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Methods for modelling wide-sense non-stationary time series

(1) **Cointegration for stochastic trends.**

(2) **Indicator saturation estimators for outliers & shifts.**

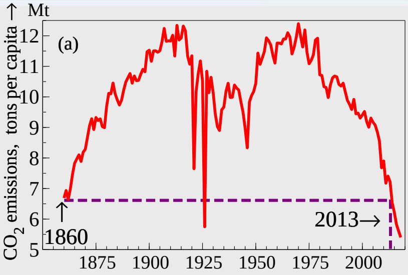
(3) **Model selection by machine learning for more candidate variables than observations.**

(4) **Retain theory-based models unaffected by selection.**

(5) **Rigorously test to evaluate empirical modelling outcomes.**

Many empirical applications to climate change issues.

Illustrative graphs of wide-sense non-stationarity: UK CO_2 emissions and fossil fuels



(a) UK's CO_2 emissions per capita below 1860, yet real incomes have risen more than 7-fold higher–highly non-stationary

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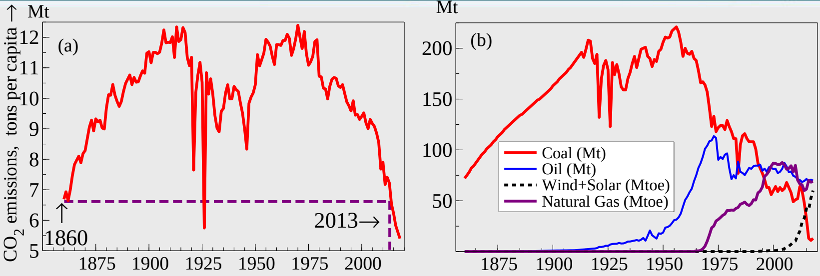
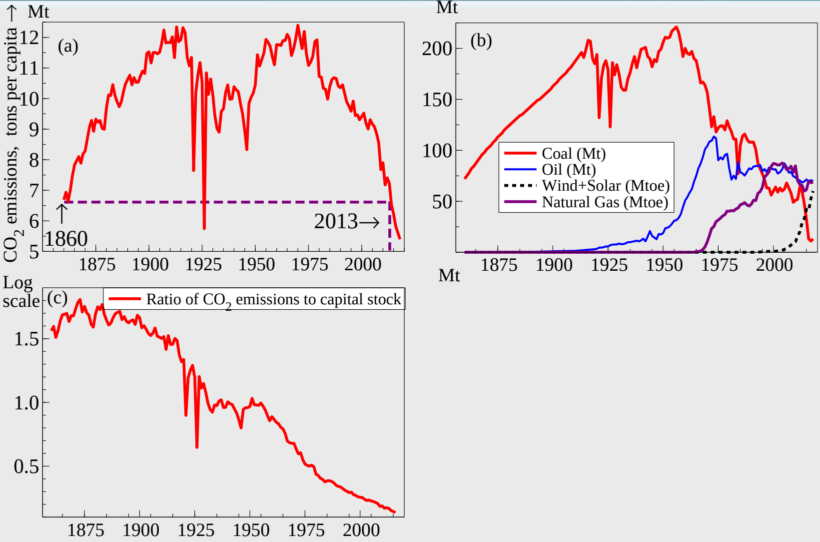


(b) CO_2 emissions mainly driven by coal usage till mid-1950s then that drops steadily, as does oil use after oil crises

Illustrative graphs of wide-sense non-stationarity: UK CO_2 emissions and fossil fuels



(c) UK's total CO_2 emissions relative to its capital stock have fallen by 92% from 1860

Illustrative graphs of wide-sense non-stationarity: UK CO_2 emissions and fossil fuels

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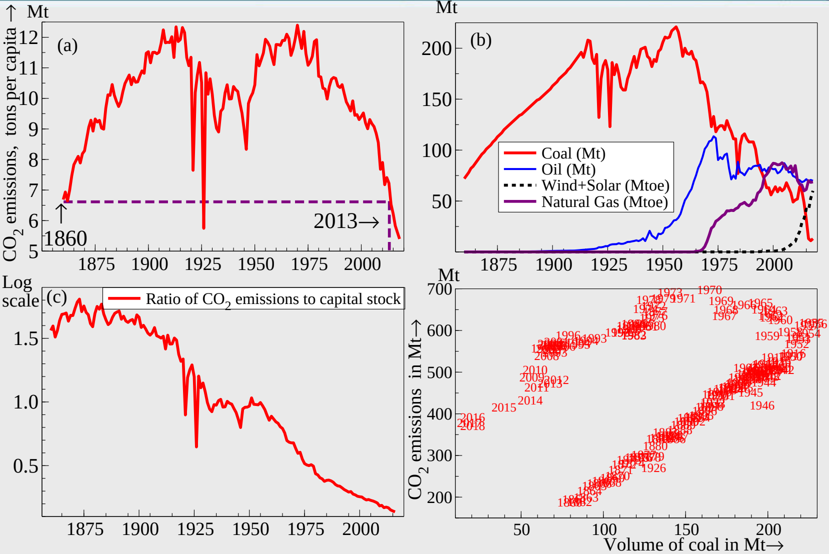
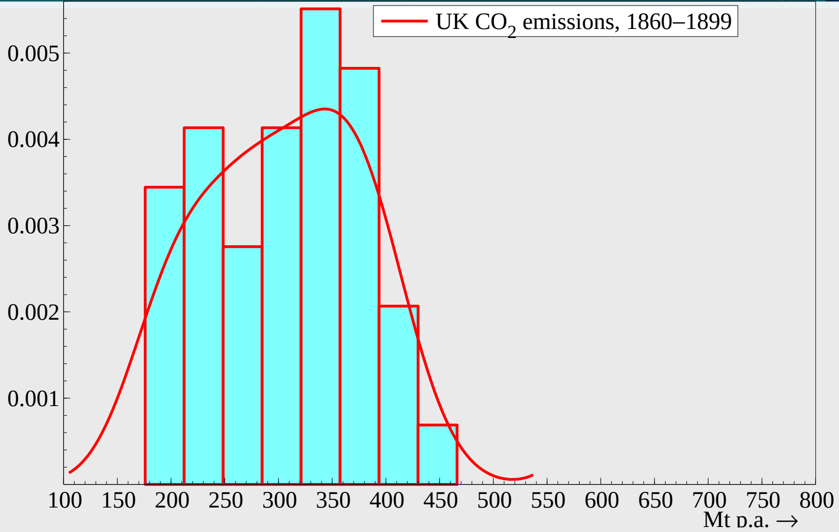


(d) CO_2 emissions have no constant relations to individual fuel usages: all variables vary hugely at different times

Distributional shifts of total UK CO2 emissions in Mt p.a.



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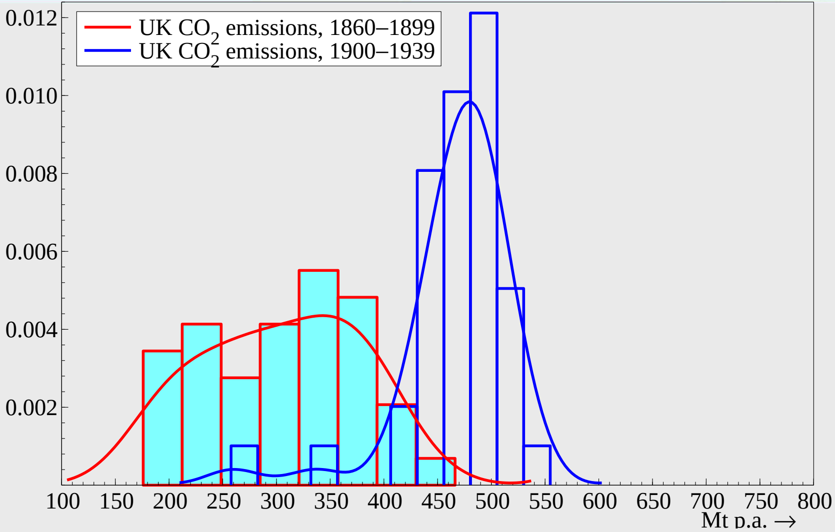

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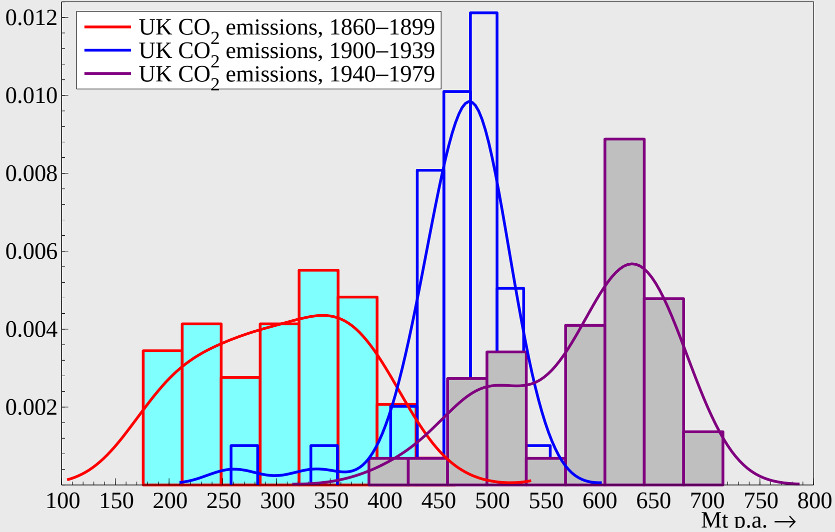

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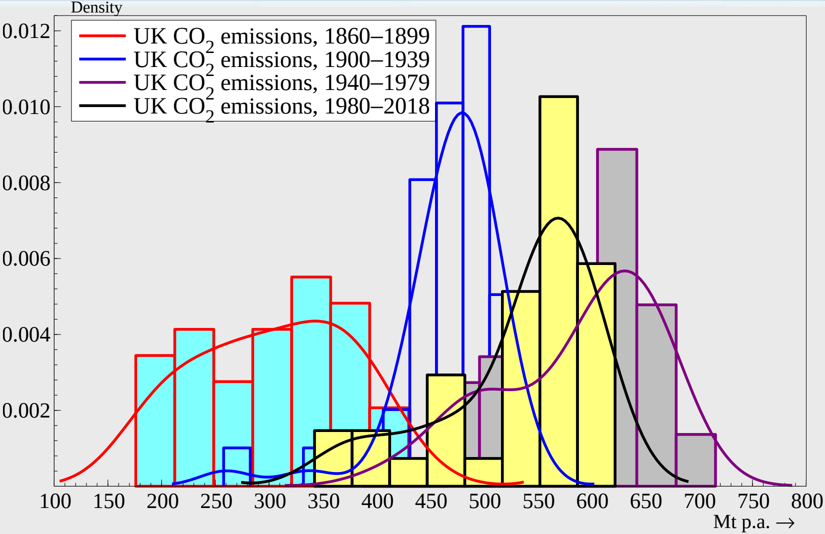

Model the evolving dynamic relation of UK's total CO_2 emissions by coal, oil, GDP and capital, allowing for shifts.

Five distinct sub-problems must be resolved simultaneously

Initial formulation—**ensure all relevant influences are included:** ***tackle by automatically creating*** **lags, non-linear functions, & indicator saturation**.

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Computation—**analyzing large numbers of candidate variables: must be fast as many sub-set multiple-block path searches.**

Approach embodied in *Autometrics*: Doornik and Hendry (2018)

Failing to include relevant variables & dynamics and handle large outliers and shifts can lead to rejecting a sound theory as shown in (e.g.) Hendry and Mizon (2011).

Hence to capture changing relations, the model includes:

(a) coal, C_t**; oil,** O_t**; capital stock,** K_t**; & GDP,** G_t;
(b) dynamics for adjustments to changes in technology, legislation & fuel prices;
(c) impulse indicators, $1_{\{t\}}$**, for outliers (e.g., mis-measurement, strike action)**;
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(c) & (d) indicators only capture features not explained by (a)–(b).

Transformed capital & GDP to logs k_t **&** g_t, **but linear for coal & oil**, C_t **and** O_t.

Model selection proceeds in four stages

First, **select impulse (IIS) and step (SIS) indicators at $\alpha_1 = 0.001$, with all other explanatory variables included freely but retained.**

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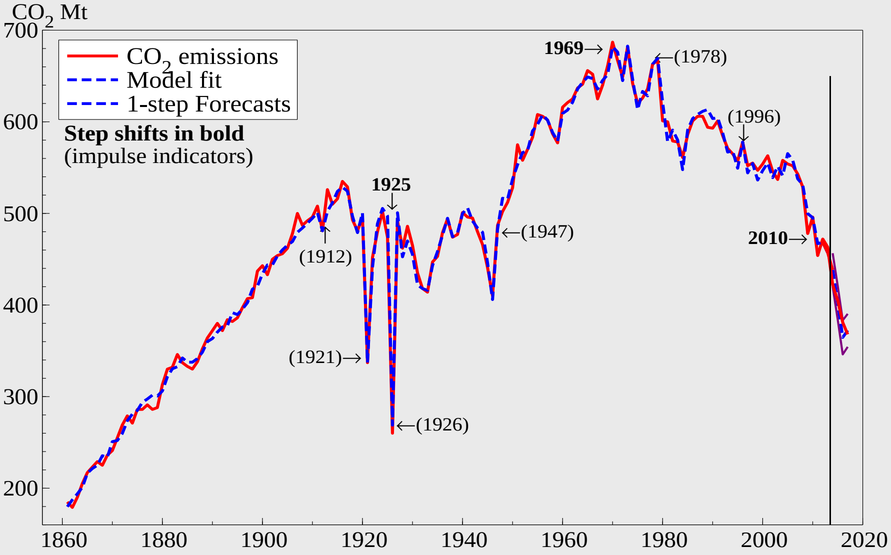
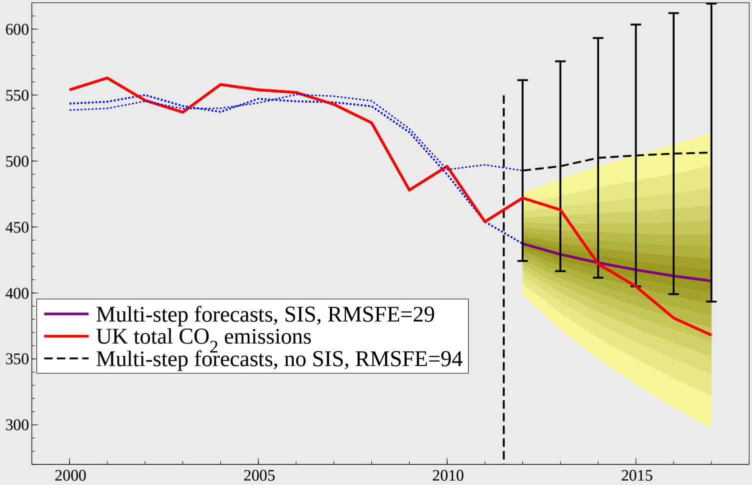
Over 1861–2013, five impulse plus three step indicators selected:
1926=Act of Parliament creating UK's nationwide electricity grid;
1969=start of conversion from coal gas to natural gas;
2010=Climate Change Act of 2008 plus EU's renewables directive of 2009.

Cointegration established and no diagnostic tests significant, including testing constancy to 2017.

Outcomes of modelling the UK's total CO_2 emissions

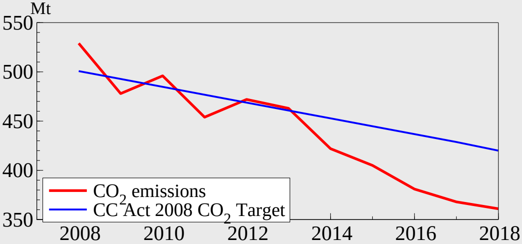


5-variable dynamic system multi-step forecasts



Emissions with h-step forecasts $\pm 2\widehat{\sigma}_f$ as fans with SIS, and bars without: little difference in fit, big difference in forecasts.

Testing UK's 2008 Climate Change Act 5 -year targets for CO_2:



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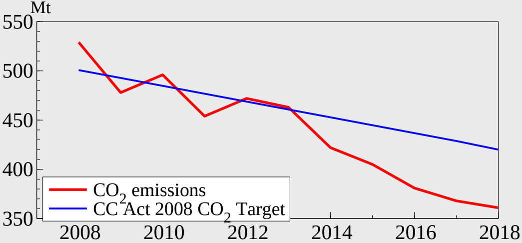

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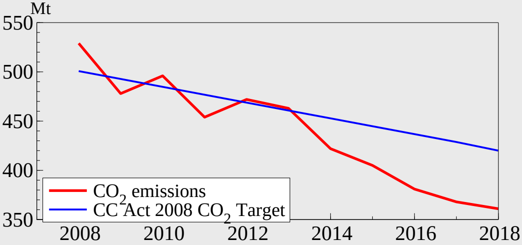

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Software available as *Autometrics* in *OxMetrics8* (Doornik and Hendry, 2018), *gets* in R (Pretis, Reade, and Sucarrat, 2018) and newly as XLModeler, an Excel Addin: https://xlmodeler.com/.

Thank You

References I

Doornik, J. A. and D. F. Hendry (2018). *Empirical Econometric Modelling using PcGive: Volume I.* (8th ed.). London: Timberlake Consultants Press.

Hendry, D. F. and G. E. Mizon (2011). Econometric modelling of time series with outlying observations. *Journal of Time Series Econometrics 3 (1)*, DOI: 10.2202/1941–1928.1100.

Pretis, F., J. J. Reade, and G. Sucarrat (2018). Automated general-to-specific (GETS) regression modeling and indicator saturation for outliers and structural breaks. *Journal of Statistical Software 68, 4*, https://www.jstatsoft.org/article/view/v086i03.