CLIMATE RISK STRESS TESTING RESEARCH

The Climate Change 'Hockey Stick' is Observable – But Climate Change Influences on Economic Risks are Not Yet Observable [1]

This research note summarizes broad empirical aspects of recent climate change discussions in the industry concerning climate stress testing and the potential influences of climate change on credit risk in the banking system. We examine broad indicators of climate change and the relationship between these indicators and measures of market and credit risk (volatility). While we substantiate the well documented relationship between atmospheric CO2 concentrations and Global Mean Temperatures('GMT') we find no statistically significant relationships between GMT and economic volatility. Thus, on the basis of available data, we can't as yet substantiate any impact of climate change on measures of market and credit risk.

Early characterisation of climate change which started roughly 60 years ago has been measured by increasing changes in atmospheric CO2 levels which look to be closely related to increases in observed GMT. Michael Mann, a climatologist along with other climate researchers have suggested these two observed phenomenon, rising CO2 and related rising GMT trends look like a 'hockey stick' i.e., there are substantial, recent changes in climate trends, relative to long-run averages going back over many centuries. This observation can be seen in **Figure 1** which depicts the original Mann climate hockey stick.

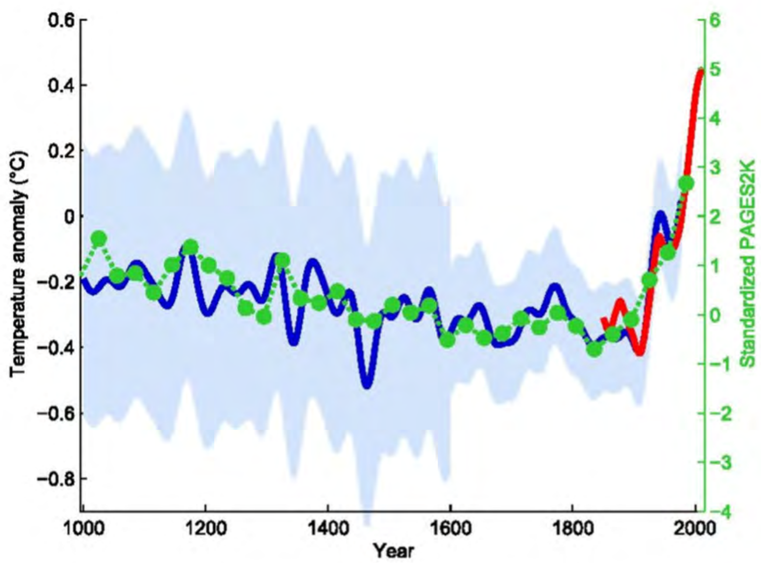

Figure 1: Climate Hockey Stick, Source, M. Mann et al., (1999)
Source: Mann, Michael E., 1999, figure sourced from Wikipedia

1 For this ZRE Climate Research Note, all feedback welcome, any errors or omissions remain the responsibility of the authors.

This observed rise in temperatures has led in recent years to a substantial focus on the future implications of rising GMT, and the potential for increases in physical damage and also increasing transition costs. Very recently, financial regulators across the world have expressed concerns that these climate changes could eventually produce material, adverse impacts creating risks to the stability of the banking system.

However, based on past theoretical and empirical studies, one finds that credit and market losses arise from unexpected shocks in prices, cash flows, and asset valeus, not from gradually changing trends in GMT, CO2, or other broad, economic indicators such as GDP. Our three recent *Climate Change Credit Risk Triptych* (2022) papers have highlighted this key distinction between trends and 'shocks'.[2]

In this note, we add some empirical evidence related to these key points by:

- Presenting simple statistical results describing the relationship between trends in CO2 concentrations and GMT,
- Assessing statistical links of GMT to broad measures of market volatility as measured by the US stress test CCAR volatiity index, and,
- Evaluating the statistical links between GMT and a broad measure of credit risk cycle volatilty derived from our Z-Risk Engine ('ZRE') models.[3]

1. Assessing GMT and CO2 Concentration Trends:

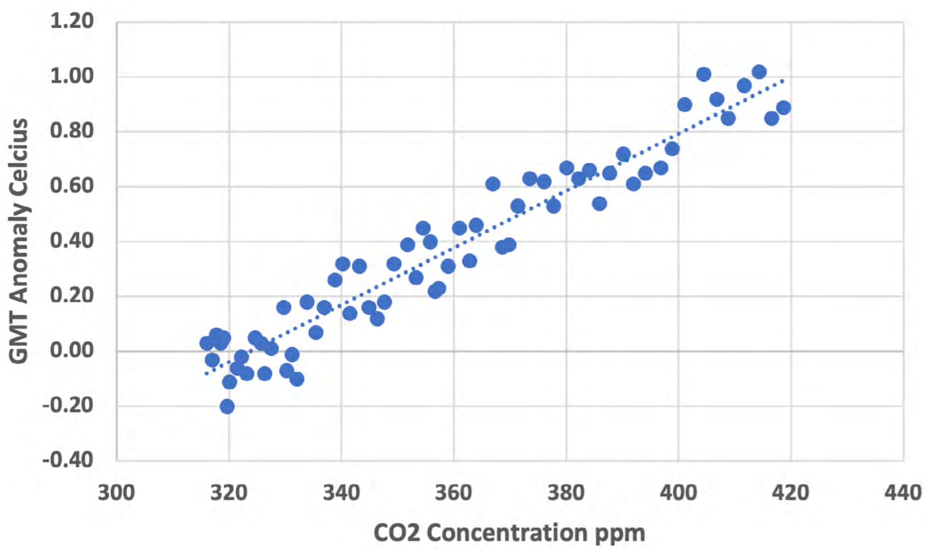

Figure 2: Observed Relationship Between GMT and Atmospheric CO2 Concentration
Data Source: NOAA
Various natural factors account for the variations around the trend line (dotted).

2 Our Climate Triptych papers are forthcoming as a single paper; '*Climate-Change Scenarios Require Volatility Effects to Imply Substantial Credit Losses – Shocks Drive Credit Risk Not Changes in Economic Trends*', in: ***Decision Making for the Net Zero Transformation: A Compendium of Best Practice***, published in, www.frontiersin.org.

3 See the **Appendix** for a definition of the global credit cycle index created by aggregating individual industry sector and regional credit cycle indices derived from Moody's CreditEdge global EDFs using the Z-Risk Engine solution.

See below in **Table 1** a numerical estimate of a the well-known linear relationship between CO2 and GMT evident from **Figure 1**:

Table 1: Linear Regression of GMT on Atmospheric CO2 Concentrations:

	Dependent Variable
Variable	GMT
CO2 Conc.	0.0095 (0.0004)
Constant	-3.08 (0.06)
R-squared	0.82
Deg of Freedom	774
Standard errors in parentheses. *Using monthly data from Mar 1958 to Oct 2022.* *Date Source: NOAA*	

In very recent years, with increasing concern over climate change from the use of carbon-based energy, focus has shifted to how short and longer run climate change may create potential macro-economic and financial impacts. But if the climate changes gradually allowing ample time for adaptation, we might expect that the effects on credit and market losses would be small.

However, if in the near or longer term, climate change triggers sharp, unexpected changes in economic conditions, then this could trigger larger losses as we pointed out in our Climate Triptych Papers (2022).

In the near-term, financial regulators led by the ECB and other, individual European Central Banks, have led the research expressing concern over the potential for long-run, adverse impacts of climate risk. This has led to a recent focus on developing climate stress test approaches that could be required by the banking sector, in a number of jurisdictions. The development of climate stress testing approaches for the banking system is also being driven by the *Network for Greening the Financial System*, a global financial 'cooperative'. The NGFS has developed a set of standardized climate financial scenarios that are designed to support climate stress testing by regulators and individual banks. NGFS scenarios focus on future, broad changes in GDP trends and other carbon mitigation impacts from potential future climate change. The focus on changes in future GDP trends is not unlike the changes in the trends of CO2 and GMT measures observed in the climate 'hockey sticks' over recent years. But as we documented empirically in the Triptych papers, smooth changes in GDP trends are not able to drive changes in future credit risks which, in the past have resulted from unexpected 'shocks' and changes in volatility measures.

Given the existence of long series on observed CO2 and GMT changes, some commentators have suggested that there should be a 'rich' set of data from the last roughly 60 years that could support the modelling of climate impacts on economic and financial markets. While these commentators suggest climate change impacts can be observed beyond the direct CO2/GMT changes shown above, we have seen no broad analysis that that has statistically linked broad climate data to more detailed economic and financial risks historically.

A number of climate impact studies however have found limited statistical impact of climate change on some specific financial assets, see Eren e. al., (2022). 'There is microeconomic evidence for the pricing of physical risks in housing markets, but the findings are not always consistent..... Even though there is some evidence that transition risks are priced in financial markets, it is unclear whether this pricing is sufficient to address transition risks effectively.' [4]

To assess in simple statistical terms the potential relationships between broad, observable climate impacts and the economy, financial markets and credit risk, we present two additional simplified model regressions:

2. Assessing the Statistical Relationship Between Climate Measures and Risk Measures:

We examine the relationship between GMT and two, broad-based, risk measures; first, using the US CCAR, market-volatility index, a measure of pending, unexpected changes in stock values as implied by equity-option prices; and secondly, the absolute value of average, MM-model residuals, a measure of the average, unexpected change in quarterly, credit-cycle-Z indices in 21 industry and 12 regional segments. [5] The former index measures implicit market volatility, whereas the latter MM-model represents a kind of historical, unexpected, credit-variability measure. *The two indicators exhibit common co-movements, with a contemporaneous correlation coefficient of 62%*.

If climate change has a material effect on risk, we'd expect to observe the risk measures trending up in tandem with the gradual change in climate. However, we see no such uptrend and regressions of the risk measures on GMT find a statistically insignificant relationship. While we get positive, but insignificant coefficients on GMT, the positive relationship is largely explained by two shocks at the end of 2008 and one in March 2020 relating to the pandemic. But few would attribute the 2008/09 Great Recession and the Covid pandemic to climate.

We assess the relationship between rising GMT and a general measure of risk, the CCAR volatility index presented in **Table 2** below to see if more narrow climate impacts can be extracted as climate commentators have suggested:

4 See, Eren et al., page 3.

5 The MM-model measures are derived from Moody's CreditEdge EDFs and represent the mean-reversion/momentum, second-order AR process observed empirically in historical, systematic credit cycle behavior and implemented in the Z-Risk Engine approach.

Table 2: Linear Regressions of CCAR Vol on GMT

Variable	Dependent Variable
	CCAR Vol
GMT	7.98 (4.88)
Constant	22.42 (2.94)
R-squared	0.02
Deg of Freedom	126
Standard errors in parentheses. Using quarterly data from 1990Q1 to 2021Q4. Data Sources: US Federal Reserve, and NOAA.	

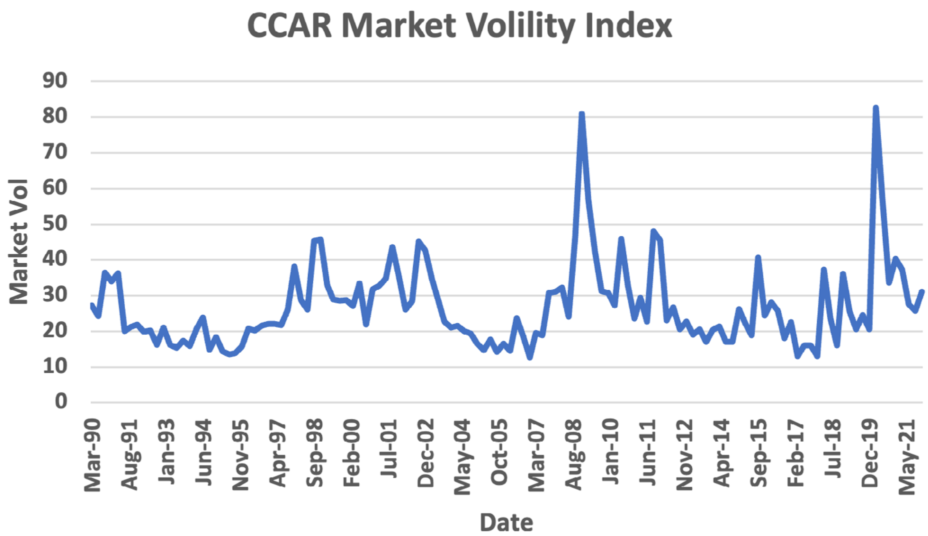

Figure 3: Historical Values of CCAR Market Volatility Index
Source: Board of Governors of the US Federal Reserve

CCAR Vol = f(GMT) – we see that there is no direct measurable statistical relationship observable of climate broadly on narrower economic and financial measures of risk such as the CCAR Vol index.

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Further we look at direct measures of drivers of credit risk, unexpected shocks as measured by our Z-Risk Engine MM-model measure ('MM' is a label used for our modelled, second-order AR credit risk cycles estimated for a set of global industry sectors and regions. 'MM' stands for 'Mean Reversion/Momentum').[6] In the regression in **Table 3** below we compare the average of the absolute values of innovations in the MM measure and GMT and also find no direct statistical impact.[7] **Figure 4** below shows the 1990-2020 history of the aggregate MM Model innovations or errors and **Figure 5** shows the absolute values of those average innovations. We use the absolute values in the regression, since they serve as indicators of the (unsigned) volatility of the shocks.

Table 3: Linear Regression of Absolute Average MM-Model Errors on GMT

Variable	Dependent Variable MM-Model Absolute Avg Error
GMT	0.08 (0.10)
Constant	0..21 (0.06)
R-squared	0.01
Deg of Freedom	120
Standard errors in parentheses. *Using quarterly data from 1990Q1 to 2020Q4.* *Data Sources: ZRE calculations, Moody's CreditEdge, and NOAA.*	

6 The aggregate, global, 'MM' Index presented here is made up of individual MM models for 21 individual global industry sectors and 12 regions (split corporate and FI)

7 It should be noted that Moody's CreditEdge EDFs are available historically from 1990 onward, so history used in regressions (2) and (3) is shorter than the horizon of the hockey stick generally. The first regression for CO2/GMT uses the longer run horizon but based upon the statistical results in Tables 2 and Table 3, longer run EDF data would not we believe change the statistically insignificant results shown here that there is currently no clear observable relationship between climate trend measures and measures of risk or volatility.

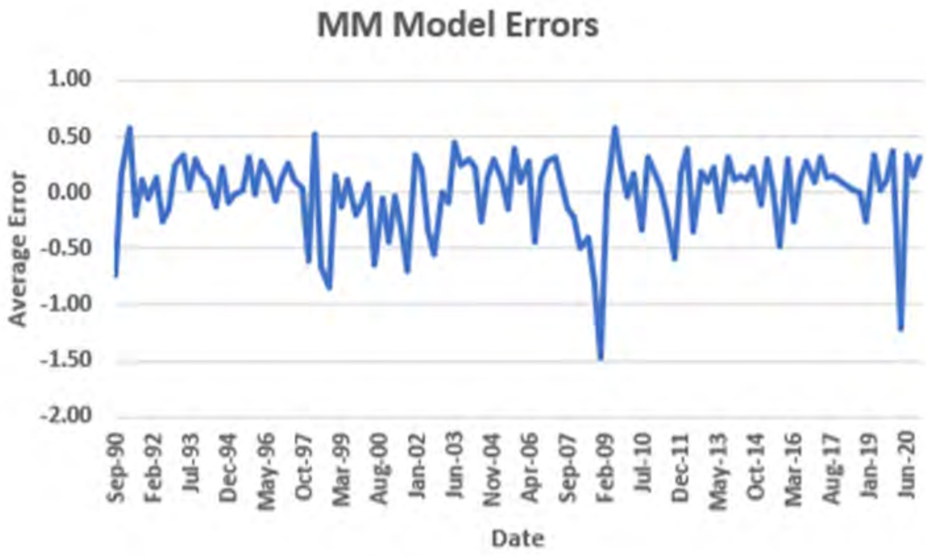

Figure 4: Observed Innovations in the Mean Reversion/Momentum Aggregate Credit Cycle Index

Source: Moody's CreditEdge EDFs and Z-Risk Engine calculations.

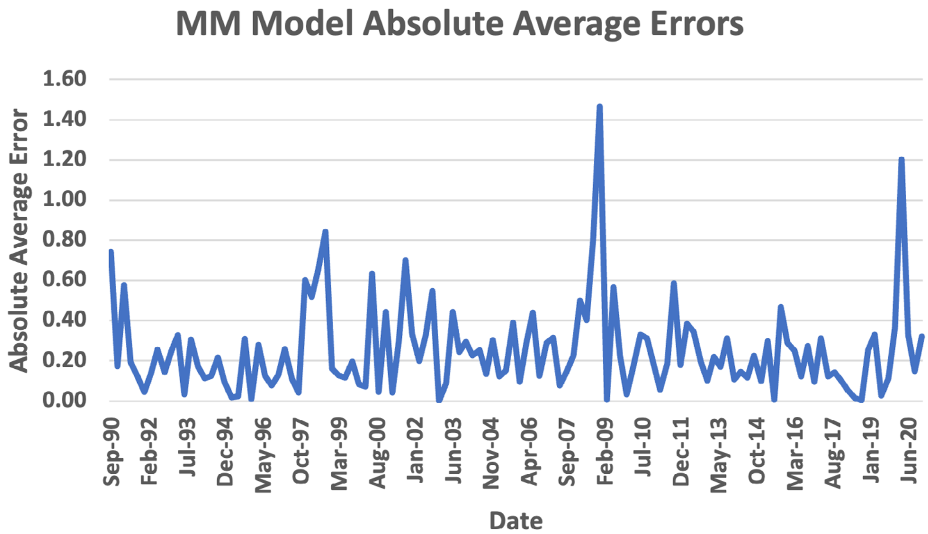

Figure 5: Absolute Average Observed Innovations in the Mean Reversion/Momentum Aggregate Credit Cycle Index

Source: Moody's CreditEdge EDFs and Z-Risk Engine calculations

Summary:

To summarise, broad climate change metrics like CO2 concentrations and rising GMT levels are observable, see, climate hockey sticks. However, using climate data measured over the last 60 years to explain more narrow, economic or financial climate risk impacts as some commentators have suggested, shows, using preliminary empirical analysis, that these impacts and relationships are not yet statistically observable.

In our forthcoming Frontiers paper, we use a well-established statistical multi-factor credit model to assess future credit risks to 2050 using the various NGFS scenarios. We show clearly that climate driven credit risk has to be driven by shocks not trends as developed in the NGFS scenario approach. For this analysis, we applied a 'GMT-to-Vol' illustrative model which produces greater volatility in credit losses in the future broadly related to climate, but to-date we have not been able to calibrate a statistical model to drive this GMT/Vol relationship. This short research note summarises further statistical analysis we have conducted on this point. Therefore, assessing future long run climate impacts on macro financial stability and future credit risk needs to be based on assumptions about future risks and volatility for now.

Contrary to some arguments currently under discussion in the industry, and arguments proposed by some climate commentators, that there is 60 years of observable climate data, the impacts from broader CO2/GMT are not yet statistically observable in economic and financial risk metrics.

Based upon the lack of direct empirical evidence of climate impacts on risk measures presented here, it is even more important that climate stress testing be developed on a solid empirical, systematic credit risk foundation. The credit factor approach in ZRE developed over the last 15 years by applying the global set of Moody's CreditEdge EDFs, provides a good starting point approach that can be adapted to support robust climate stress testing.

Authors

Scott D. Aguais, *Managing Director and Founder*, has over 30 years' experience developing and delivering advanced credit analytics solutions for large banking institutions. He led the successful Basel II Waivers at Barclays Capital and RBS, including leading the industry in implementing the first advanced Dual Ratings approach using both Point-in-Time (PIT) and Through-the-Cycle (TTC) risk measures. He then established the Z-Risk Engine ('ZRE') solution which uses the PIT/TTC methodology to support IFRS9/CECL and Stress Testing. A recent Case Study at DBS bank in Singapore outlines their implementation and business benefits of using ZRE. Dr Aguais holds a PhD in Economics.

Lawrence R. Forest Jr., *Global Head of Research*, leads all of ZRE's credit risk analytics research, model development and design. Dr. Forest has over 30 years', experience, designing and developing advanced credit analytics solutions for large banking institutions, including leading the design of the first advanced PIT/TTC Dual Ratings for Barclays Capital, RBS and ZRE. He led the econometric design and development of advanced Basel 2 PD, LGD and EAD credit models and most recently the application of ZRE to assessing climate driven credit risks. Dr Forest holds a PhD in Economics.

info@z-riskengine.com

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Appendix – Individual Mean Reversion/Momentum Credit Cycle Models Making up the Aggregate 'MM' Credit Cycle Index:

The 'MM' (Mean Reversion/Momentum') global credit cycle index utilised in the regression in **Table 3** and shown in **Figure 5** (absolute errors) is developed by aggregating individual 'MM' second-order, auto-regressive credit cycle indices ('Z') developed using the full, global history of Moody's CreditEdge EDFs back to 1990. These individual industry sectors and regions are listed below, with the regional indices split into corporate and financial firms. The aggregate global MM Z index is developed from the 21 industry sectors and 12 regions below by applying equal weights.

GLOBAL INDUSTRY SECTORS:

AEROSPACE & DEFENSE
AGRICULTURE
BANKING
BASIC INDUSTRIES
BUSINESS & CONSUMER SERVICES
CHEMICALS & PLASTIC PRODUCTS
CONSTRUCTION
CONSUMER PRODUCTS
FINANCE, INSURANCE & REAL ESTATE
MOTELS & LEISURE
MACHINERY & EQUIPMENT
MEDIA
MEDICAL
METALS
MINING
MOTOR VEHICLES & PARTS
OIL & GAS
RETAIL & WHOLESALE TRADE
TECHNOLOGY
TRANSPORTATION
UTILITIES

REGIONAL SECTORS:

NA CORPORATES
UK CORPORATES
EUROPE CORPORATES
LATAM CORPORATES
ASIAN CORPORATES
PACIFIC CORPORATES
NA FINANCIALS
UK FINANCIALS
EUROPE FINANCIALS
LATAM FINANCIALS
ASIAN FINANCIALS
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info@z-riskengine.com

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Developed by Aguais And Associates Ltd, Z-Risk Engine® (ZRE) provides a highly accurate, centralised, and integrated solution supporting global bank's compliance for IFRS9, CECL and Stress Testing regulations. ZRE is also being adapted to support Climate Stress Testing.

ZRE is a proven and efficient route to regulatory compliance for CROs and CFOs that also delivers up to a 30% reduction in IFRS9 modelling operational costs. As an advanced suite of Python or SAS® based software that works with a bank's own IRB wholesale internal credit models, ZRE unlocks complex industry and regional credit cycles to accurately convert TTC PD, LGD and EAD models into PIT measures. Whilst lowering implementation risk, the solution is also highly configurable and customisable to support large bank's detailed portfolio mix of commercial, corporate and bank clients.

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