Models have their limitations – but they *are* useful[1]

- *The real world is complex. Hence climate, economic, and financial analysts build models*
- *They have to be suitable for purpose, be it simulating, developing scenarios, or forecasting*
- *Models can sometimes also give insight into the properties of the system that they depict*
- *Many considerations affect model design, including complexity, history, memory, and size*
- *Our CEF model captures key climate, economic, and financial system interactions*
- *Our model is easy to understand, has no 'black boxing', and is economical to set up and run*

The world's climate, economic, and financial systems are highly complex – and the interactions between them are even more so. To have any hope of understanding these, the human mind needs all the help it can get.

Hence models. Climate scientists, economists, and financial analysts all construct them. They know that their models are simplifications of reality; but they also appreciate that that is also their virtue.

Simulation models are libraries

A model can be thought of as a 'library' of all the various relationships that an analyst has come to consider important.[2] It thereby equips the analyst to think through and simulate, carefully, the implications of changing one thing at a time – an essential process if muddle is to be avoided – while at the same time not forgetting other relationships that have been found to be important.

On occasion, a model may even surprise, suggesting properties of the complex system that it represents that had hitherto not been suspected.

- For example, a fairly small global linkage model, OECD's INTERLINK, was found to exhibit the apparently odd simulation property that not only did a large *rise* in world oil prices cause a slowdown in world GDP, but so too did a large *fall* in oil prices. While this seemed counterintuitive, careful investigation found that, as one person put it at the time "*the model is trying to tell us something"*. Indeed, it was, and it was right.[3]

Models perform other functions too, and be used in a variety of modes, depending on purpose. But, they need to be used carefully.

Projection

Often, projections deliberately embody at least some assumptions that are known to be unrealistic. But this can be a virtue. In medium-term projections of GDP, trend-like factors of importance will typically be included, but cyclical factors will not. This makes sense: while business cycles are important conjuncturally, they cannot be predicted very far ahead; and in any case they are not the important part of any medium-term story.

On occasion, not least in policymaking, simulations can be particularly useful in revealing not what is likely to happen, but rather what is not.

- For example, a projection of world temperature on the assumption that world GDP continues to grow at its historical average rate (3% per year), and that greenhouse gas emissions continue to grow in the same relationship with world GDP as they have had historically (two-thirds as fast), produces a mean world temperature of around 3.5°C above pre-industrial levels.

  This – it is to be hoped – is most unlikely to happen. Long before such a temperature is reached and much of human life on earth becomes unsupportable, it is to be hoped that policy will have intervened, whether to slow GDP growth or (preferably) to change the relationship between emissions and economic growth.

Forecasting

While technically forecasting is like a projection, it has the added requirement that *all,* not just *some,* of the assumptions/inputs are deemed to be realistic. Thus, whereas a medium-term projection of GDP will generally not attempt to simulate the economic cycle, a forecast should, and will.

- For example, forecasts by economists in the private sector – and particularly those serving traders and other high-frequency decisionmakers – will include forecasts of what policy itself will do. By contrast, policy so-called forecasts, whether made nationally or by the international organisations, are often really projections, the purpose of which is to show what is most likely to happen on present policies. The aim is to give policymakers a basis for considering whether they want to change policy settings.

Considerations in the construction of a model

Given that all models are reduced forms of the highly complex world that they seek to depict, much of the skill in designing and building a model lies in ensuring that it is well suited to focus on specific issues.

Thought has to be given to a range of considerations, including: 'complexity and detail'; 'history; 'memory'; and size. These issues, while important, are scarcely esoteric: there are for example many analogies with map-making.

Complexity and detail

The appropriate degree of detail, and thereby complexity, of a map is a function largely of the purpose to which it is to be put.

The granularity that a traveller will require will depend on whether he or she will be walking a short distance within a town, driving a significant distance from one town to another, or flying a great distance between countries. Similarly, it may be appropriate, depending on purpose, for the map to show political boundaries, geographic features, or geological structure. So it is with models.

- For example, in the early 1980s, following the popularising of the theory of rational expectations by Lucas and Sargent in the 1970s, Rudi Dornbush became interested in simulating the effects in an international linkage model. However, modifying appropriately even the OECD's relatively small INTERLINK model, let alone Lawrence Klein's huge LINK model, would have been a demanding and time-consuming task.

  So Dornbush built one over a weekend, on a small desk-top computer, using parameter values given to him by Paul Krugman. His model was able to address fewer issues than INTERLINK could, and far, far fewer than LINK could: but it could examine the potential effects of introducing rational expectations. And apparently, depending on assumptions about parameter values, they could be considerable.

History

The shape and location of London's present-day office blocks and tube stations are in part determined by Roman planning two millennia ago. Travelers today are notoriously called upon to "mind the gap" when using the underground system.

This is because some London Underground platforms are curved to follow the shape of Roman public roads: a reminder that distant infrastructural investment can carry unexpected reverberations over the span of millennia.[4] The same Roman road plans left plots too small to suit trading room floors of the 1990s, leading directly to the proliferation of skyscrapers in Canary Wharf.

Such 'path dependency' is extremely important in the economic/climate change world, and hence has to be incorporated in any model with pretensions to realism.

- For example, the costs of renewable energy in 2050 will be a function, in part, of choices and decisions made today and the history of technology, institutional, and behavioural innovation.

At the same time, while there can be only one history, there are many potential futures: and here the phenomenon of 'memory' is important.

Memory

Again, arguing first by analogy, maps, like the world they depict, evolve. An aerial map of Yiwu, China, in 1984 (population 73,000), would probably have helped someone get around that town in 1986. But by 2016, when the population was 1.1 million, it would have been all but useless. (See figures 1 and 2).

However, the 1984 map of Yiwu could in principle give important clues as to the make up of Yiwu in 2016. A main road, river bridge, or rail station built in a given location in 1984 would likely increase the chance of a dense agglomeration in the surrounding region. Even the Romans could have predicted such effects, well before the term 'railway' had any meaning.

So it is with models. An economic model calibrated on the tastes and preferences, technological production possibilities, and relative prices from, say, the 19th century will make for useless predictions in 2024. Similarly, assumptions using today's costs for renewable energy systems will be of limited value in making predictions for 2050.

Fortunately, however, it is possible to say something about the forces that change tastes, preferences, and production possibilities through time. And, importantly, society can steer and even drive them. Parameters not only change through time, but often they can change in broadly predictable ways in response to known forces. They build on history. Put another way, the processes can be predicted, even if the ultimate technologies cannot.

- For example, the costs of renewable and energy efficient technologies fall sharply as a result of deployment. But deployment increases as a result of falling costs. This generates an unstable reinforcing feedback.

  Hence, even though it is not possible to predict accurately what the costs of renewable technologies will be in 2050, it is possible to predict, with confidence, that incentivising renewable investment will lead to a world with more cost-effective renewables. It also suggests that costs are likely to be higher if action is delayed and the transition is left unmanaged.

Thus, models of structural transition need to be informative of such dynamic processes. Static models are unhelpful. A good model of structural change provides a map that evolves over time.

Size

An important part of any model-building decision concerns the appropriate size of the model. Regardless of size, all are (heavily) reduced form versions of the real world. But, within that, there are advantages and disadvantages both to big and to small models.

Big models can address many questions, and sometimes this is essential.

- For example, the UK Treasury's model has to address a wide range of issues of great policy importance, such as expenditure and tax receipts for many groups in the economy. There is no alternative in this case to having a large model.

Figure 1: Aerial map of Yiwu, China, 1984

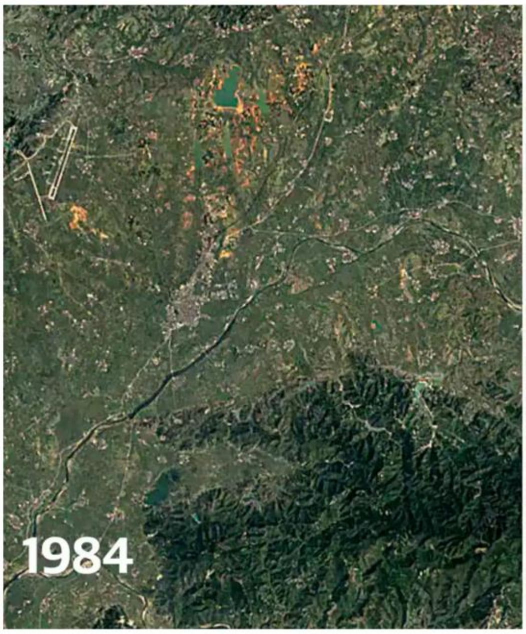

Figure 2: Aerial map of Yiwu, China, 2016

Source: The Guardian

But large models are expensive both to build and to maintain, and can as a result be inflexible. And pressure for increased detail and supposed greater realism can all too easily lead to their becoming too complex for all but the most expert to understand.

- For example, OECD's INTERLINK model succumbed to this fate. Originally a small- to medium-sized model, the purpose of which was to model the transmission of demand-side shocks between countries, pressure developed to extend it by adding a supply-side bloc. The result was a model that produced results that were not only not intuitive *ex ante*, but all too often were not intuitive *ex post* either. Results could not be interpreted. Shortly after that, and in part for that reason, the model was killed off.

Small models can address fewer questions than can large models: but they are cheaper to build, set-up, and run, and are more flexible.

- For example, the small Dornbusch rational expectations model is one case in point. And another, particularly interesting, case is the Nordhaus DICE model. Various critics claimed that DICE understated the costs of climate change and overstated the costs of decarbonisation.[5] However, because the model is simple, transparent, and readily understandable with key parameters that can easily be changed, researchers have been able to show, in two cases, how differences in assumptions, expressed through small and highly plausible tweaks to key parameters, could lead to radically different conclusions.

  Thus, both Stern and Dietz (2016) and Grubb and Wieners (2020) varied parameters in DICE to introduce stock-flow feedback, and thereby illustrate the sensitivity of results to historical events, and thereby the path-dependency of outcomes.[6] Both small changes overturned the original cost-benefit results presented by Nordhaus.

Thus, the simple, transparent, model was able to be used as a useful tool to show that assumptions matter and sensitivities need testing.

Independent Economics' (CEF) model

It is against the background of these considerations that we have built our *Independent Economics* climate, economics, and finance (CEF) model. Principal characteristics include:

1. Small size.
2. Easy for the non-specialist user to understand and interpret (there is no element of 'black boxing').
3. The key climate, economic, and financial relationships have been established not by us, but by scientists, economists, and financial analysts in their respective areas.
4. Parameter values similarly are derived from comprehensive expert studies.
5. Parameters can readily be changed:
   - In light of new scientific, economic, or financial evidence; or
   - To see what difference doing so makes (users can supply their own parameter values or apply sensitivities to historical pathways).

   Or parameters may evolve, often in a predictable manner.
6. Equally importantly, it is fairly easy for *Independent Economics* to change the structure of the model in key ways so as to meet particular purposes.
7. In many applications the model will be run to simulate the effects of shocks, expressed as deviations from baseline.
   - However, the model can also generate its own baselines.

We are keen not to overclaim for our model. But we have already learned a lot from building it, and there is more to come.

We will shortly be releasing a paper giving more detail, together with a suite of basic simulations to show the climate bloc in use.■

[1] People are often rude about models. They point variously to unreal assumptions; missing effects; uncertainties about parameter values, and more. Fair enough. But they can make these criticisms only because models are, by their very nature, transparent. Instead, critics often simply offer up an impressionistic 'judgement', in which neither the data nor the relationships are spelled out.

When one of us was asked, as Chef de Cabinet to the Secretary General of the OECD, to arrange meetings between high-powered national delegates from a member country and someone appropriate from the OECD Secretariat, we often found yourself choosing a model builder. Invariably, reports of the meeting were good. Why? Because, in constructing their models, model builders have to think through all the key mechanisms, and attach orders of magnitude to them. As my friend and colleague Lee Samuelson, who built the OECD's macro model INTERLINK used to say, "Modellers tell the best stories."

[2] This colourful way of depicting a model owes to the late Chris Higgins, who was Secretary of Australia's Department of the Treasury.

[3] The explanation, once found, turned out to be simple. When a large amount of money is transferred from one entity to another, the gainer is under less time pressure to adjust than is the loser. Thus, on the occasions of the two great oil shocks, in 1973/74 and 1978/79, the transfer of around 2% of OECD countries' GDP to OPEC did not lead to an immediate increase in OPEC expenditure – it took over a year for them to develop projects to spend most these huge amounts. By contrast, OECD consumers, whose real incomes had been sharply reduced, perforce reacted much more quickly. Hence world savings thereby rose, by around 1% of OECD GDP, pushing OECD economies in the direction of recession.

When, in the first half of 1986, oil prices collapsed back to the pre oil shock level, the first simulations suggested, counterintuitively, that the effect would be negative for world GDP. But careful forensic work revealed the reason for this: while this time OPEC were the losers and OECD consumers the gainers, again the losers had to adjust quicker than did the gainers. Again, world savings thereby rose, and world GDP was pushed in the direction of recession.

[4] Zenghelis, D. "Nodes of capital: cities, wealth, and the era of urbanisation" in *National Wealth: What is Missing, Why it Matters*. (Eds.). (2017). Hamilton, K., & Hepburn, C. Oxford University Press.

[5] For two broad summaries of the various critiques, see Steve Keen (2020) *'Nobel prize-winning economics of climate change is misleading and dangerous – here's why'*, University College London https://www.ucl.ac.uk/news/2020/sep/nobel-prize-winning-economics-climate-change-misleading-and-dangerous-heres-why and also Bob Ward, 2019 *'A Nobel Prize for the creator of an economic model that underestimates the risks of climate change'*, Grantham Research Institute on climate change and the environment, London School of Economics https://www.lse.ac.uk/granthaminstitute/news/a-nobel-prize-for-the-creator-of-an-economic-model-that-underestimates-the-risks-of-climate-change/ .

[6] Both Stern and Dietz (2016) and Grubb and Wieners (2020) varied parameters in DICE to introduce stock flow feedback and illustrate the sensitivity of outcomes to historical events, and thereby the path-dependency of outcomes. Stern and Dietz showed that the cumulative impact of climate and resource depletion damages mount much more quickly as productivity growth is eroded through endogenous effects of devalued and destroyed capital. Grubb and Wieners used Nordhaus's DICE to incorporate the historical path of investment in clean technologies as a parameter determining their current cost. This allowed DICE to proxy the cost impact of induced innovation. Both exercises yielded massively different results on the costs of action to decarbonise relative to Nordhaus's base projections. In so doing the model helps to highlight the importance of assumptions. The simulation results were telling, overturning the cost benefit predictions assumed using the static parameters. See Dietz, S. and N. Stern, (2016), *'Endogenous growth, convexity of damages and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions'.* Centre for Climate Change. Economic Journal. Volume125, Issue583. March. Pp 574-620 and Grubb M, and Wieners C, (2020) *Modeling Myths: 'On the Need for Dynamic Realism in DICE and other Equilibrium Models of Global Climate Mitigation'* INET Working Paper No. 112 January