MILLIMAN REPORT

Causal modelling: A possible application considering climate risk and asset returns

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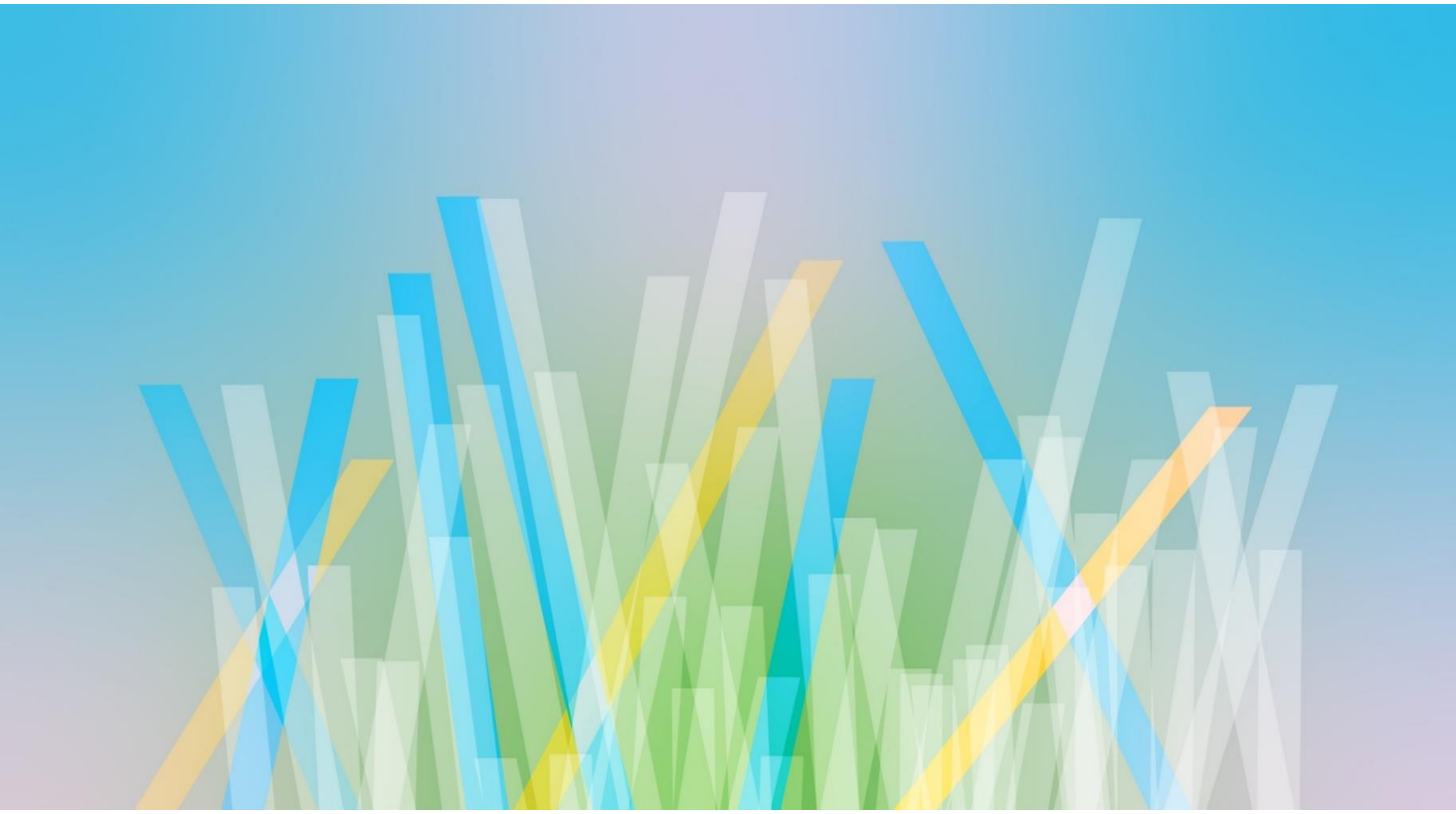

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Introduction

Climate change is undoubtedly one of the defining risks of our time and for the foreseeable future. Many papers have been written on this topic and there will be many more to come, so why read this one?

Our opening answer to that question is typically actuarial—"it depends." In short, our aim in this paper is to illustrate a modelling approach we feel can offer a useful tool to explore the potential impacts of climate risk on future asset returns. The challenge itself is clearly very topical, as expected climate risks and impacts already feature in investment decisions and their influence is expected to grow as data, analysis and understanding develops. However, huge uncertainty remains over the scale of impacts, their timing and the transmission mechanisms through which these impacts will drive changes in future returns. We have no silver bullets, but the view of the authors is that the modelling approach described in this paper is well suited to the complexity and uncertainty involved.

Alongside our curiosity about how climate factors could influence future asset returns, we are also well aware of current, and expected, regulations focussed on the impact of climate change on the financial system. The aims of regulators in this area include ensuring that financial institutions:

- Consider climate risks in business decision making and strategic planning
- Effectively disclose and report on climate-related risks and opportunities
- Adopt a consistent and reliable means of assessing, pricing and managing climate-related risks
- Incorporate environmental, social and governance (ESG) factors into investment management decisions
- Incorporate financial risks from climate change into existing risk management processes
- Use scenario analysis to inform risk identification and to estimate the impact of financial risks arising from climate change
- Consider the impact of climate risks on the ability to meet obligations towards policyholders and other key stakeholders

The modelling approach proposed in this paper would also help investors to meet many of these objectives through the insights obtained.

So if our objective resonates with you, please read on.

The remainder of the paper is laid out as follows:

- The initial section provides context to this paper by describing some of the expected influences and implications of climate change on asset returns. This is an enormous topic and so we have focussed particularly on the listed equity of companies in the real estate sector.
- In the second section, we present an overview of the modelling approach we have used, namely causal modelling based on Bayesian statistics.
- The third section describes the key features of the model we developed and presents some illustrative results.
- In the final section we contemplate some of the many areas in which we are aware that our model could be further enhanced and provide some brief closing thoughts.

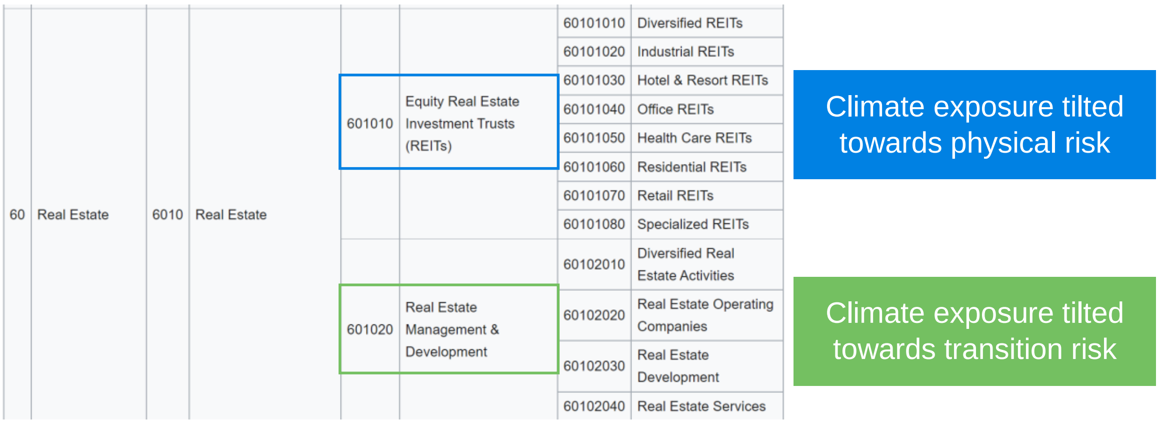
We hope you enjoy the paper.

Climate implications for asset returns

The general aspects of possible climate impacts on asset returns, in terms of either physical risks or transition risks, has been covered extensively in other literature and we assume that the audience has some familiarity with them.

In terms of the application within this paper, we have chosen to illustrate the concepts and results using a single asset class—listed equity of companies in the real estate sector. Use of a single asset class was felt to be sufficient to provide an interesting case study to convey the approach while enabling us to keep this paper relatively concise.

FIGURE 1: GICS[1] STRUCTURE FOR THE REAL ESTATE SECTOR



60	Real Estate	6010	Real Estate	601010	Equity Real Estate Investment Trusts (REITs)	60101010	Diversified REITs
						60101020	Industrial REITs
						60101030	Hotel & Resort REITs
						60101040	Office REITs
						60101050	Health Care REITs
						60101060	Residential REITs
						60101070	Retail REITs
						60101080	Specialized REITs
				601020	Real Estate Management & Development	60102010	Diversified Real Estate Activities
						60102020	Real Estate Operating Companies
						60102030	Real Estate Development
						60102040	Real Estate Services

Climate exposure tilted towards physical risk

Climate exposure tilted towards transition risk

We debated several equity sectors but felt that the real estate sector offered scope to consider the impacts of both physical and transitional climate risks. Furthermore, looking down to the second level of the Global Industry Classification Standard (GICS) hierarchy, we expected some differentiation within this overall category in terms of physical and transition impacts. We have postulated that physical risks play the lead role for the real estate investment trust (REIT) subsector, as the underlying assets could be significantly affected by physical climate damage. Similarly, we have assumed that transition risk plays a main role for the Real Estate Management and Development subsector, due to the need to transition these activities to low-carbon models over the near term. Modelling at a more granular level is ultimately possible, but the challenges of model complexity and the volume of assumptions required would increase markedly. Indeed, if the purpose of the exercise is to inform long-term strategic asset allocation (SAA) then considering GICS Level 1 sectors may be deemed sufficiently granular already.

The current value and prospects for the future appreciation of both commercial and residential property will undoubtedly be influenced by the physical risks arising from climate change.

Looking briefly at some specific risks:

SEA LEVEL RISE (SLR):

The threat of rising sea levels to commercial and residential property located in low-lying geographies is clear. However, there is far less clarity over the severity of the rises which may occur. Additionally, the timescales over which impacts will play out are expected to be decades rather than years. Having said that, a recent paper from the Joint Forum on Actuarial Regulation entitled “The Science of Climate Change” noted that sea levels have already risen about 20 centimeters since 1900 and the rate of increase has accelerated being about 3.7 millimeters per annum (p.a.) over the period from 2006 to 2018.[2]

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[1] Table extracted from Wikipedia: Global Industry Classification Standard. Retrieved 30 September 2022, from https://en.wikipedia.org/wiki/Global_Industry_Classification_Standard.

[2] Joint Forum on Actuarial Regulation (June 2022). The Science of Climate Change. Retrieved 30 September 2022, from https://www.actuaries.org.uk/system/files/field/document/JFAR%20The%20Science%20of%20Climate%20Change.pdf.

However, the financial impact of SLR on property values can be difficult to untangle from other aspects of property valuation. For instance, demand for residential property near the coast usually means these properties benefit from greater price tags and there has been little evidence yet of the value of more desired seafront properties being impacted by SLR. Additionally, commercial properties in city centers are often on the banks of rivers; there has been little evidence of price impacts as a result of SLR, with the general sentiment being that the problem is so big that it is one for which governments will need to step in and mitigate before SLR becomes a real threat.

CHRONIC CHANGE IN WEATHER PATTERNS:

This can take a number of forms:

- Temperature – in extremis, rising temperature is predicted to make some areas of the world essentially uninhabitable, with obvious implications for the value of any property located there. However, far more modest increases may still impact the usability and thus value of properties. As temperatures rise, working conditions in factories and warehouses, for example, may be adversely affected, reducing demand from tenants and rental values unless mitigating measures are taken. Mitigation will clearly involve up-front costs for property owners, the ease and scale of which will vary with existing building design and construction.
- Rainfall – climate change is expected to bring elevated levels of rainfall in some areas. Wetter weather means an increased chance of damp in buildings and, coupled with storms, high winds increase the likelihood of rain penetration which can cause serious damage to property structures and contents. However, increased rainfall may be seasonal with reduced rainfall being seen at other times of the year. In the UK a number of areas, such as East Anglia, are expected to experience wetter winters in future but also drier summers. Reduced rainfall can see soils dry out, which can increase problems related to subsidence with the impact depending on soil structure and construction standards such as the depth of foundations.

SEVERE WEATHER EVENTS:

Severe weather can also take a number of forms and will be exacerbated by chronic weather changes:

- Storms – there is strong evidence that increasing sea temperatures increase the intensity of tropical storm wind speeds[3], potentially resulting in more damage if these storms make landfall. High winds can deliver physical damage to properties directly or via impacts from flying debris. In addition, damage to physical infrastructure in the surrounding areas, such as roads and power lines, can render properties unusable even absent from direct physical damage.
- Floods – we do not need to think very hard about the devastating impact of severe flooding on properties and livelihoods. As a severe event it is one that can be brought about by a variety of chronic and severe weather factors; consider the flooding in Louisiana as a result of Hurricane Katrina in 2005 and the heavy rainfall which led to severe flooding in some parts of Western Europe in July 2022.

The precise impacts of these risks will depend significantly on the geographical location of properties within a portfolio and even then can vary markedly with the precise topology of the land and age of the property. Thus, small and/or highly concentrated portfolios could experience very different outcomes. However, to make our case study generic, we have aimed to be broadly geographically agnostic, consistent with exposure to a very large and well diversified portfolio of underlying properties.

In addition to the physical risks described above, the costs and risks associated with the transition to a low-carbon economy are also expected to impact our chosen asset class. For example:

- **Stranded assets:** In some cases properties will be tied to industries in long-term decline. Sometimes it may be possible and economically viable to repurpose properties but there will inevitably be instances where this is not the case, e.g., it may be hard to repurpose a chemical plant.
- **Energy efficiency:** Inevitably the energy efficiency of both residential and commercial properties will come into sharper focus, with properties that are already highly energy efficient—or can be made so at reasonable cost—seeing increased demand. The corollary is that other properties are likely to see reduced demand and downward pressure on rents and prices.

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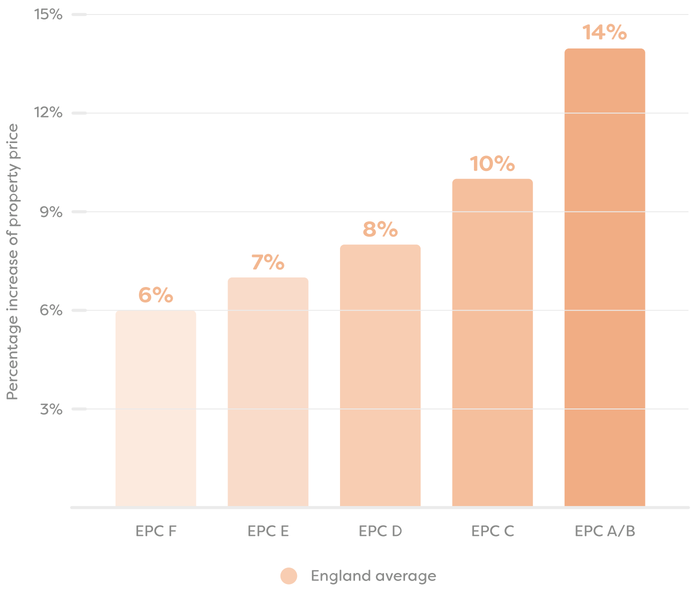
[3] NASA Science. Climate Variability. Retrieved 30 September 2022, from https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/climate-variability.

> *“[E]missions from homes and from commercial and public sector buildings account for 19 per cent of total UK greenhouse gas emissions.”[4]*

A key driver in this area is expected to be regulation. For example, in the UK there is a system of Energy Performance Certificates (EPC) where a rating is assigned to a property denoting its energy efficiency. “G” is the poorest rating and “A” the best. At present, in most cases, a residential property must have an EPC rating of at least “E” in order to be let. However, there are proposals in the pipeline to increase that requirement to a “C” rating[5] from 2025 for new tenancies and for all tenancies from 2028. We understand the UK government has indicated average costs for compliance of around £4,700.[6] Based on an average UK house price of £283,000 in May 2022,[7] that represents a cost of just 1.7% of value though there is bound to be a wide variation in that figure.

Set against this, there are indications that in some areas investment in mitigation can flow through into higher values. In Figure 2 we note some results provided by the price comparison website Money Supermarket.

FIGURE 2: RELATIONSHIP BETWEEN EPC RATING AND UK RESIDENTIAL PROPERTY VALUES



Source: Money Supermarket - https://www.moneysupermarket.com/gas-and-electricity/value-of-efficiency/

Turning to commercial property in the UK, properties must be at least EPC “E” at the start of a new lease but from April 2023 that requirement will apply to all leases. In a consultation paper from the Department of Business, Energy and Industrial Strategy in October 2019, the UK government estimates that about 18%[8] of commercial properties are below the required rating. However, there is more to come with proposals in the same document (and reiterated in the 2020 Energy White Paper) that all commercial properties achieve a “B” rating by 2030 where it is cost-effective to do so. Costs are estimated at £6.1 billion, with savings expected to exceed that amount significantly over time.

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[4] HM Government (December 2020). Powering Our Net Zero Future, p. 98. Energy White Paper. Retrieved 30 September 2022, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf.

[5] National Residential Landlords Association. EPC Rules for Rented Property: What You Need to Know. Retrieved 30 September 2022, from https://www.nrla.org.uk/news/epc-rules-for-rented-property-what-you-need-to-know.

[6] HomeOwners Alliance (27 April 2022). EPC changes: How much could it cost you? Retrieved 30 September 2022, from https://hoa.org.uk/2022/04/epc-changes/.

[7] Office for National Statistics. UK House Price Index: May 2022. Retrieved 30 September 2022, from https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/housepriceindex/may2022.

[8] Department of Business, Energy and Industrial Strategy (7 January 2020). The Non-Domestic Private Rented Sector Minimum Energy Efficiency Standards, P. 13. Retrieved 30 September 2022 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/839362/future-trajectory-non-dom-prs-regulations-consultation.pdf.

CONSTRUCTION STANDARDS:

It is likely that the bar will be raised significantly in relation to standards of construction for new properties, which will inevitably have implications for costs in the first instance, with less clarity on the extent to which those costs will be able to be passed on to buyers and tenants as a "green premium." Again, the UK's "The Future Homes Standard" will require new-build homes to be fitted with low-carbon heating and high levels of energy efficiency, with a consultation likely to be forthcoming on similar proposals for commercial properties.

Finally in this section, we consider briefly some other avenues by which climate impacts may be transmitted through to returns for our asset class:

- **Sentiment:** This can be a powerful driver subject to tipping points resulting in marked changes in demand for particular products (or properties), as their perceived attractiveness undergoes a sharp shift. Note that the impact of sentiment can be both negative and positive and has the capacity to drive greater volatility in future asset returns. There is some evidence to support such effects already, for example:
  - A paper entitled "Carbon Tail Risk" from the Frankfurt school of Finance and Management studied the option market and noted that, for carbon-intense firms, the cost of protection against downside tail risk is magnified at times when the public's attention to climate change spikes.[9]
  - A Staff Report from the Federal Reserve Bank of New York entitled "Climate Regulatory Risks and Corporate Bonds" considered the impact of step changes in climate risk perceptions, e.g., due to the Paris Agreement, and noted bonds of firms with greater carbon exposure suffered increased downgrades, supporting the hypothesis that changes in climate regulatory risk impact bond ratings for firms most exposed to the consequences.[10]
- **Cost of financing:** Research has noted a positive link between financing costs and the carbon intensity of businesses, possibly reflecting the risk of assets becoming stranded or the elevated risk to business models of firms forced to transition their operations to align with a low-carbon economy.[11]
- **Availability of insurance:** The intensification of physical climate risks in particular brings the possibility that some properties will become uninsurable, affecting the availability of finance for those assets. Furthermore, pressure on insurers to embed ESG factors into their activities may also drive a contraction of supply to certain industries. On this point, the results from the Climate Biennial Exploratory Scenario (CBES) run by the Bank of England noted:

  "... there could be economic consequences if limits on lending and insurance to corporates involved in the supply of more carbon-intensive energy run ahead of the expansion of renewable energy supply and other measures to improve energy efficiency."

In summary, assessing the expected impact of climate change on asset returns is a complex question, as even establishing the historical contribution of climate risk to past returns is challenging. This quote from a paper reviewing a broad range of academic literature perhaps sums it up rather well:

"The extent to which physical climate risk is presently capitalised in assets and markets is unclear."[12]

Nevertheless, given the direction of travel, there are strong reasons to believe that climate risk and its associated regulation will have an impact on asset returns in the future. The CBES results referred to earlier appear to support that view as we can see from Figure 3.

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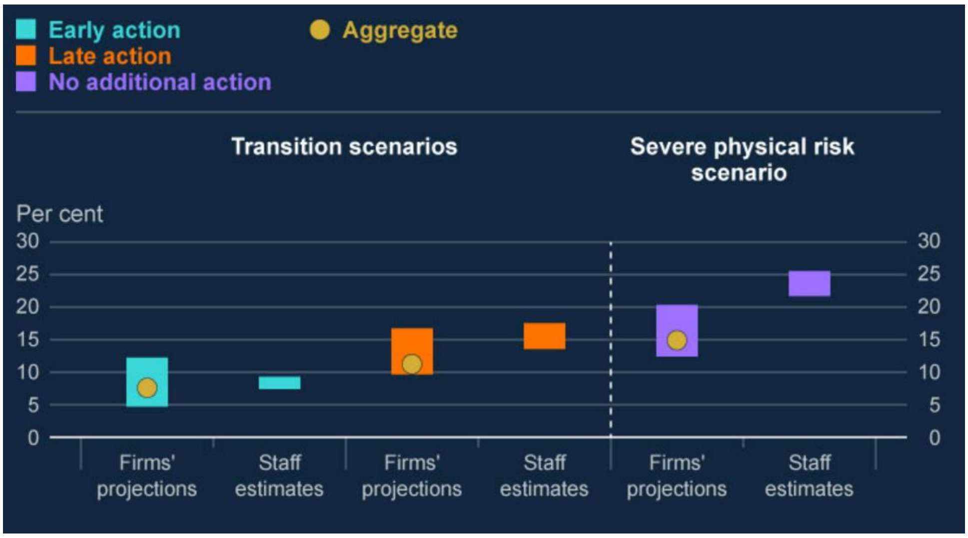
[9] Ilhan, E. et al, (2021). Carbon Tail Risk. Retrieved 30 September 2022 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3204420.

[10] Seltzer, L. et al. (25 April 2022). Climate Regulatory Risks and Corporate Bonds. Retrieved 30 September 2022 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3563271.

[11] Delis, M.D. et al. (15 July 2021). Being Stranded With Fossil Fuel Reserves? Climate Policy Risk and the Pricing of Bank Loans. Retrieved 30 September 2022 from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3125017.

[12] UN Environment Programme (August 2021). Climate Risk and Commercial Property Values. Retrieved 30 September 2022 from https://www.unepfi.org/industries/investment/climate-risk-and-commercial-property-values/.

FIGURE 3: CBES RESULTS: EXPECTED INVESTMENT LOSSES FOR LIFE INSURERS



Source: Bank of England - https://www.bankofengland.co.uk/stress-testing/2022/results-of-the-2021-climate-biennial-exploratory-scenario

Causal modelling: An overview

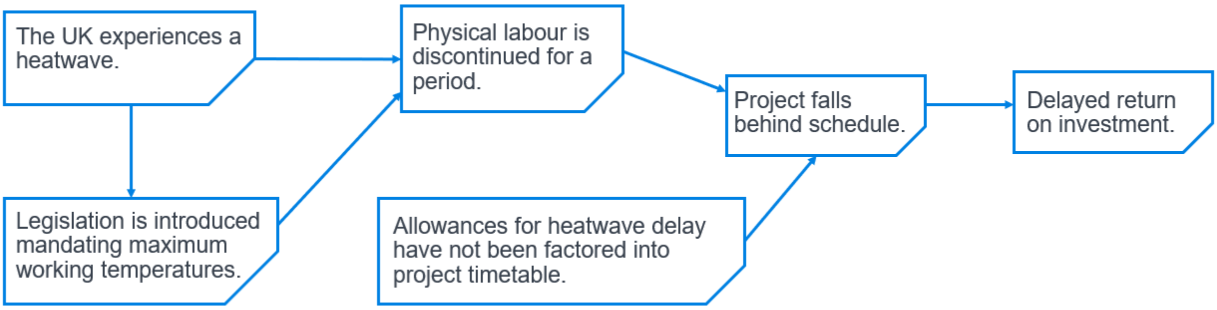
"All models are wrong but some are useful." – George Box

When tackling complex situations, like the impact of climate factors on asset returns, the initial barrier to progress is often that the complexity can feel overwhelming. A frequent response is to adopt a hasty reductionist approach which tries to simplify things and with a preconceived end result in mind. This can leave out important information about how a system interacts to produce novel outcomes, and how a complex system may evolve in the future. Causal modelling is one approach that can be used to attempt to understand complexity and, in our case, the multifaceted and highly uncertain nature of climate risk.

The technique makes use of expert judgement about the composition of the problem, in this case how real estate asset returns might be impacted by climate-related risks, to develop a picture of the risk using structured and unstructured data. This ”picture” typically captures causal links between the understood elements of cause and effect to create a nonlinear model of the problem. The result is a model which describes the multiple risk outcomes through a series or chain of events.

Consider the simplified example in Figure 4 where a heatwave could impact returns on an infrastructure project. Legislation, however, has the potential to amplify the risk outcomes.

FIGURE 4: SIMPLIFIED EXAMPLE OF A CAUSAL CLIMATE PROBLEM



Once the model has been developed it becomes a tool against which expert opinion can be tested about how the risk could manifest and evolve. Having considered the evidence, a revised theory can be postulated and then implemented to mature the illustration of the risk. The causal model then enables the experts to consider the outcomes that might result from different sets of initial conditions, and also to explore which conditions would be required in order to obtain particular outcomes. This ongoing cycle of learning and predicting enables the experts to update their understanding as the situation adapts and/or additional information becomes available; a technique that enables progress to be made even where knowledge and/or data is still emerging and incomplete.

We accept that some aspects of climate risk will evolve only slowly but in many areas research offers a flow of fresh insights. Regulation is likely to continue to evolve quickly. A causal model can assist in analysing the implications of such changes within a structured framework.

In addition to being able to handle complex problems, causal modelling is also particularly well suited to our case study due to its inherent characteristics. Causal models:

- Clearly and intuitively combine data with judgement to explain how loss outcomes are driven by the states in which underlying drivers exist
- Can be less abstract than other frameworks, so more directly capture what you want to model
- Use the language of the user specifying the model, so are easy for non-specialists to understand and situate in the context of their environments, facilitating engagement with stakeholders and communication of findings
- Reduce the likelihood of producing preconceived ideas of the outcome to the problem as justification needs to be provided for each causal step in the model to arrive at a distribution of the outcomes

Milliman has used causal modelling to show the financial impact, or value of business decisions, across a wide variety of complex problems, with examples including:

- The interacting, and amplifying, effects of credit and operational risks
- To determine the impact of a ransomware attack and the business case for mitigation
- To model policyholder behaviour

Our model

Having set out some of the climate implications for real estate asset returns and described causal models at a high level, this section describes in more detail a causal model we have built to help understand the potential impact on a diversified portfolio of listed real estate equity.

The aim of our model is to provide projections for the distribution of total equity returns expected by an investor in the real estate sector over a 10-year time horizon, in the context of three distinct climate pathways.

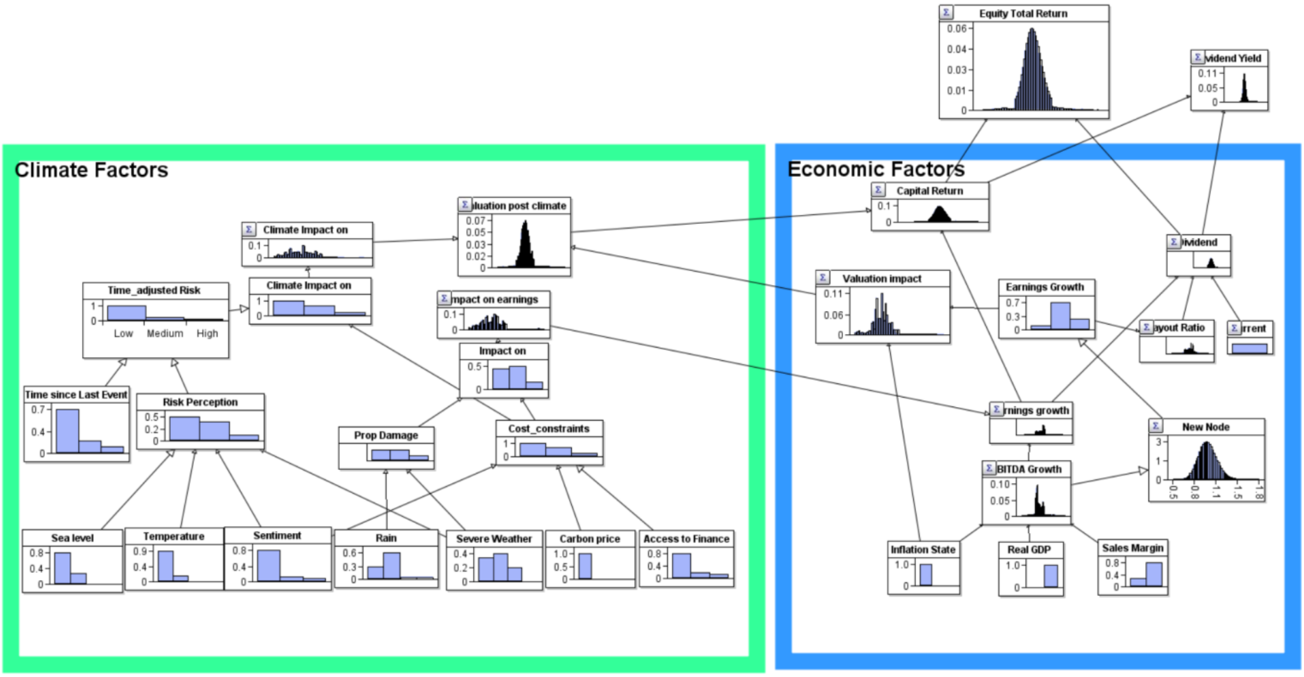
The model is a simplification of what one could expect to develop in practice, but we hope that it provides a starting point for illustrating the potential uses of causal modelling in a climate context. For example, we have not assumed a specific investment portfolio either in terms of geographic location or property type, nor have we accounted for any taxes or transaction costs a real-world investor would expect to deal with.

We recognise that climate impacts will influence outcomes for key economic drivers such as future inflation and rates of growth in real gross domestic product (GDP). These effects will impact all asset classes to some degree, lowering (or raising) all boats. In our model we have ignored these effects, a significant simplifying assumption, in order to focus the work on the more idiosyncratic impacts expected for our example asset class. This approach also enables us to consider the economic and climate sections of our model separately.

MODEL STRUCTURE

The diagram in Figure 5 shows the full structure of the one-year model. It can be broadly considered as two interconnected “halves”—a network on the right modelling the impact of economic drivers such as inflation, and a network on the left modelling the impact of climate-related drivers.

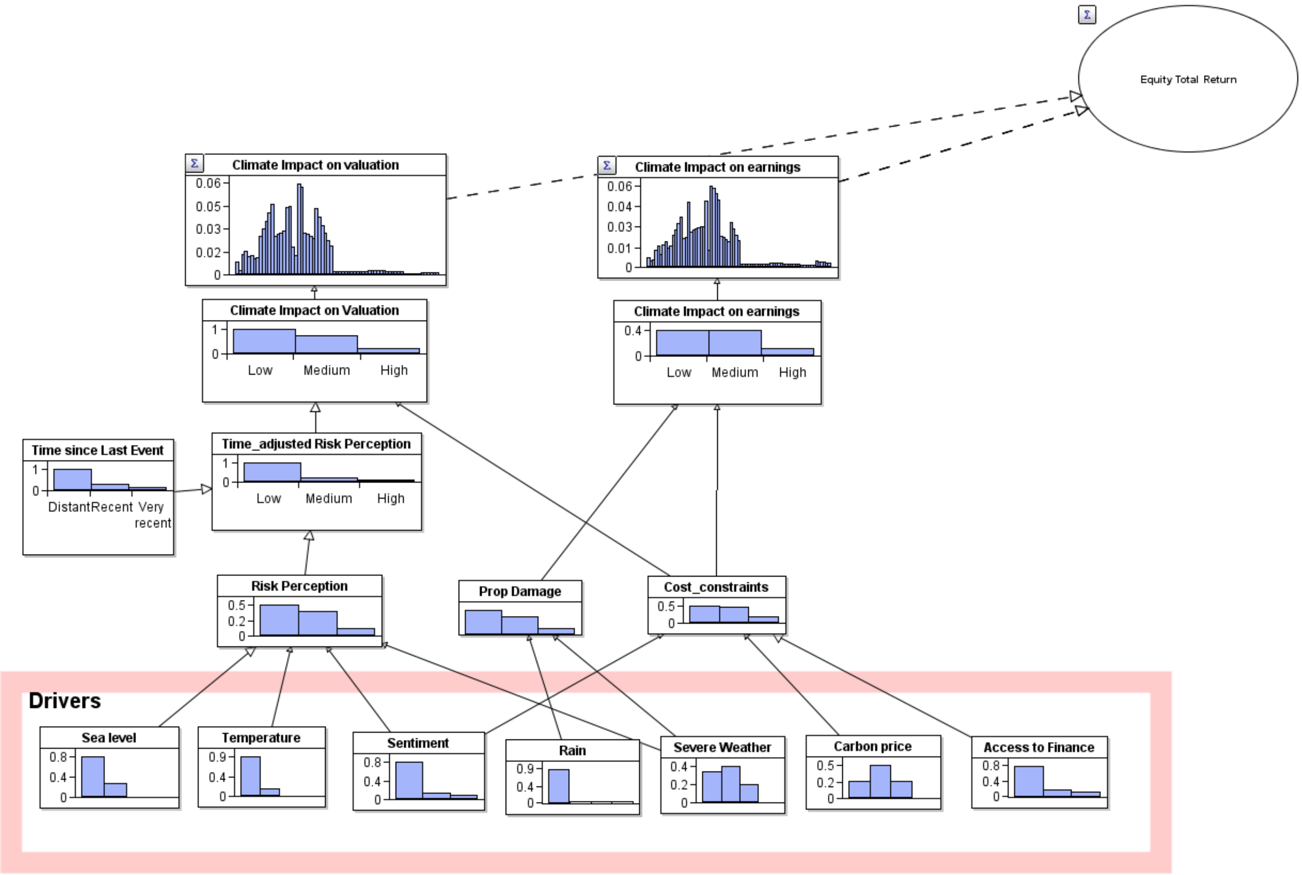
FIGURE 5: OVERVIEW OF CAUSAL MODEL STRUCTURE



Climate

The structure of our model subsection concerned with climate factors can be seen in Figure 6.

FIGURE 6: MODEL STRUCTURE – CLIMATE IMPACTS



The financial risks associated with climate change can be broadly grouped into two categories:

- **Physical risks**, including risks from extreme weather events (such as property damage from storms, droughts and flooding) and risks from the more gradual change in physical conditions (such as property damage from mold worsened by changes in temperature and precipitation)
- **Transition risks** resulting from the move towards reduced reliance on fossil fuels (such as impacts on asset values, or increased volatility in certain markets) as well as impacts as a result of climate sentiment

The structure of our model reflects both sets of influences. Climate-related risks have an impact on the overall total return via two channels:

1. Climate impact on earnings
2. Climate impact on valuation

Note that these channels are not mutually exclusive, a single climate driver can have an impact on both earnings and valuation. For example, increased frequency of severe weather events may have an impact on earnings (e.g., cost of repairs associated with property damage), but may also have an impact on valuation (e.g., perception of increased risk to future earnings associated with the real estate sector).

Drivers

The model incorporates the climate drivers shown in Figure 7.

FIGURE 7: SPECIFICATION OF MODEL STATE DRIVERS (CLIMATE)

DRIVER	MEASURE	PARTITION
Rainfall	– Used a proxy for non-coastal flooding and soil moisture. – Absolute % change in average annual precipitation rate vs. pre-industrial average	Low/Medium/High/Very High
Sea Level	– Used as a proxy for coastal flooding and erosion. – Change vs. pre-industrial average (metres)	Low/Medium/High/Very High
Severe Weather	– Used as proxy for storms and other extreme weather events. – Absolute % change in max. daily near-surface wind speed vs. pre-industrial average	Low/Medium/High/Very High
Temperature	– Used as a proxy for chronic warming. – Change in maximum daily near-surface air temperature vs. pre-industrial average (°C)	Low/Medium/High/Very High
Carbon Price	– Used as a proxy for the cost of new technology, regulations and policies. – US dollars (2020) per tonne	Low/Medium/High/Very High
Public Sentiment	– Used as a proxy for wider public and market opinion regarding climate change, the pace of transition and the associated risks and benefits. – Self-reported positive/negative feeling regarding the future of the environment	Positive/Negative/Very Negative
Access to Finance	– Used as a measure of climate impacts on the availability of finance to the real estate sector.	Easy/Moderate/Poor

We can divide these drivers broadly into physical (the first four) and transition (the latter three) variables but, as discussed above, many have cross-cutting impacts from both physical and transition risk.

The drivers impact the rest of the model via three nodes on the next level of the causal map, shown in Figure 8.

FIGURE 8: NODES

NODE	DESCRIPTION	DRIVERS
Risk Perception	This signifies the extent of risk as perceived by the public (including the investor community). It does not always coincide with the actual level of risk. For example, in our calibration we assumed that perception is more immediately impacted by the frequencies of severe weather, as it raises more awareness of climate risks, through the media for example, compared to a rise in temperature and sea level. Sentiment is obviously also an important factor in the risk perception. There is also some evidence that the risk perception is impacted by how recent the events associated with the climate risk are[13]—the less time since the event, the higher the level of the perceived risk, so we introduced a concept of a time-adjusted risk perception.	Sea Level, Public Sentiment, Severe Weather, Temperature
Property Damage	Property damage signifies physical risk and how severe the physical impacts are on the value of the properties in the portfolio. In our hypothetical portfolio, any damage comes from rain and severe weather events.	Rainfall, Severe Weather
Cost/Constraints	This is a combined cost coming mainly from the transition risk, allowing for the carbon price (cost of new technology or an increase in regulations) and potentially poorer access to finance for companies in the sector, exacerbated by public sentiment.	Access to Finance, Carbon Price, Public Sentiment

These three nodes feed into the overall total return via the two main impact channels, as discussed above and shown in Figure 9.

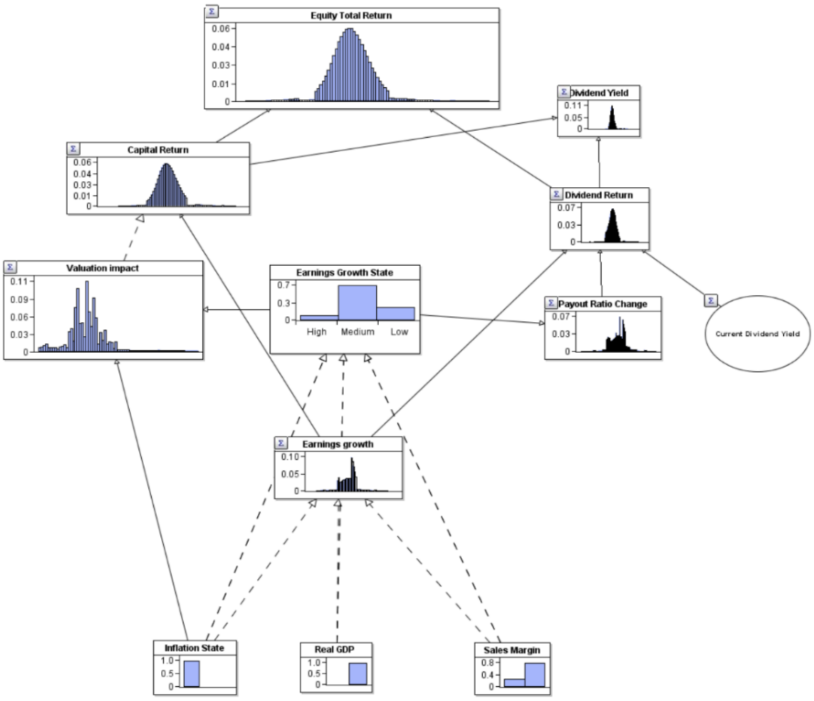
FIGURE 9: MODELLED TRANSMISSION OF CLIMATE IMPACTS TO EARNINGS AND VALUATION

NODE	PARENT NODES
Climate Impact on Earnings	Property Damage, Cost/Constraints
Climate Impact on Valuation	Risk Perception, Cost/Constraints

Economic

The structure of our model subsection which concerns economic factors can be seen in Figure 10.

FIGURE 10: MODEL STRUCTURE – ECONOMIC IMPACTS



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[13] UN Environment Programme (August 2021), Climate Risk and Commercial Property Values, ibid. Noted that price declines are seen after physical events but tend to be relatively short-lived unless the events are extraordinary in relation to prior experience.

An investor in equities will make a return on their investment via two channels—the cash received from dividend payments, and/or the capital gain achieved upon selling shares where the price has grown from the initial purchase price. Our model reflects this, and the ”Equity Total Return” output node in the model has two components:

- **Dividend return:** The forecast return from dividend payments
- **Capital return:** The forecast return from changes in equity share prices

The capital return is itself the sum of two components:

- **Earnings growth:** The forecast change in the share price due to growth in earnings
- **Valuation impact:** The forecast change in the share price due to changes in the valuation of future earnings

Note that our model is based on investment return data that is gross of tax, and we have not attempted to account for the impact of:

- Income tax on the rate of dividend return
- Capital gains tax on the rate of capital return
- Any other transaction costs or taxes which could affect the total rate of return

Drivers

At the base of the model structure, we have three macroeconomic factors, shown in the table in Figure 11, considered to have a causal impact on the components of equity return.

FIGURE 11: SPECIFICATION OF MODEL STATE DRIVERS (ECONOMIC)

DRIVER	MEASURE	PARTITION
Inflation	Such as annual change in consumer price index (CPI).	High/Normal/Deflation
Real GDP Growth	Annual change in GDP adjusted for inflation.	Normal/Recession
Sales Margins	Such as ratio of earnings before interest, taxes, depreciation and amortisation (EBITDA) to sales value.	Normal/Supra-normal

The drivers impact the rest of the model via three nodes on the next level of the causal map, shown in the table in Figure 12.

FIGURE 12: SPECIFICATION OF MODEL NODES (ECONOMIC)

NODE	DESCRIPTION	DRIVERS
Earnings Growth	Earnings before interest, taxes, depreciation and amortisation (EBITDA) has been chosen as the measure of earnings, as we have excluded the effects of taxation, financing and accounting policies. This node is a product of distributions fitted to empirical data dependent on the states of the preceding economic drivers, as well as any effect of the Climate Impact on Earnings node.	Inflation, Real GDP Growth, Sales Margins
Valuation Impact	The Valuation Impact node translates changes to equity earnings into changes in price and thus capital return. The extent to which a change in EBITDA feeds through into a change in price is dependent on investor sentiment and the perceived information content of changes in EBITDA. This node is a product of distributions fitted to empirical data dependent on Inflation and the state of the Earnings Growth node, as well as any effect of the Climate Impact on Valuation node.	Inflation, Earnings Growth, Climate Impact on Valuation
Payout Ratio Change	Payout ratio is a metric representing the proportion of a company’s total earnings that is paid in shareholder dividends. This node is a product of distributions fitted to empirical data dependent on the state of the Earnings Growth node.	Earnings Growth

Projection

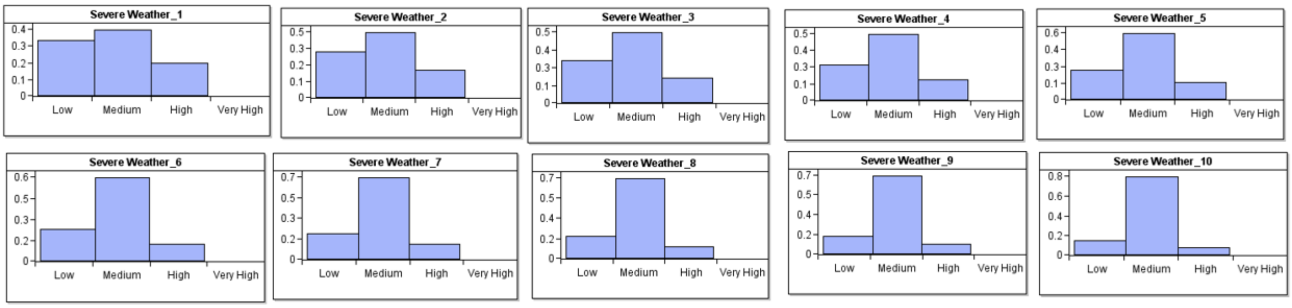
Each year of the 10-year model replicates the one-year model, but with the dividend yield portion of the total return passed forward from the previous year:

Dividend Yield (Year N) → **Current Dividend Yield** (Year $N+1$)

Furthermore, we can define both climate and economic drivers independently for each year of the 10-year time horizon, allowing for construction of a range of scenarios. We will discuss the driver pathways used for the generic model further in a later section, but we have broadly attempted to give a “best estimate” based on current conditions (high inflation and recession for the first three years, and three variable pathways with differing severities of worsening climate conditions based on CBES Early Action, Late Action and No Additional Action scenarios).

The diagram in Figure 13 shows the calibration example for one of the climate change drivers (severe weather); for each year the probability of the driver being in a particular state is calibrated, i.e., in this case the probability of the frequency of the severe weather to be in Low, Medium, High or Very High states.

FIGURE 13: CLIMATE CHANGE DRIVERS



As you can see, the frequency of severe weather is gravitating away from Low state and moving into High state; this particular example comes from the Early Action scenario and therefore has zero probability of the Severe Weather driver to be in Very High state. More detail about the calibration of the drivers can be found in the next section.

Model calibration

For our illustrative model we have aimed, as far as possible, to develop a generic calibration as a case study which reflects the broad characteristics and climate exposures of the real estate sector, without attempting to account for any specific features of a given economy or investment portfolio.

Economic

Data to help inform and predict the state of the economic drivers can be obtained indirectly via the identification and observation of factors expected to be leading indicators. Whether a significant correlation exists, and to what extent, will depend upon the market under consideration, and the data window used. Appropriate regression analyses can be performed in order to explore and justify relationships used to inform the behaviour of the economic drivers. This data-driven approach can be very useful in cases where we want to consider driver variables (e.g., Inflation) that have established relationships with other factors such as exchange rates or commodity prices and where data is available over a sufficient horizon to underpin analysis.

In our work, we have found that regression analysis can be helpful to guide a short-term forward view. However, where one is taking a longer-term view, or where one expects near-term market conditions to diverge significantly from past experience, then setting the state probabilities inevitably relies more heavily on judgement.

To establish the causal effects of each of the economic drivers on nodes further up the network, we take the following approach:

1. **Establish a sensible partition for the node states:** This involves defining what is meant by saying “High” inflation for the Inflation node, or “Recession” for the GDP node. This could involve commonly used definitions (e.g., a recession as two consecutive quarters of negative GDP growth), or nonstandard interpretations to suit the particular application of the model.

2. **Perform analysis to quantify a causal relationship:** Once one has defined driver states, one can look at data for the nodes influenced by the drivers, and try to quantify the causal relationship. If driver node X influences node Y, and node X has two states (A and B), we will want to find conditional distributions for Y|(X in state A), and Y|(X in state B). For example, this could involve examining the sample distributions of Earnings Growth in recessionary quarters, and Earnings Growth during quarters of normal GDP growth.
3. **Validate:** Confirm that the distributions obtained for non-driver nodes stand up to sense checks, for example in relation to the behaviour of historical market data where relevant.

The economic components of return nodes are calibrated by fitting analytical distributions to the data, with distributional selections and parametrisations guided by the broad features of the data and states of the driver variables:

- We first excluded certain distributions based on the broad features of what the node in question represents—for example, if it does not make sense for an economic component of return to have a negative value, one should exclude distributions whose supports are not strictly positive.
- Then one can use statistical techniques such as minimising the Akaike Information Criterion[14] (a log-likelihood measure which penalises increased complexity) to inform the selection of a distribution and parameters.

Forecast returns are calculated as follows, based on preceding nodes:

- *Capital Return = Valuation Impact * Earnings Growth – 1*
- *Dividend Return = Current Dividend Yield * Earnings Growth * Payout Ratio Change*
- *Total Return = Capital Return + Dividend Return*

Climate

Unlike the calibration of the economic drivers, using data-driven regression analysis to inform the states of the climate drivers is likely to be more challenging and for many potential drivers less helpful for a variety of reasons, but chiefly:

- It is not necessarily expected that past experience will be a good indicator of future outcomes.
- The behaviour of potential indicator variables may be such that any correlation with our specified climate drivers emerges only over a long time horizon during which other changes and influences also emerge, making it harder to separate signal from noise.

Where a data-driven approach is infeasible, progress can still be made by leveraging a robust process to form a set of expert judgements to support the analysis—these judgements are then tested and refined over time. In a realistic setting, a process for this would involve the following steps:

- Workshops with experts from the business, aiming to have a group who bring a reasonably diverse set of perspectives so they can spark ideas off each other. The aim is to have a discussion about the states of the climate drivers (what constitutes High/Medium/Low change in a particular climate variable) and what is viewed as a probability of being in each state going forward.
- The discussion can be backed by data, where available.
- Then the summary of discussion and data is converted into calibration. Once calibrated, various scenarios can be run in the model, to gauge the reasonableness of results—this typically is played back to the experts, and the calibration can be refined as a result. The scenarios can be used for back-testing the model as well.

The above approach works well in reality but is disproportionate and difficult to apply to a theoretical case study. Thus, our approach in the case study used a combination of existing data and projections—we used the physical and transition variable pathways provided by the Bank of England as part of the CBES to inform the partitioning of our climate state drivers. This was supplemented by a set of purely illustrative judgements.

We also would like to point out that the CBES scenarios for physical risks consider multiple geographies. As we aimed to have a generic model for our illustrative case studies, the calibration used data across the full range of territories and so is not specific to any particular country or region. However, transitional risk-related calibration is more UK-specific as it is driven mainly by assumptions about the UK policies and regulations, those which are already in place and those anticipated.

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[14] AIC = (-2) * (Log-Likelihood) + 2 * (Number of parameters).

Also, the calibration considered the Real Estate Management and Development sector (GICS 601020)—as indicated in previous sections, we felt that the impact on the returns for this sector is tilted towards transition risk. We will comment on the specific points on calibration where we think the calibration would markedly differ for the Equity Real Estate Investment Trusts (REITs) sector.

The climate driver nodes impact the next layer of nodes in the network in the following ways:

- Property damage: Weighted aggregation of probability states of Rain and Severe Weather nodes, with a greater impact from Rain than Severe Weather. It was felt that in the context of Property Damage, heavy rainfall and subsequent flooding was likely to be more impactful than storms and other severe single climatic weather events in terms of:
    - A larger potential drag on property values
    - A larger potential inflator of property repair costs
- There is evidence that property prices revert to the trend following damaging weather events,[15] but whether this is an indicator that markets already incorporate some reasonable allowance for the associated risk—or whether such events simply fade over time as a focus and concern for investors (implying the risk becomes underpriced until the next event)—is unclear.
- Costs and constraints: Weighted aggregation of probability states of Carbon Price, Access to Finance and Public Sentiment nodes. Carbon Price and Access to Finance have equal weighting, while Public Sentiment has less weighting. Transition to a low-carbon economy is expected to bring additional costs, which may be direct via carbon taxes or indirect as regulation constrains certain activity and forces changes to business models and associated operational processes. Where business models are subject to far-reaching change, then the risks associated with the provision of finance increase with the result that the supply may fall, as the risk pushes beyond the appetite of some lenders and its cost increases. For our generic illustration, we assumed that carbon price, increased cost of regulation and poorer access to finance influence the level of total costs associated with the climate change than Public Sentiment for the GICS sector chosen; in comparison, for the Equity Real Estate Investment Trusts, Public Sentiment can contribute more to the level of total costs (for example, through marketing materials and campaigns).
- Risk perception: Weighted aggregation of probability states of Severe Weather, Pubic Sentiment, Temperature and Sea Level, in that order. The perception among investors of the risk associated with real estate investment increases with coverage or experience of relevant climate-related events such as storm damage. Temperature-related events also contribute to a perception of increased climate risk. Public Sentiment may also affect levels of media coverage and thus levels of risk perception.

Property damage, costs, constraints and risk perception influence the Climate Impact on Valuation and Climate Impact on Earnings nodes in the following ways:

- Climate Impact on Valuation (discrete node where states are ranked) Weighted aggregation of (Time-Adjusted) Risk Perception and Costs/Constraints. The Risk Perception has a larger weighting and impact than Costs/Constraints.

  If investors begin to perceive real estate management and development investment as having more risk, they will negatively reappraise their valuations of future earnings. We made the illustrative assumption that the perception of the climate risk as a material risk is a more significant factor to the market view of the valuation multiplier than current or expected increases in costs associated with climate change through the increased regulation and poorer access to finance. However, it would be advisable in practice to run workshops and discussions with relevant experts to gauge judgement on the importance of the contribution to the costs from different factors, to get wider views and perspective.
- Climate Impact on Valuation (continuous distribution node): Weighted convolution of the probability distributions assigned to the states of the Climate Impact on Valuation (discrete) node; it translates the level of impact on the valuation multiple expressed in discrete terms (High/Medium/Low) into numerical impact. Again, here the calibration could be different for REITS, with the impact on valuation being higher for the same state (e.g., level perceived as High).

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[15] Beltrán, A., Maddison, D. & Elliott, R. J. R. (2018). Is Flood Risk Capitalised Into Property Values? Ecological Economics, 146: 668-685.

- Climate Impact on Earnings (discrete node where states are ranked): Weighted aggregation of Property Damage and Costs/Constraints nodes. We assumed that Property Damage has more material contribution to the level of impact on earnings from the climate change than the costs from climate change policies and other costs associated with the climate change, as it has a more immediate effect on earnings.
- Climate Impact on Earnings (continuous distribution node): Weighted convolution of probability distributions associated with the states of the Climate Impact on Earnings (discrete) node; similarly to above, it translates the level of impact earnings expressed in discrete terms (High/Medium/Low) into numerical impact. Again, here the calibration could be different for REITS, with the impact on earnings being different for the same state (e.g., level of impact on earnings perceived as High)—this can be informed by the combination of expert judgement and data, available for the specific portfolio.

Model scenarios and results

In this section we present results, to illustrate the workings of the model and how it responds to the changes in the climate-related factors considered; we demonstrate the results for a ”climate-neutral” model and also for different developments of climate change scenarios.

The ”climate-neutral” version of our model is one in which the Climate Impact on Earnings and Climate Impact on Valuation nodes have no impact on economic factors further up the model. This essentially means the climate section of our model has been “switched off,” and we are considering a counterfactual scenario in which climate change is either not occurring, or has no bearing on investment decisions. This is only a modelling approximation, as in reality the economic and market data on which our model is calibrated is likely to include at least some market pricing of climate change impacts.[16]

Modelled scenarios

The climate scenarios are based on CBES scenarios of Early Action (EA), Late Action (LA) and No Additional Actions (NAA). The CBES scenarios describe different pathways of transition to a net-zero emission economy and provide pathways for the climate parameters based on the speed and order of that transition. Here is an overview of the CBES scenarios:

- **Early Action**: The transition to a net-zero emissions economy starts in 2021—carbon taxes and other policies intensify relatively gradually over the scenario horizon. Global carbon dioxide emissions (and all greenhouse gas emissions in the UK) drop to net-zero around 2050.
- **Late Action**: The transition is delayed until 2031, at which point there is a sudden increase in the intensity of climate policy. In the UK, greenhouse gas emissions are successfully reduced to net-zero around 2050, but the transition required to achieve that is more abrupt and therefore disorderly.
- **No Additional Action**: No new climate policies are introduced beyond those already implemented prior to 2021.

Note that the CBES scenarios are defined over 30 years. We have limited our modelling to a shorter projection period of 10 years. Nevertheless, in order to illustrate the impacts of the development of various factors, we have compressed the changes contemplated by the CBES scenarios into our timeframe. The primary reason for this is simplification and ease of illustration. However, we also note that investment markets would be expected to price these changes in well before they actually occur.

The key features of our scenarios are summarised in Figure 14.

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[16] Schlenker, Wolfram & Taylor, Charles (February 2019). Market Expectations About Climate Change. NBER Working Paper No. w25554.

FIGURE 14: MODELLED SCENARIOS – KEY FEATURES

<table>
<tr><td rowspan="2">Base Scenario</td><td>High inflation
Suppressed economic growth</td><td>Inflation is back to normal
Economic growth picking up</td></tr>
<tr><td colspan="2">Climate factors are neutral and do not have impact on the returns</td></tr>
<tr><td rowspan="3">Early Action</td><td colspan="2">Climate factors consistent with CBES EA scenario</td></tr>
<tr><td>Relatively high carbon price</td><td>Carbon price decreases and remains steady throughout the later years</td></tr>
<tr><td colspan="2">Sentiment remains positive throughout, and access to finance is relatively easy</td></tr>
<tr><td rowspan="4">Late Action</td><td>Climate factors as per EA</td><td>Climate factors deteriorate slightly creating a drag on returns</td></tr>
<tr><td>Low carbon price indicating no policy introduction</td><td>Carbon price sharply increases and stays high</td></tr>
<tr><td colspan="2">Sentiment starts from neutral/negative and quickly deteriorating to negative; late policy introduction does not help improve the public and analysts’ sentiment</td></tr>
<tr><td>Access to finance is not affected at the start</td><td>Access to finance starts getting poorer</td></tr>
<tr><td rowspan="4">No Additional Action</td><td colspan="2">Climate factors as per CBES NAA scenario, with increasing frequency of severe weather, rising sea level, temperature and precipitation</td></tr>
<tr><td colspan="2">Carbon price is low throughout the timeline</td></tr>
<tr><td colspan="2">Sentiment quickly deteriorating to very negative and remains at this level</td></tr>
<tr><td colspan="2">Access to finance is affected from early years and deteriorates to poor towards the end</td></tr>
</table>

Note that in all scenarios (Base, EA, LA and NAA) we have adopted common economic assumptions, namely, high inflation and recessionary GDP outlook for the first three years of the modelled 10-year horizon. The Base scenario is the ”climate-neutral” model described above, in which all explicit climate factors are ignored.

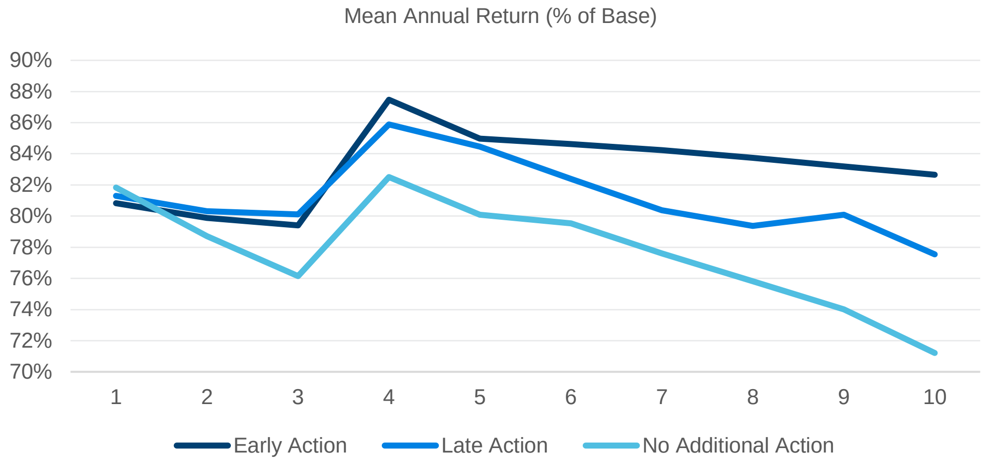
The LA scenario starts with a low carbon price followed by sharp and abrupt increases in later years, signifying sudden changes in policies and regulations, which brings some disruption and therefore a drag on the returns, Contrary to the EA scenario, the ”sentiment” driver within this scenario is less positive as it is expected that public opinion and markets would not entirely welcome non-introduction of regulations initially. In this scenario, the policies are introduced later in the timeline and it is modelled through a sharply increased carbon price (as a proxy in our model for cost of regulations), which creates a further drag on the returns. Additionally, physical climate change impacts start to appear towards the end of the projection timeline.

The NAA scenario, on the other hand, is modelled to not have any impact from the carbon price node (as a proxy for the cost of regulations) but is impacted significantly by negative sentiment and physical climate factors changing and increasing in intensity over the years.

Modelled results

The graph in Figure 15 shows how the total return as a proportion of the return for the Base scenario is impacted.

FIGURE 15: IMPACT OF CLIMATE RISKS ON EXPECTED RETURNS



Projected mean returns for our asset class are below those expected in the Base (climate-neutral) conditions across all scenarios. With high awareness of climate change and burgeoning regulation very much a feature of the current economic and political environment, when we move from Base to each of our climate scenarios, our results quickly reflect priced-in future costs and drags on returns associated with climate-related financial risk. Views can certainly differ around this, and other configurations of the model could reflect a more gradual path.

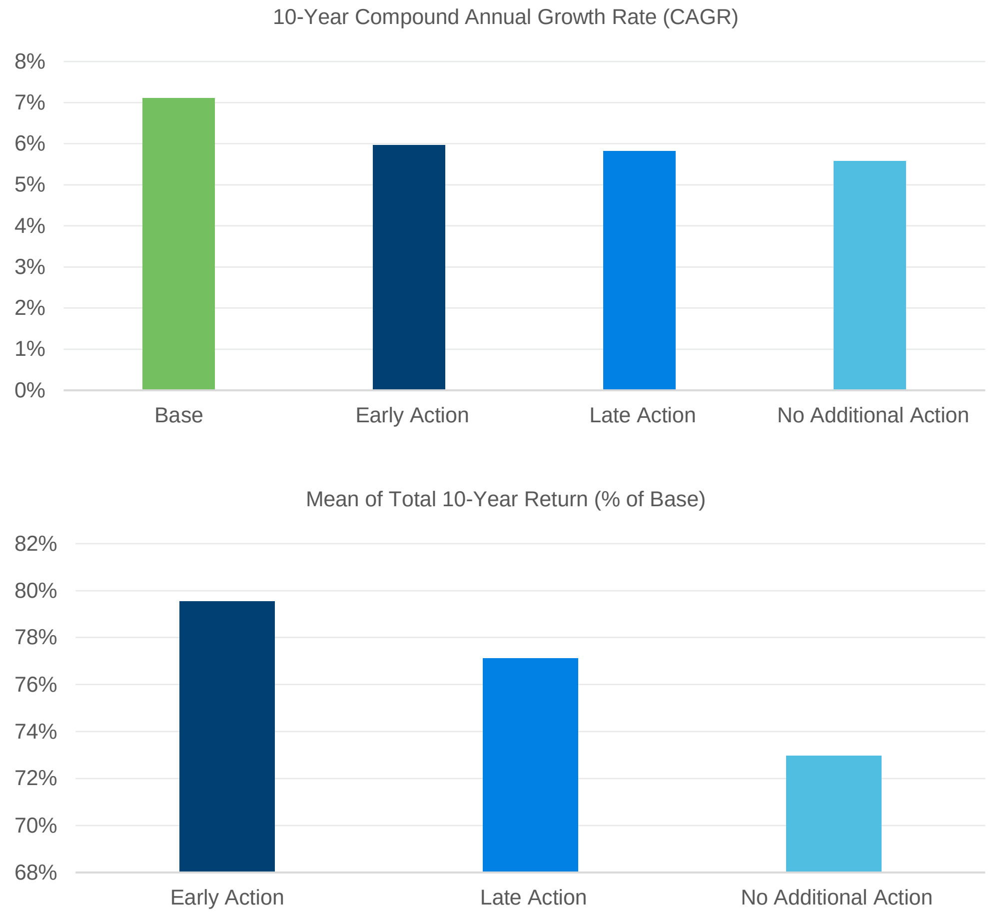
The spike in returns around Year 4 is due to our assumption of adverse economic conditions in the early part of the projection, which are followed by a rapid recovery to more typical long-term conditions.

For all scenarios the returns start from approximately the same place, with NAA return being the highest at outset. The EA and LA scenarios display returns that initially follow each other closely, where EA returns are experiencing the drag from the carbon price impact and LA returns are being impacted more by negative sentiment. It is interesting to note that total return is impacted in a similar way over the initial five years despite the causal drivers for these two scenarios being different.

In later years, however, the LA scenario returns succumb to the abruptly increasing carbon price, continuing negative sentiment and somewhat restricted access to finance for companies in this sector. One observation worth pointing out is that the property sector we are considering has a substantial part of returns coming through the dividend yield, which is fairly resilient in our scenarios as we have kept the fundamentals of the equity markets unaffected by climate within our model—the relationship between earnings and payout ratio remains as in the ”pre-climate” model, where in the years of lower earnings the payout ratio increases to keep the dividend fairly stable. In our climate scenarios this leads to an increasing payout ratio, with more income being paid out as dividends year on year. In reality, while firms may well seek to support dividends out of reserves for a period, if earnings come under sustained pressure there will inevitably come a time when this is no longer feasible and dividends are cut. Our illustrative model does not capture this effect, but it is a refinement that could be added.

The total 10-year returns shown before follow the story above, with returns getting progressively lower when moving from the Base scenario to the NAA scenario.

FIGURE 16: IMPACT OF CLIMATE RISKS ON EXPECTED RETURNS



The drag on returns for EA, LA and NAA compared to the ”pre-climate” model returns is largely consistent with the CBES analysis.

The other part of the story that emerges from our causal model is that climate risk increases the uncertainty over future returns. Figure 17 indicates an elevated standard deviation of future returns across all three scenarios considered but with the EA scenario delivering a more stable outcome over time versus the other two scenarios, which point to increasing uncertainty in the later periods.

FIGURE 17: IMPACT OF CLIMATE RISKS ON VOLATILITY OF RETURNS

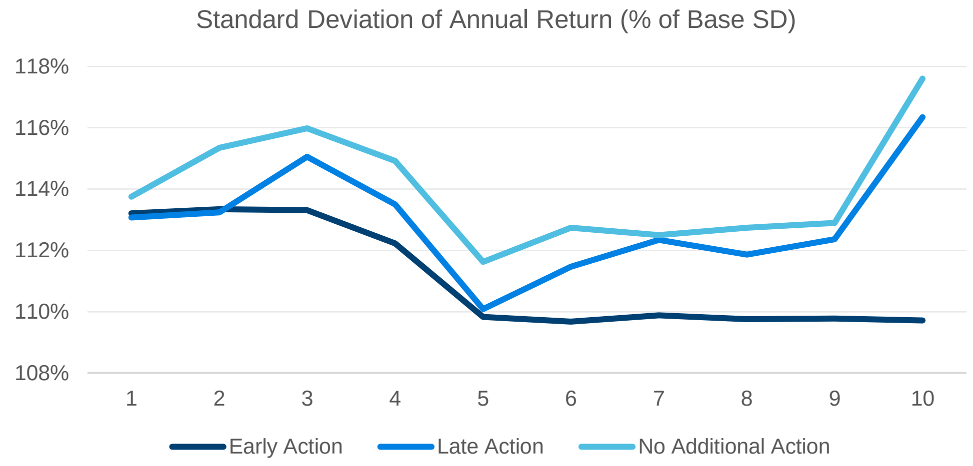
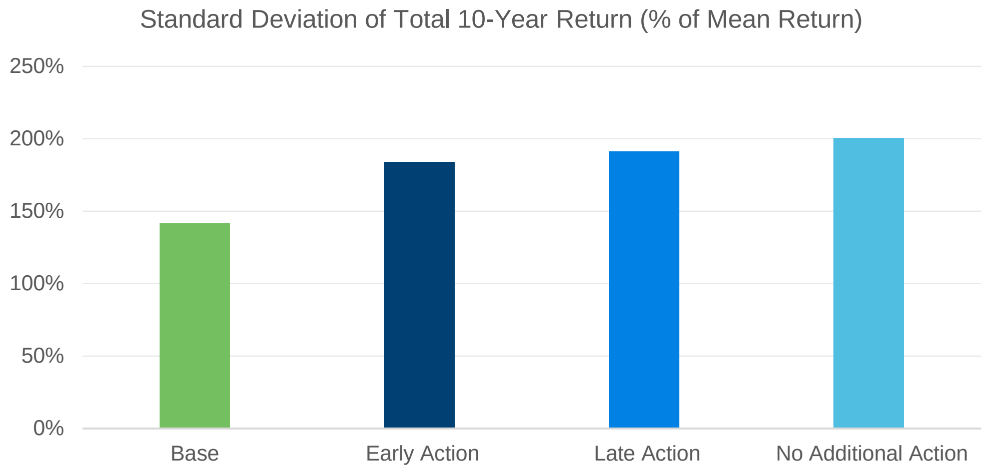


FIGURE 17: IMPACT OF CLIMATE RISKS ON VOLATILITY OF RETURNS (CONTINUED)



Overall, the modelling results demonstrate how the climate change drivers work in combination and how they may develop over time. As expected, the EA scenario shows the highest total return and the highest certainty (though both returns and certainty are lower than for the Base case). The LA scenario, despite starting from a higher return than EA, exhibits a bigger drag on return over the modelled period, with increasing uncertainty. The NAA scenario exhibits the highest negative impact on returns and the biggest uncertainty around the level of returns.

Possible model extensions

As discussed earlier, one of the main features of causal models is that they can easily be further developed and adapted, following an improved understanding of the relationship between climate factors and asset returns, development of this relationship in time or taking account of other emerging factors. The model developed as a case study for this paper is an initial attempt to model the impact of climate factors on a specific equity sector. This model can be adapted to be used for different sectors (which might involve inclusion of additional or different drivers, specific for the sector) or include different interactions between the drivers. Below are examples of the potential extensions:

- An alternative structure can be explored, e.g., impact of the climate drivers on the margins rather than directly on earnings, as a different approach to allow for pass-through of some of the climate costs to end consumers.
- In the current model, the economic drivers remain isolated from the climate drivers, i.e., there is no interaction between them. It is possible to further develop the model to include the relationship between the climate drivers and, say, GDP growth. It may be also worth looking into how the fundamentals of the modelled sector might change, i.e., the relationships between earnings and valuation multiple, and earnings and payout ratio.
- When modelling other sectors, additional climate drivers can be included—for example, for Consumer Staples, agricultural yield can be added to the climate drivers with the influence on the GICS L2 Food sector.
- The modelling can become more nuanced, for example not only allowing for the increase in precipitation, but for whether it has a seasonal impact, i.e., increases in summer, decreases in winter. These sorts of nuances become more important to the outcomes of the model when considering the specifics of a given portfolio, rather than the example model we have developed.

Summary

The results from our illustrative model, that climate influences are likely to reduce expected future investment returns and increase risk,[17] are not immediately encouraging though they are not surprising. However, we must hold up our hands at this point and admit that the positive effects of current and future mitigation and adaptation strategies are not well reflected in our simple model; however, neither are all of the complexities of the problem. We are aware that there are many developments and initiatives underway (e.g., carbon sequestration through regenerative farming or direct air capture technologies) that together offer the prospect of a far more positive outcome. Such influences are currently very challenging to quantify in terms of impact and timing, but in a real-world application a causal modelling approach would still enable us to make a start based on current knowledge and judgements. We are not claiming causal modelling to be a crystal ball into the future of what climate change holds. However, we hope to have demonstrated that, as a decision support tool, causal modelling can help users get a better frame of reference and appreciate the dynamics of a complex problem like climate change. This should help institutions get a feel for the particular challenges posed to their business models and their key drivers and then help explore potential mitigating solutions based on the information we have available now.

We hope this paper has provided an interesting insight into causal modelling generally and possible applications to explore climate risk impacts in particular.

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[17] As measured by return volatility

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