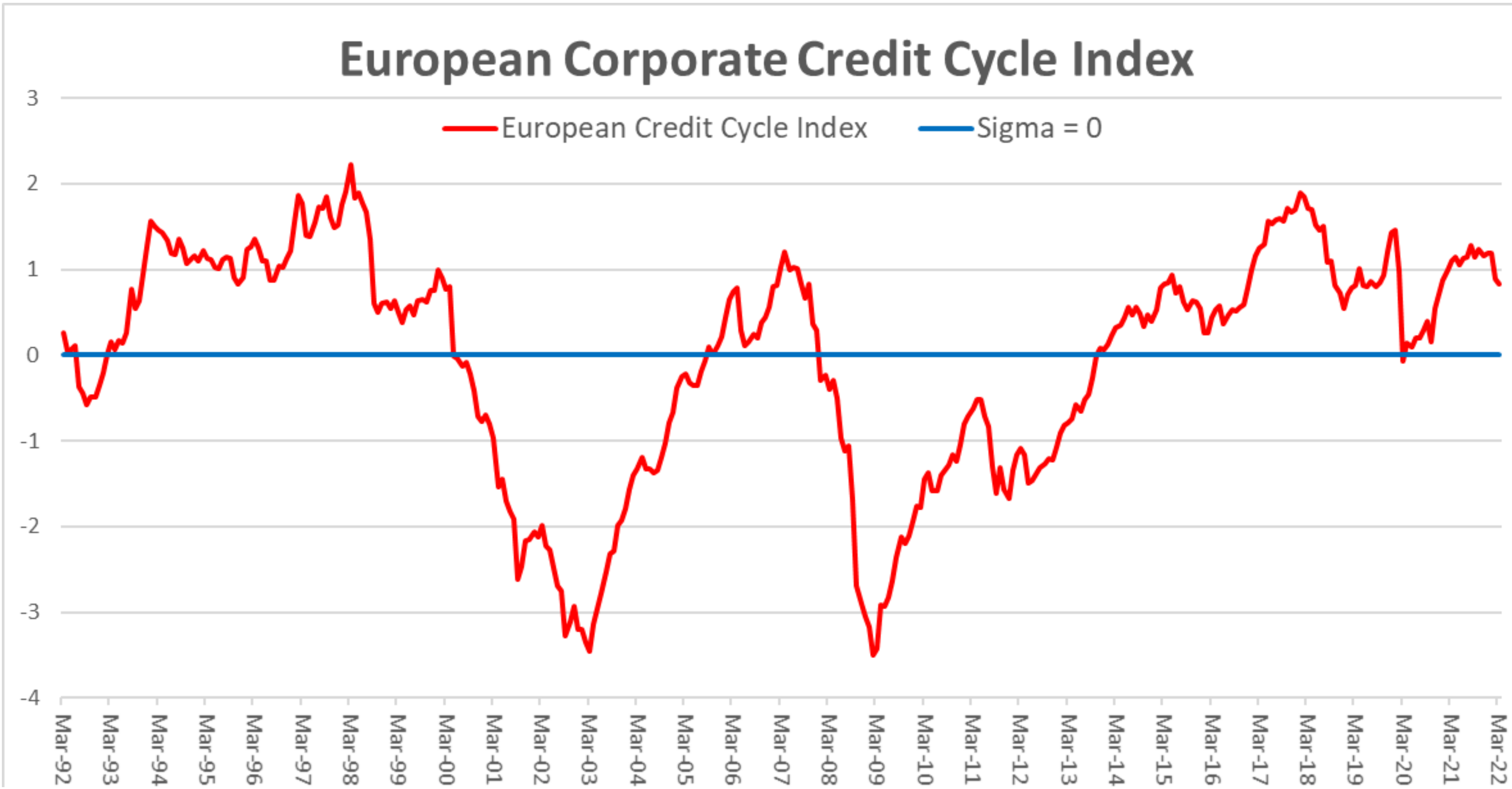
Mean Reversion & Momentum Estimated 1990-2022
Use Credit Cycle Model to Forecast PIT PDs

STD DEV

PIT<TTC

PIT=TTC

PIT>TTC

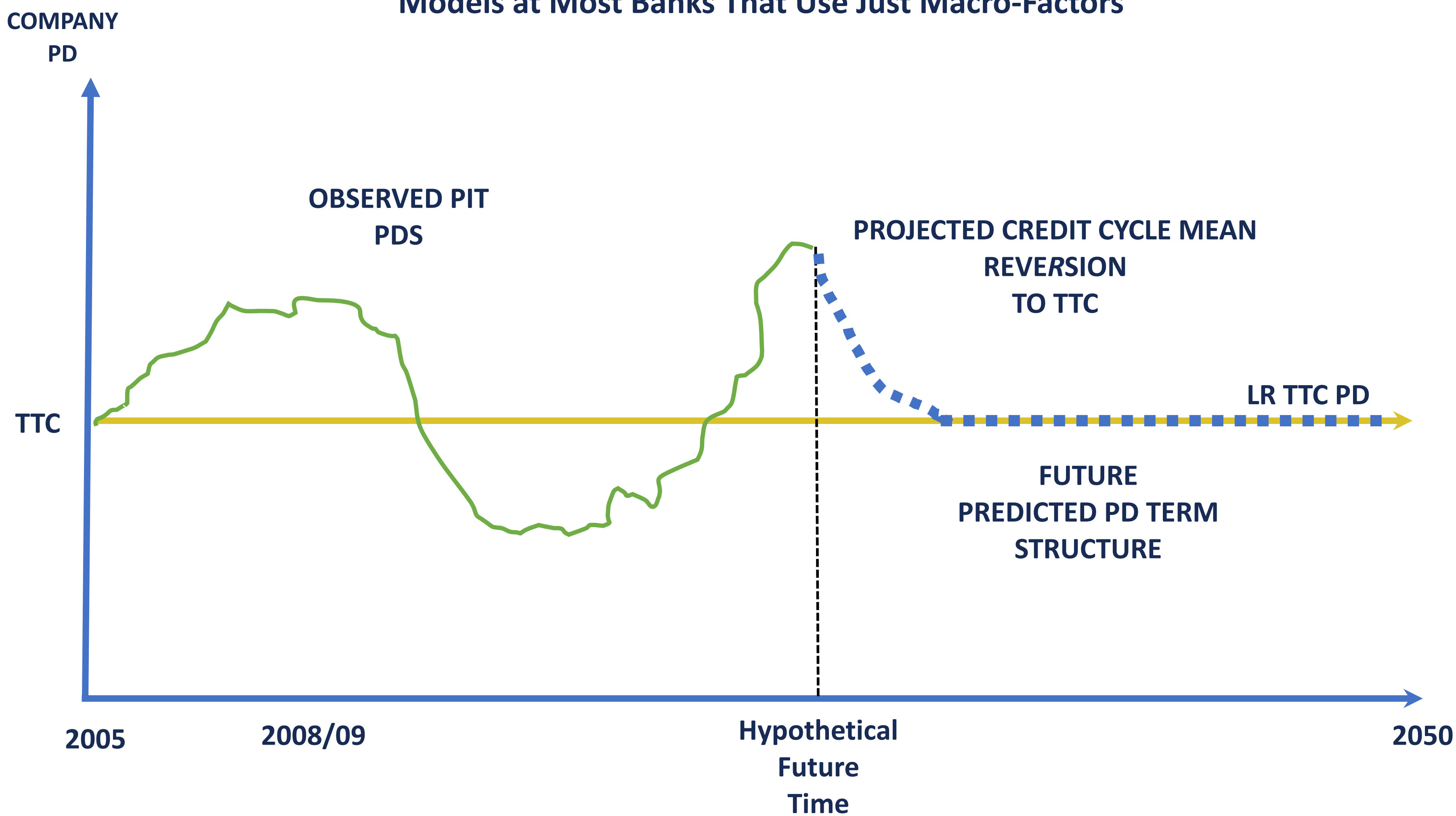


Source: Moody's EDFs & Z-Risk Engine Research

Z-Risk Engine

PIT/TTC Ratings Approach Adds Z Systematic Factors for Accurate PIT Coupled With Mean Reversion to LR TTC PDs for Individual Firms or Portfolios

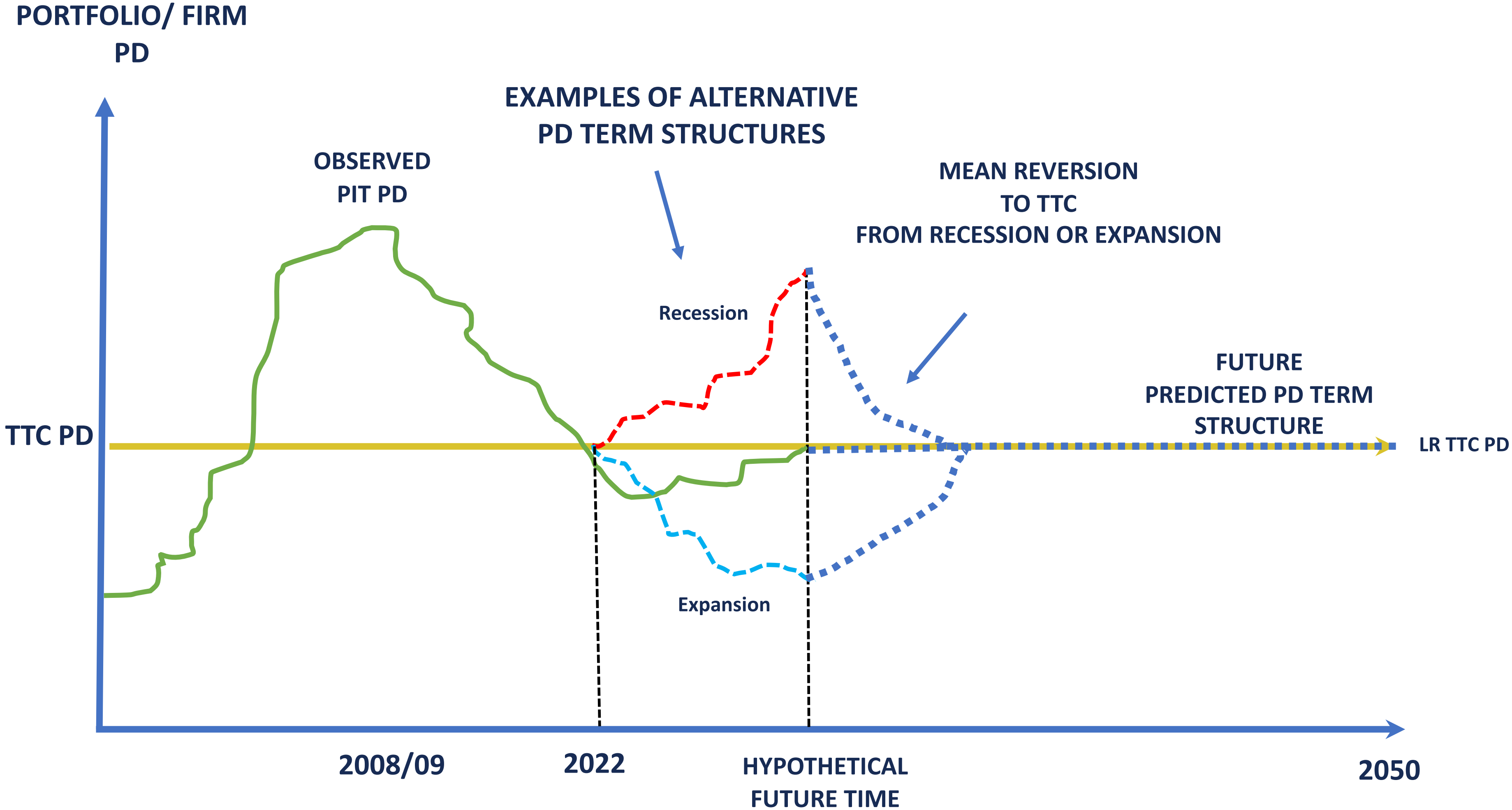
Projecting Portfolio ECLs is Roughly 2X More Accurate Than Current IFRS9 Models at Most Banks That Use Just Macro-Factors



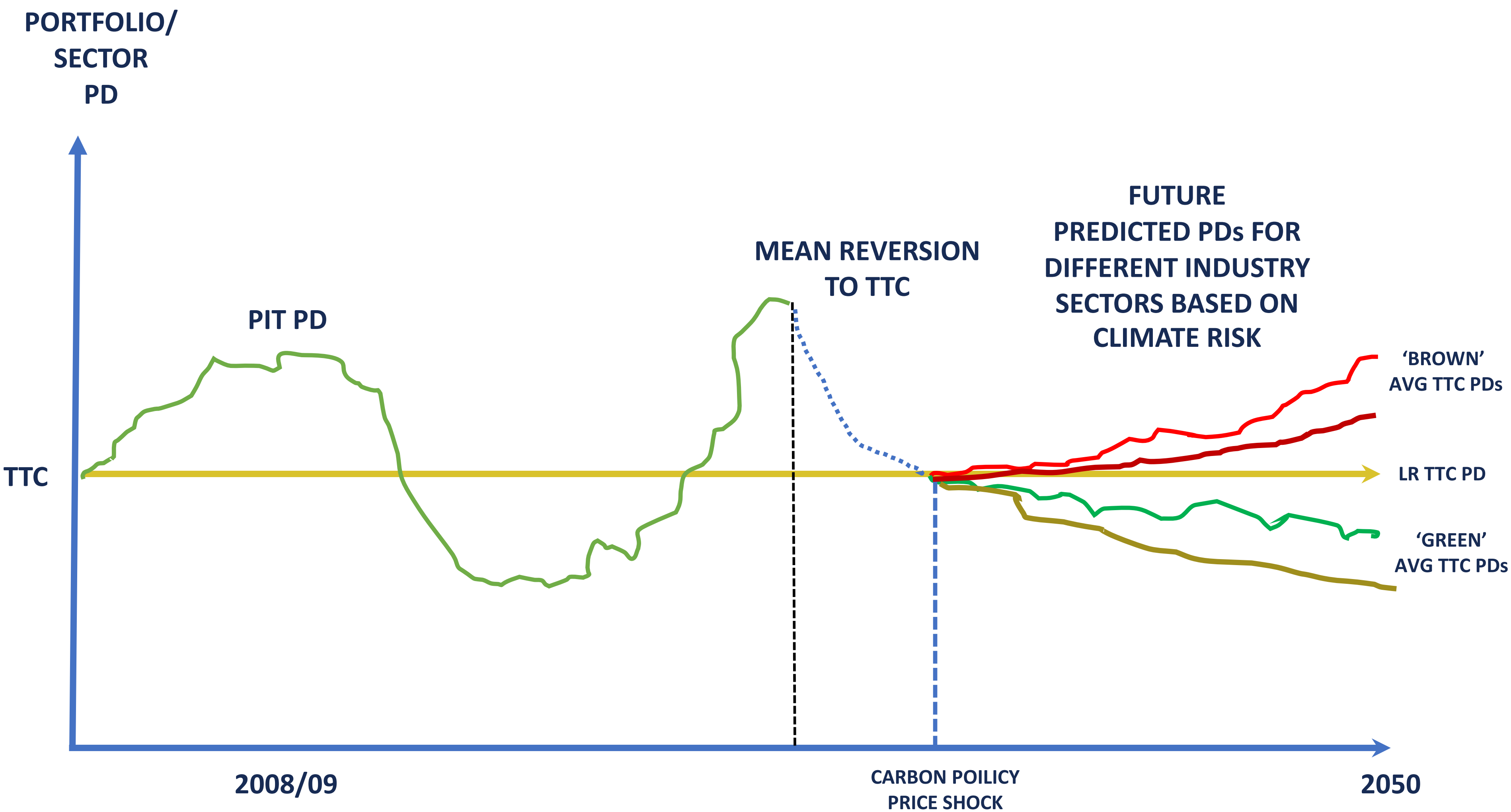
Z-RiskEngine

PIT/TTC Ratings Approach Adds Z Systematic Factors for Accurate PIT Coupled With Mean Reversion to LR TTC PDs for Individual Firms or Portfolios

Industry/Region Factors Projected from Mean Reversion/Momentum Model Used to Predict Future Systematic Cycle Impact on Credit Risk



Carbon Policy Shocks Create Differential Systematic Credit Risk for ‘Brown’ vs ‘Green’ Industries – ‘Brown’ (Negative Cost Shocks) ‘Green’ (Positive Tech Improvements)



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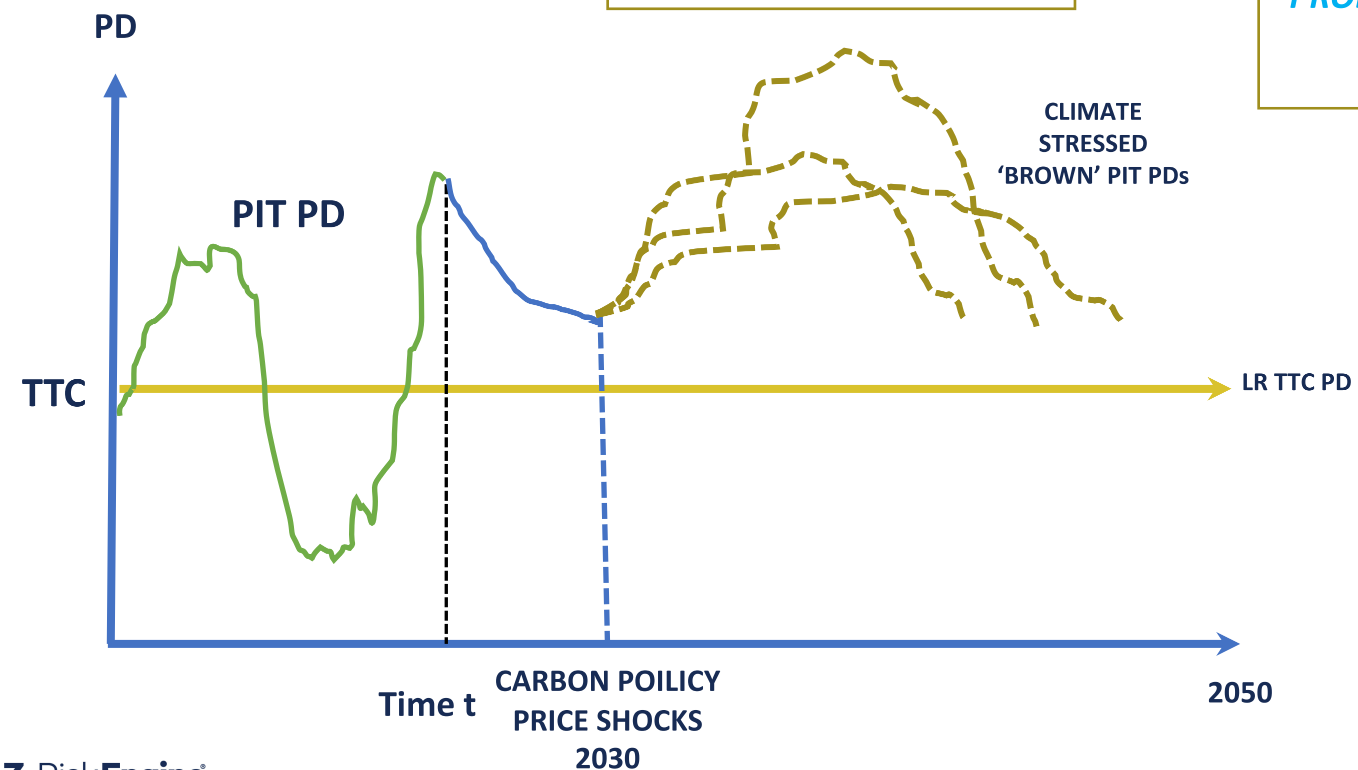
Multiple Carbon Policy Shock Scenarios Can Test Stranded Asset Impacts Or Run ‘Reverse Climate Stress Test’ - What Carbon Price Shocks Mimic ‘Great Recession’

CLIMATE UNCERTAINTY IS LARGE – IT’S NOT CLEATR AT ALL YET WHETHER IT’S ‘BIGGER OR SMALLER THAN A BREADBOX’ – THEREFORE NEED A FLEXIBLE FRAMEWORK

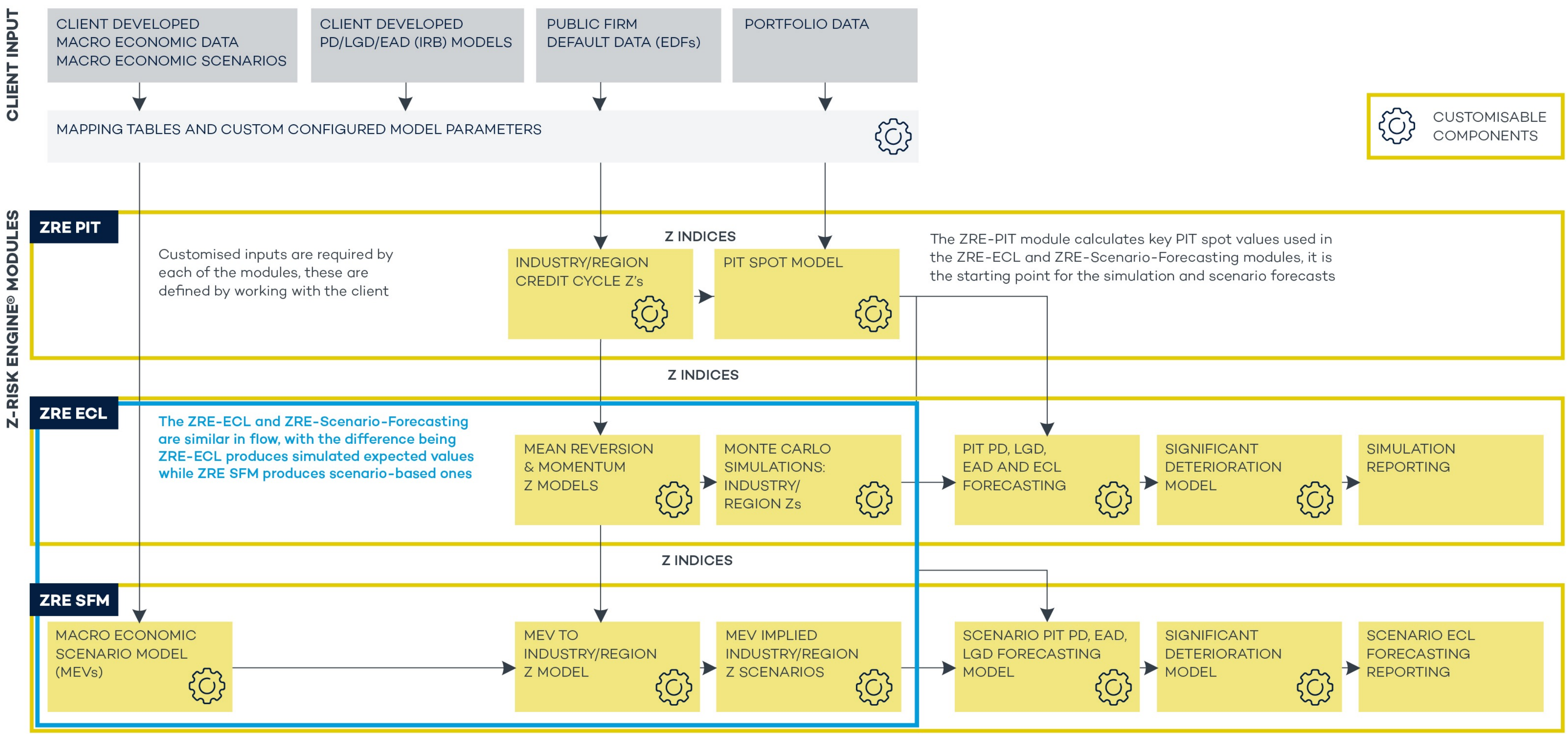
‘RUN VARIOUS CARBON TAX/PRICE SCENARIOS (UNEXPECTED SHOCKS)

‘REVERSE CLIMATE STRESS TEST’ WHAT CARBON PRICE SHOCKS RE-PRODUCE GREAT RECESSION 3X PIT PD INCREASES



ZRE in Production Python Assesses Future ECLs Under PIT & TTC Credit Conditions Using Systematic & Macro Risk Factor Scenarios

ZRE – Solid Risk Factor Foundation to Add Climate Z Factors



Z-Risk Engine Solution Offering Overview

- Centralized automated E2E batch process for corporate & commercial portfolios
- Available as SAS or Python – cloud managed service or source code with perpetual IP license
- Supports IFRS9 & Stress Testing with plan to add Climate Risk in 2022
- Utilizes each bank's own IRB PD, LGD & EAD models as inputs
- Automated architecture provides substantial cost savings compared to most bank internal two-stage IRB-IFRS9 models
- Calibrated & implemented on a custom basis for each bank's specific portfolio & regional/industry risk factors
- Integrated with custom or regulatory stress scenarios
- Calibrated to 37k public-firm EDFs through Z region/sector credit cycle indices

Key ‘Musing’ Presentation Points

- **Focus on Transition Risk** - credit risk metric for corporate/commercial firms
- Modeling long-run climate-driven credit risks requires models with **multiple systematic factors**
- **Unexpected carbon policy shocks** drives climate credit risks
- Climate risk modelling is in it’s **INFANCY**
- ‘Jury’ is out on whether climate driven credit risks in the future are ‘**bigger or smaller than a breadbox**’
- Modelling climate credit risks can be integrated into **PIT/TTC ratings frameworks** that utilize systematic risk factors
- Need flexible, multi-factor approach to assess the substantial climate uncertainty that currently exists

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Appendix: Climate Risk Modelling Summary DRAFT Notes

	ECB	Baldassarri et al (2020)
APPROACH	• Credit Risk • Top-Down & Bottom-Up • Physical (primary) & Transition Risk • 4 mil firms assessed • Uses NGFS Scenarios • Emissions for Scope 1, 2 & 3 • 30-year horizon primarily • Derives firm and sector specific PDs	• Credit Risk • 3 key carbon price scenarios • 30-Year Horizon to 2050 • S&P Merton PD Model (PDMS) DD • 'Carbon Price Risk Premium' for Scope 1 & Scope 2 • Carbon price scenarios impact firm costs with various price elasticity assumptions sector on possible cost pass-through
SCOPE/DATA	• 1600 Euro Banks included • Multiple public & private data sets used • Probably most extensive top-down & granular 4 mil firms climate stress conducted to-date • Some data sources: Urgentem scope 1-3 methodology • Four Twenty Seven – for physical & specific location risk	• Emissions data source: TruCost • 'Carbon Intensity': Carbon Emissions per $ firm revenue • 739 firms with $1bil used for emissions data aggregated to sector • Fast Transition 7X carbon prices to 2030 at $120 in OECD
IMPACTS	• 'High risk' corp portfolios see roughly 30% rise in average PDs • 'Low-Risk' firms see smaller PD increases	• Aggregate public company PDs rise across the board • Utilities, martials, energy and consumer staples sectors present the highest default rates

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Appendix: Climate Modelling Summary DRAFT Notes

	Dutch National Bank	Banc de France
APPROACH	• Vermuelen et al (2019, 2021) • Top-down stress test + sector details • Carbon price + technology shocks by sector • 5-Year Horizon • Derive 'TVF' – Transition Vulnerability Factor – Beta Scale Factor • Credit Risk + Market Risk • Equity return drops trigger credit rating notch downgrades	• Credit risk – stress test • IAM/NGFS/NiGEM/Sector/Firm Rating Model • 2020-2050 horizon • Carbon prices shocks 2030/2035 • Sector model uses 'production networks' and I/O model • Static multi-country, multi-sector General Equilibrium
SCOPE/DATA	• Aggregate Dutch banking system • 80 Banks, Insurers + Pension Funds • EXIOBase Emissions + I/O VA Data • 56 Industry Sectors	• About 15 key macro-economic variables • 56 Industry Sectors • France/Rest oif EU/US/Rest of World
IMPACTS	• Up to 11% portfolio value drop • Up to 4.3% CET drop compared to roughly similar capital impacts from recent stress test • 'Sizable impacts but Manageable'	• Largest PD increases on order of +500 bps • Largest sector VA declines of 20-40% roughly • Largest GDP decline for France of about 5-6% in adverse scenario to baseline

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Appendix: Climate Risk Modelling Summary DRAFT Notes

	Bouchet et al (2020)	Adenot et al (2022)
APPROACH	• Credit Risk (debt) focus • 5-Year & 40-Year Horizons (2060) • Range of IPCC Carbon Price Scenarios with increases in the $200-700 range • Credit Risk PD Changes from EBITDA Impacts on Firm Cash-Flows • No 'Adaptation' or technology changes assumed	• 'Cascading Carbon Price Effects Through Value Chain & Individual Firms' • Focus on Cross-Sector diffusion of carbon price shocks using I/O global cross-country model • Utilizes • 40-Year Horizon to 2060 • $50, $100 & $300 carbon price shocks consistent with other 2030/2040 carbon price scenarios • EBITDA shocks from carbon price scenarios applied direct/indirect
SCOPE/DATA	• MSCI World Index 1644 start data • 795 Large-Mid Corps in 23 countries with Scope 1 Data • Emissions Data: Carbon Disclosure Project (CDP), TruCost (Benchmarking)	• MSCI World Index 1552 firms across 23 countries • WIOD – World I/O Database
IMPACTS	• Biggest sector impacts on Utilities, Materials & Energy Sectors • 40 Year Cumulative PD Impacts above 'Carbon Price Threshold' at roughly 75%	• Worst case shock impact up to 47% enrings reduction in Utilities • Less carbon intensive Information Technology sector suffers up to 23% earnings reduction

Appendix: Climate Risk Modelling Summary DRAFT Notes

	Battiston et al (2017)	Monasterolo – CLIMAFIN (2019)
APPROACH	• Equities & debt stress tests • 'Network approach' to interdependent financial system risks – looks at direct & indirect effects • Focus Banking systemic losses both direct and indirect using 'Climate VaR' • Primary shocks defined as climate-relevant firms losing 100% of their equity • Banking debt impacts flow from equity shocks	• Financial stress test framework – IAM macro shocks defined as differences between 'adverse' & 'very adverse' climate scenarios • Shocks impact Risk-Neutral PDs on financial contracts (Sov Bonds) – Climate VaR • One version assesses Defaultable Sovereign Bonds – direct & indirect effects
SCOPE/DATA	• Euro & USA listed firms – roughly 15k firms & 65k shareholders • Array firms/shareholders by 'climate relevant' sectors • Includes analysis of top 50 EU Banks	• LIMITS Scenario data – Global CO2 Emissions • 'CPRS' 'Climate Relevant Policy Sectors' includes Fossil fuel, utilities, energy-intensive, housing & transport • Major bank equity exposures
IMPACTS	• Direct effects not that big, indirect effects large • 'Portion of bank's loan portfolios exposed to 'climate relevant sectors' is roughly equal to bank's capital' (Battiston 2017, p283)	

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Appendix: Climate Risk Modelling Summary DRAFT Notes

	Reinders et al (2020)	Capasso et al (2020)
APPROACH	• Finance 'valuation' approach + Merton • Aggregate industry focus • Carbon price asset value shocks coupled with pass-through assumptions of zero & 50% • EU100 & EU200 carbon price shocks • Overnight and phased in price shocks • Horizon unclear…2050 ?	• Uses Merton DD approach to assess climate change & firm credit risk • High 'climate footprints'' or 'climate intensity' cet par increases credit risk (PDs) • Climate 'exogenous' shock defined as 2015 Paris agreement as major 'climate policy change' • DD Model F(Carbon Intensity) • Partial, comparative static model
SCOPE/DATA	• Corporate debt & residential mortgages • Dutch banking system – exposure data for 2017 • 2,346 Listed firms from EU15 index to calibrate Merton DD model • Carbon 'vulnerability' ('intensity') assessed using Eurostat SBS data on emissions	• 458 listed firms with bonds • 2007-2017 data • Considered Scope 1 direct emissions only sourced from Asset4
IMPACTS	• Bank asset value declines up to 63% worst case • EU200 shock yields up to 63% decline in Dutch Banking CET capital	• Higher emissions footprint/intensity reduces firm default distance set par

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