IIF Distinguished Lecture Series on:

“Climate Change Forecasting with Econometric Methods”

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Extreme weather events occurring around the world are a daily reminder that our climate is rapidly changing. As greenhouse gas emissions like carbon dioxide, nitrous oxide and methane are a major cause of climate change, and are generated by human activity, it is not surprising that the tool set designed to empirically investigate economic outcomes should be applicable to studying many empirical aspects of climate change. Economic and climate time series exhibit many commonalities. Both data are subject to non-stationarities in the form of evolving stochastic trends and sudden distributional shifts. Consequently, the well-developed machinery for modelling and forecasting economic time series can be fruitfully applied to climate data. To understand how the climate is changing and prepare for the future, both in terms of mitigation and adaptation, we need accurate forecasts of the climate. This IIF Distinguished Lecture Series explores the use of econometric forecasting tools in climate-economic research.

OUTLINE

Lecture 1: *Econometric Forecasting of Climate Change*

We discuss how climate scientists and climate econometricians produce forecasts, drawing parallels between the scenario projections of climate scientists based on varying initial conditions and the conditional forecasts of econometricians capturing model uncertainty. The success of forecasts made by either approach hinges on the ability to handle unanticipated shifts as climate change is characterised by ‘the change in the change’. While unanticipated changes cannot be avoided, whether shifts that were once in the future were expected or not, they later become in-sample, so empirical modeling must take account of those to avoid distortions in parameter estimates and the resulting forecasts. We look at why it is important to identify and model shifts and how doing so improves the verisimilitude of the model and its forecasts. Using indicator saturation estimators to capture in-sample shifts, improved econometric models and their forecasts can be achieved, as demonstrated within a system of four of the key climate variables consistent with a physical model of energy balance; atmospheric CO_2, global mean surface temperature deviations, ocean heat content deviations and global sea-level rise. We also use saturation estimators to improve forecasting during shifts, with an application to forecasting the temperature response to volcanic eruptions from just one observation.

Lecture 2: *Climate Applications of Econometric Forecasting*

We first establish some key forecasting principles established from the results of large-scale forecasting competitions. These principles are then applied to two climate settings. We demonstrate how modern climate econometric methods can be used to investigate both long-run natural climate dynamics and contemporary anthropogenic emissions. First, we develop a simultaneous-equation model of ice volume, atmospheric CO_2 and temperature over the past 800,000 years, incorporating orbital forcing, dynamics, non-linearities and structural shifts to examine the causal role of CO_2 during the Ice Ages. The analysis finds that CO_2 was largely an endogenous component of the natural climate system during glacial cycles, while simulations with exogenously elevated CO_2 imply substantial future warming under continued anthropogenic emissions. Then we apply the same econometric framework to UK annual CO_2 emissions since 1860, showing how model selection and saturation estimation can identify the key drivers of emissions in the presence of structural change and non-stationarity. The results attribute the UK's long-run emissions decline primarily to changes in energy use and capital accumulation rather than income growth alone, illustrating how rigorous empirical modeling can improve understanding of climate processes, evaluate policy effectiveness, and inform pathways towards emissions reduction and climate resilience, as well as reject incorrect models like the Climate Kuznets Curve.

Lecture 3: ***Forecasting Climate Change using a Multivariate Cointegrated System***

The concept of cointegration is extremely useful in forecasting as it characterises non-stationary time series with long-run stable relationships between trending variables and short-run dynamic adjustments with feedback, providing regularities that can be forecast. One field in which cointegration has proven to be effective in modeling and forecasting underlying physical relationships is climate. We build a cointegrated vector equilibrium correction model of key climate variables including sea surface temperature, ocean heat content, Arctic sea-ice extent and sea-level change, driven by radiative forcing in which a stochastic trend arises due to anthropogenic emissions of greenhouse gases. A valid and congruent statistical model requires saturation estimation to model breaks in trends, while also conditioning on natural radiative forcings and El Niño–Southern Oscillation. The model is stable over 150 years, reflecting the slow adjustment of the deep oceans to increased greenhouse gas concentrations, and predicts an equilibrium climate sensitivity of 2.6°C. The cointegrated VAR methodology enables quantification of uncertainty, including model uncertainty, parameter estimation uncertainty and uncertainty over future paths of greenhouse gas emissions. The framework ensures a congruent model forms the basis of forecasting, where forecasts are driven by long-run stable cointegrating relationships proxying physical relationships, in which we produce projections out to 2100, which highlight likely sea-level rises.

Lecture 4: ***General-to-Specific Modeling of Hemispheric Sea Surface Temperatures under Anthropogenic Warming***

Typically, climate forecasting models focus on either short-run drivers to be used in weather forecasting applications, which include thermodynamics, circulation, radiation, clouds and remote modes, or the long-run relationships for climate change studies, driven by greenhouse gas emissions and aerosols, along with the transfer of heat to the deep oceans. We investigate the benefits of jointly modeling short-term (seasonal, cyclical) and long-term (anthropogenic) drivers of sea surface temperature changes to improve forecasts. The modeling approach undertaken is within the general-to-specific framework which allows for many possible explanatory factors, non-linear relationships, outliers and structural breaks. The approach uses the physical theory of the ocean heat budget to motivate the initial model specification but uses a statistical machine learning algorithm to identify the main drivers while ensuring a statistically congruent model specification. We disaggregate the model by hemisphere to allow for differing seasonal patterns while conditioning on the same greenhouse gas emissions. Short-run forecasts of sea surface temperature for each hemisphere show diverging trends with increasing seasonal variation. Scenario projections out to 2100 are produced using the same model, allowing for alternative greenhouse gas emissions paths based on shared socio-economic pathways which show rising sea surface temperatures in almost all scenarios. Policy implications will be drawn, including how we nearly avoided the climate crisis and sensitive intervention points to achieve net zero.