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Why Is the World Always Changing?

Abstract Empirical models used in disciplines as diverse as economics through to climatology analyze data assuming observations are from stationary processes even though the means and variances of most ‘real world’ time series change. We discuss some key sources of non-stationarity in demography, economics, politics and the environment, noting that (say) non-stationarity in economic data will ‘infect’ variables that are influenced by economics. Theory derivations, empirical models, forecasts and policy will go awry if the two forms of non-stationarity introduced above are not tackled. We illustrate non-stationary time series in a range of disciplines and discuss how to address the important difficulties that non-stationarity creates, as well as some potential benefits.

Keywords Sources of change · Wages, prices and productivity · Modelling non-stationarity

Many empirical models used in research and to guide policy in disciplines as diverse as economics to climate change analyze data by methods that assume observations come from stationary processes. However, most ‘real

world' time series are not stationary in that the means and variances of outcomes change over time. Present levels of knowledge, living standards, average age of death etc., are not highly unlikely draws from their distributions in medieval times, but come from distributions with very different means and variances. For example, the average age of death in London in the 1860s was around 45, whereas today it is closer to 80—a huge change in the mean. Moreover, some individuals in the 1860s lived twice the average, namely into their 90s, whereas today, no one lives twice the average age, so the relative variance has also changed.

3.1 Major Sources of Changes

As well as the two World Wars causing huge disruption, loss of life, and massive damage to infrastructure, there have been numerous smaller conflicts, which are still devastating for those caught up in such conflict. In addition to those dramatic shifts noted above as causes of structural breaks, we could also include for the UK the post World War I crash; the 1926 general strike; and the creation of the European Union with the UK joining the EU (but now threatening to leave). There were many policy regime shifts, including periods on then off the Gold Standard; the Bretton Woods agreement in 1945; floating exchange rates from 1973; in and out of the Exchange Rate Mechanism (ERM) till October 1992; Keynesian fiscal policies; then Monetarist; followed by inflation targeting policies; and the start of the Euro zone. All that against a background of numerous important and evolving changes: globalization and development worldwide with huge increases in living standards and reductions in extreme poverty; changes in inequality, demography, health, longevity, and migration; legal reforms and different social mores; huge technology advances in electricity, refrigeration, transport, communications (including telephones, radio, television, and now mobiles), flight, nuclear power, medicine, new materials, computers, and containerization, with major industrial decline from cotton, coal, steel, and shipbuilding industries virtually vanishing, but being replaced by businesses based on new technologies and services.

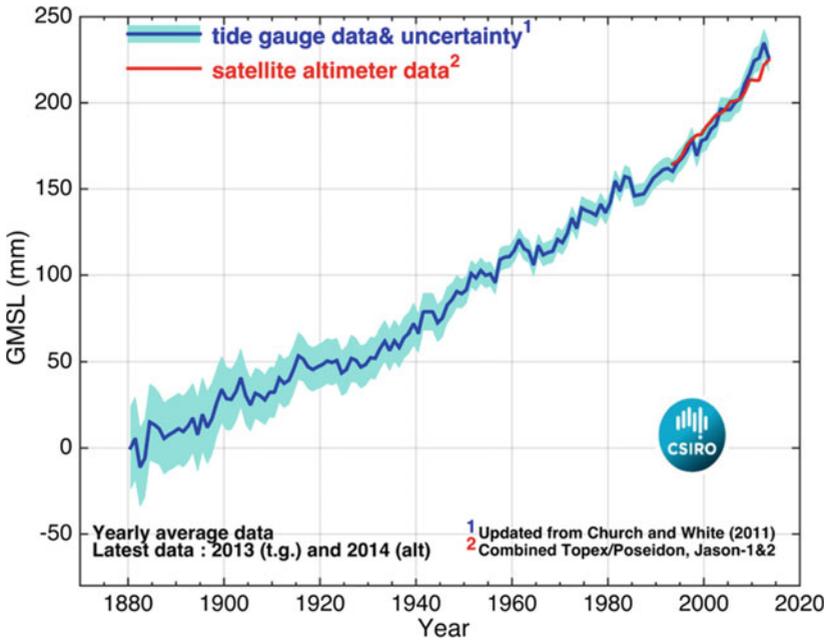


Fig. 3.1 Global mean sea-level (GMSL) has risen by more than 20 cm since 1880 (Source CSIRO)

Because economic data are non-stationary, that will ‘infect’ other variables which are influenced by economics (e.g., CO₂ emissions), and so spread like a pandemic to most socio-economic and related variables, and probably will feed back onto economics. Many theories, most empirical models of time series, and all forecasts will go awry when both forms of non-stationarity introduced above are not tackled. A key feature of processes where the distributions of outcomes shift over time is that probabilities of events calculated in one time period need not apply in another: ‘once in a hundred years’ can become ‘once a decade’. Flooding by storm surges becomes more likely with sea-levels rising from climate change. Figure 3.1 shows that global mean sea-level has risen over 20 cm since 1880, and is now rising at 3.4 mm p.a. versus 1.3 mm p.a. over 1850–1992 (see e.g., Jevrejeva et al. 2016).¹

¹See https://www.cmar.csiro.au/sealevel/sl_data_cmar.html.

More generally, an important source of changes are environmental, perhaps precipitated by social and economic behaviour like CO₂ emissions and their consequences, but also occurring naturally as with earthquakes, volcanic eruptions and phenomena like El Niño. Policy decisions have to take non-stationarities into account: as another obvious example, with increasing longevity, pension payments and life insurance commitments and contracts are affected.

We first provide more illustrations of non-stationary time series to emphasize how dramatically many have changed. Figure 3.2, left-hand panel graphs UK annual nominal wages and prices over the long historical period 1860–2014. These have changed radically over the last 150 years, rising by more than **70,000%** and **10,000%** respectively. Their rates of growth have also changed intermittently, as can be seen from the changing slopes of the graph lines. The magnitude of a 25% change is marked to clarify the scale. It is hard to imagine any ‘revamping’ of the statistical assumptions such that these outcomes could be construed as coming from stationary processes.²

Figure 3.2, right-hand panel, records productivity, measured as output per person per year, with real wages (i.e., in constant prices), namely the difference between the two (log) time series in the left-hand panel. Both trend strongly, but move closely together, albeit with distinct slope changes and ‘bumps’ en route. The ‘flat-lining’ after the ‘Great Recession’ of 2008–2012 is highlighted by the ellipse. The wider 25% change marker highlights the reduced scale. Nevertheless, both productivity and real wages have increased by about sevenfold over the period, a huge rise in living standards. This reflects a second key group of causes of the changing world: increased knowledge inducing technical and medical progress, embodied in the latest vintage of capital equipment used by an increasingly educated workforce.

Figure 3.3(a) plots annual wage inflation (price inflation is similar as Fig. 2.4(b) showed) to emphasize that changes, or growth rates, also can be non-stationary, here from both major shifts in means (the thicker black line in Panel (a)), as well as in variances. Compare the quiescent 50-year

²It is sometimes argued that economic time series could be stationary around a deterministic trend, but it seems unlikely that GDP would continue trending upwards if nobody worked.

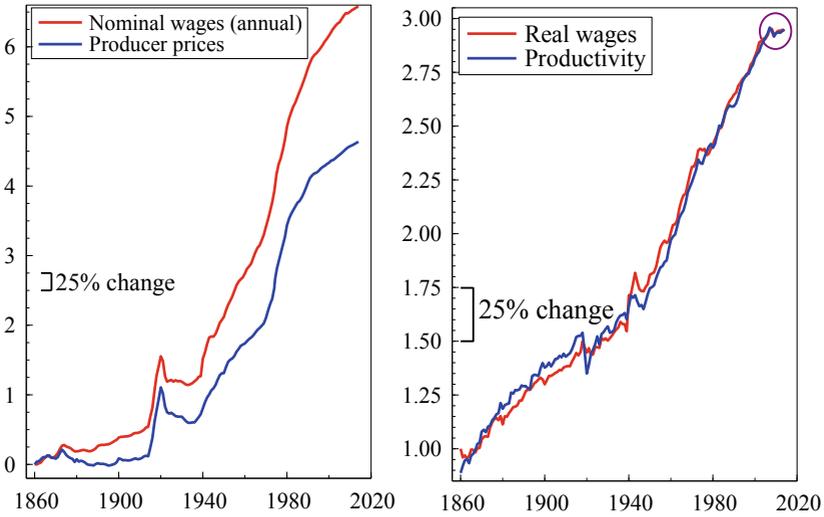


Fig. 3.2 Indexes of UK wages and prices (left-hand panel) and UK real wages and productivity (right-hand panel), both on log scales

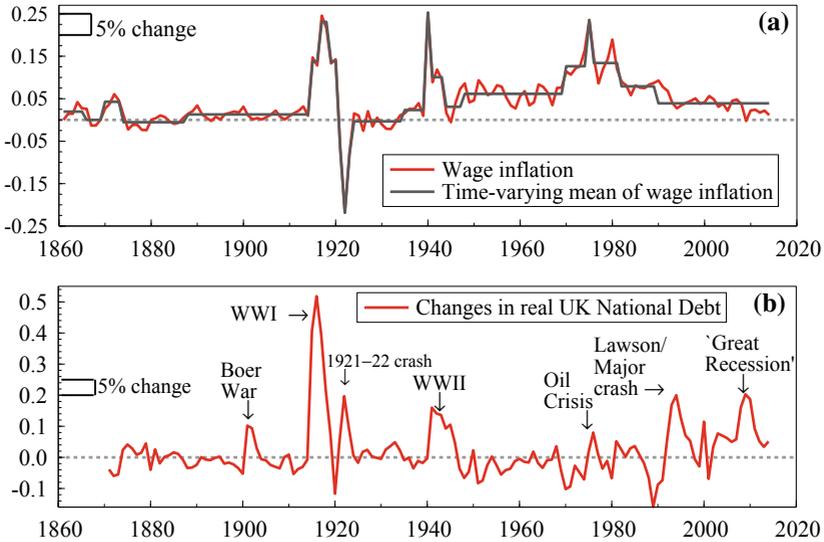


Fig. 3.3 (a) UK wage inflation; and (b) changes in real national debt with major historical events shown

period before 1914 with the following 50 years, noting the scale of 5% in (a). Historically, wages have fallen (and risen) more than 20% in a year.

Figure 3.3(b) records changes in real UK National Debt, with the associated events. In any empirical, observationally-based discipline, ‘causes’ can never be ‘proved’, merely attributed as overwhelmingly likely. The events shown on Fig. 3.3(b) nevertheless seem to be the proximate causes: real National Debt rises sharply in crises, including wars and major recessions. Even in constant prices, National Debt has on occasion risen by 50% in a year—and that despite inflation then being above 20%—although here the 5% scale is somewhat narrower than in (a). Wars and major recessions are the third set of reasons why the world is ever changing, although at a deeper level of explanation one might seek to understand their causes.

None of the above real-world time series has a constant mean or variance, so cannot be stationary. The two distinct features of stochastic trends and sudden shifts are exhibited, namely ‘wandering’ widely, most apparent in Fig. 3.2, and suddenly shifting as in Fig. 3.3, features that will recur. Such phenomena are not limited to economic data, but were seen above in demographic and climatological time series.

Figure 3.4 illustrates the non-stationary nature of recent climate time series compared to ice-age cycles for global concentrations of atmospheric CO₂ relative to recent rapid annual increases (see e.g., Sundquist and Keeling 2009). The observations in the left-hand panel are at 1000 year intervals, over almost 800,000 years, whereas those in the right-hand panel are monthly, so at dramatically different frequencies.

Given the almost universal absence of stationarity in real-world time series, Hendry and Juselius (2000) delineated four issues with important consequences for empirical modelling, restated here as:

- (A) the key role of stationarity assumptions in empirical modelling and inference in many studies, despite its absence in data;
- (B) the potentially hazardous impacts on theory analyses, empirical modelling, forecasting and policy of incorrectly assuming stationarity;
- (C) the many sources of the two main forms of non-stationarity (evolution and abrupt shifts), that need to be considered when modelling;
- (D) yet fortunately, statistical analyses can often be undertaken to eliminate many of the most adverse effects of non-stationarity.

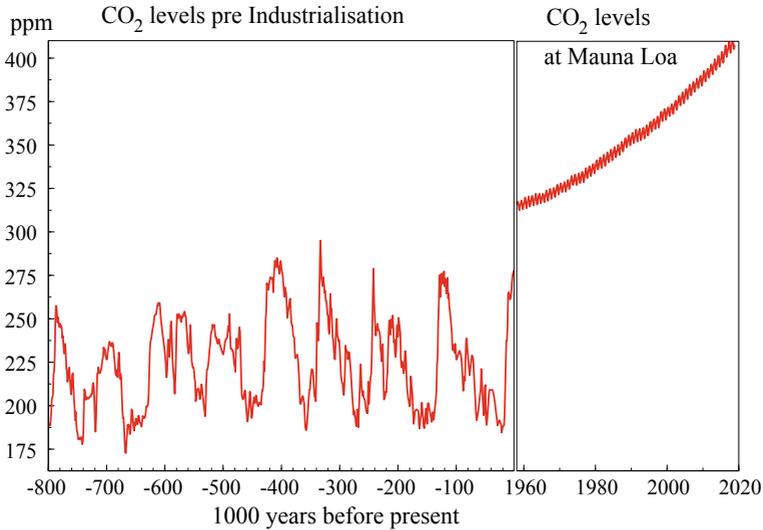


Fig. 3.4 Levels of atmospheric CO₂ in parts per million (ppm)

We now consider issues (A), (B) and (D) in turn: the sources referred to in (C) have been discussed immediately above.

3.2 Problems if Incorrectly Modelling Non-stationarity

(A) Theories and models of human behaviour that assume stationarity, so do not account for the non-stationarity in their data, will continually fail to explain outcomes. In a stationary world, the best predictor of what we expect an event to be like tomorrow should be based on all the information available today. This is the conditional expectation given all the relevant information. In elementary econometrics and statistics textbooks, such a conditional expectation is proved to provide the smallest variance of all unbiased predictors of the mean of the distribution. An implicit, and never stated, assumption is that the distributions over which such conditional expectations are calculated are constant over time. But if the mean of its distribution shifts, a conditional expectation today can predict a value

that is far from tomorrow's outcome. This will create a 'disequilibrium', where individuals who formed such expectations will need to adjust to their mistakes.

(B) In fact, the mathematical basis of much of 'modern' macroeconomics requires stationarity to be valid, and fails when distributions shift in unanticipated ways. As an analogy, continuing to use such mathematical tools in non-stationary worlds is akin to insisting on using Euclidian geometry to measure angles of triangles on a globe: then navigation can go seriously adrift. We return to this aspect in the next chapter.

In turn, the accuracy and precision of forecasts are affected by non-stationarity. Its presence leads to far larger interval forecasts (the range within which a forecaster anticipates the future values should lie) than would occur in stationary processes, so if a stationary model is incorrectly fitted, its calculated uncertainty can dramatically under-estimate the true uncertainty. This is part of the explanation for the nonsense-regressions issue we noted above. Worse still, unexpected location shifts usually lead to forecast failure, where forecast errors are systematically much larger than would be expected in the absence of shifts, as happened during the Financial Crisis and Great Recession over 2008–2012. Consequently, the uncertainty of forecasts can be much greater than that calculated from past data, both because the sources of evolution in data cumulate over time, and also because 'unknown unknowns' can occur, especially unanticipated location shifts.

Scenarios based on outcomes produced by simulating empirical models are often used in economic policy, for example, by the Bank of England in deciding its interest-rate decisions. When the model is a poor representation of the non-stationarities prevalent in the economy, policy changes (such as interest-rate increases) can actually cause location shifts that then lead to forecast failure, so after the event, what had seemed a good decision is seen to be badly based.

Thus, all four arenas of theory, modelling, forecasting and policy face serious hazards from non-stationarity unless it is appropriately handled. Fortunately, in each setting some actions can be taken, albeit providing palliative, rather than complete, solutions. Concerning theory derivations, there is an urgent need to develop approaches that allow for economic agents always facing disequilibrium settings, and needing error-correction

strategies after suffering unanticipated location shifts. Empirical modelling can detect and remove location shifts that have happened: for example, statistical tools for dealing with shifts enabled Statistics Norway to revise their economic forecasts within two weeks of the shock induced by the Lehmann Brothers bankruptcy in 2008. Modelling can also avoid the ‘nonsense relation’ problem by checking for genuine long-run connections between variables (called cointegration, the development of which led to a Nobel Prize for Sir Clive Granger), as well as embody feedbacks that help correct previous mistakes. Forecasting devices can allow for the ever-growing uncertainty arising from cumulating shocks. There are also methods for helping to robustify forecasts against systematic failure after unanticipated location shifts. Tests have been formulated to check for policy changes having caused location shifts in the available data, and if found, warn against the use of those models for making future policy decisions.

(D) Finally, although non-stationary time series data are harder to model and forecast, there are some important benefits deriving from non-stationarity. Long-run relationships are difficult to isolate with stationary data: since all connections between variables persist unchanged over time, it is not easy to determine genuine causal links. However, cumulated shocks help reveal what relationships stay together (i.e., cointegrate) for long time periods. This is even more true of location shifts, where only connected variables will move together after a shift (called co-breaking). Such shifts also alter the correlations between variables, facilitating more accurate estimates of empirical models, and revealing what variables are not consistently connected. Strong trends and location shifts can also highlight genuine connections, such as cointegration, through a fog of measurement errors in data series. Lastly, past location shifts allow the tests noted in the previous paragraph to be implemented before a wrong policy is adopted. The next chapter considers how to model trends and shifts and the potential benefits of doing so.

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