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Have we reached the limits to growth?

A healthy scepticism of computer models, particularly those that portend to forecast the complex workings of our economies, would generally seem rather justified. Even short-term forecasts of various economic factors we constantly hear of in the media, such as quarterly growth rates, movements in interest rates and employment conditions, appear to be considerably unreliable – more so now than the rather maligned weather forecast. Evidently the vast majority of economists also did not have an inkling of the global financial crisis. Yet conventional neoclassical economists readily dismissed the modelling of the global economic and environmental system made famous in *The limits to growth* (LtG), a report sponsored by the Club of Rome and first published in 1972. Their dismissal was not based on sound rationale, but effectively constituted a smear campaign according to Ugo Bardi in his *The limits to growth revisited*, with similarities to resistance to antismoking and climate change science.

It seems the reaction against the LtG was founded on a dislike of the message, which was simply too challenging for many. That message was delivered through a dozen scenarios simulated in a global model (World3) of the environment and economy, by the team of scientists at MIT led by Dennis Meadows. They identified that a sustainable ('stabilised' in their words) future was attainable only if considerable change in social behaviour and technological progress was made sufficiently ahead of environmental or resource issues. In the simulated scenarios when this was not achieved, 'overshoot and collapse' of the economy and human population occurred in the 21st century, sometimes reducing living conditions to levels akin to those in the early 20th century.

That accelerating growth could not proceed forever – either by design or terminated by collapse – was not an acceptable finding for many, which helps to explain the longevity and vitriol of the campaign initiated against the LtG following its launch. In more recent times for example, the 'sceptical environmentalist' Bjorn Lomborg joined in, relegating the LtG to the 'dustbin of history' through the use of selective quotes out of context. The attacks created the widespread myth that the LtG had been spectacularly wrong.

Consequently, a common means of discounting any research that seemed to threaten the growth concept was to label the work as a variant of the LtG, implying it to be flawed. So when our group in CSIRO studying the Australian economy was tarred with the LtG brush, I was curious to understand more about this infamous work. On reading the original 1972 book, it

A 40-year-old model and forecasts of the global economic and environmental system – that many had relegated to the 'dustbin of history'– appears to be standing the test of time surprisingly well. The insight and messages of *The limits to growth* stand as a warning of potential global collapse – perhaps more imminent than generally recognised.

BY GRAHAM M. TURNER

became obvious that, not only were the criticisms clearly false, but there was an opportunity to compare the World3 model outputs with some 30–40 years of independent and measured data. I found the data compared most favourably with the 'standard run' scenario (Figure 1), or what we would now call business as usual (BAU).

In contrast, the comparison with other scenarios ('comprehensive technology' and 'stabilised world') showed substantial differences. The surprisingly good agreement between the data and the BAU scenario is an important test of the World3 model used in the LtG. As for any scientific modelling, if the model doesn't produce suitable 'predictions' or understanding of the system being studied, then it has little value. Unfortunately, this sort of reality check is rarely undertaken for other global or national economic models.

Both the model and the data in Figure 1 make clear that during the 20th century there is overall growth and increasing prosperity, with the exception of increasing pollution and decreasing resources. Expanding population and demand for material wealth drives more industrial output, which grows at a faster rate than population. There is a draw-down of non-renewable resources as the increased economic activity requires more inputs. Pollution from increasing economic activity also grows, but from a very low level, and does not seriously impact on the global population or environment. With more physical capital and materials made available from the industrial system, output from agriculture and services such as health and education also expands, even in per capita terms. The increase in material wealth, food and services provides the foundation for decreasing birth and death rates; the latter falls before births, leading to population growth. The World3 model has therefore captured internally the dynamics of 'demographic transition'. There are some signs of strain, however, in the slowing of growth in per capita food supply and industrial output.

The LtG model then provides an insight into how the global future could unfold (Figure 2). Essentially, this BAU scenario undergoes collapse caused by resource constraints. How this

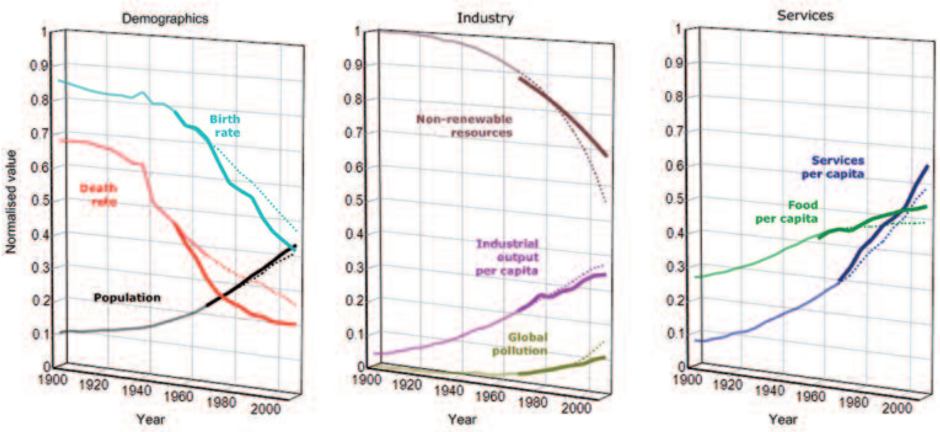

Figure 1. Comparison of historical data over the last 40 years (solid bold lines) against *The limits to growth* 'business as usual' scenario outputs of the World3 model (dotted lines). (The period from 1900 to 1970 shows the model output as calibrated to data available at the time.)

comes about is important. The increased industrial activity requires ever increasing resource inputs (albeit offset by improvements in efficiency), and resource extraction requires capital (machinery), which is produced by the industrial sector (which also produces consumption goods). Until the non-renewable resource base is reduced to about 50% of the original level, the World3 model assumed that only a small fraction (5%) of capital is allocated to the resource sector, simulating access to easily obtained or high-quality resources, as well as improvements in discovery and extraction technology. However, as resources drop below the 50% level in the early part of the simulated 21st century and become harder to extract and process, the capital needed begins to increase. For instance, at 30% of the original resource base, the fraction of total capital that is allocated (in the model) to the resource sector reaches 50%, and continues to increase as the resource base is further depleted.

With significant capital subsequently going into resource extraction, there is insufficient available to fully replace degrading capital within the industrial sector itself. Consequently, despite heightened industrial activity attempting to satisfy multiple demands from all sectors and consumption, actual industrial output (per capita) begins to fall precipitously, from about 2015. At the same time, pollution from ongoing industrial activity continues to grow. The reduction of inputs to agriculture due to competition from industry, combined with pollution impacts on agricultural land, leads to a fall in agricultural yields and food produced per capita. Similarly, services (e.g. health and education) are not maintained because of insufficient capital and inputs.

Diminishing per capita supply of services and food causes a rise in the death rate from about 2020 (and somewhat lower rise in the birth rate, due to reduced birth control options). The global population therefore falls, at about half a billion per decade, starting at about 2030, while the economic system continues to break down. Following the collapse, the output of the World3 model for the standard run (Figure 2) shows that average living standards for the aggregate population (material wealth, food and services per capita) resemble those of the early 20th century.

One of the surprising features of this BAU scenario is the apparent imminence of collapse, with the model indicating falls beginning within the decade and even in a matter of years for some sectors. We should be very cautious about interpreting the scenario trajectories too precisely in terms of timing or absolute values, since this 40-year old model is very aggregate and roughly calibrated. Nevertheless, there are some recent real-world events that curiously align with features of the BAU scenario. In particular, the ongoing disruptions of the global financial crisis and the advent of peak oil may be very poignant.

'Peak oil' refers to the situation when the *rate* of supplying oil reaches a peak and then falls, leaving a growing gap of unmet demand and consequently high oil prices. This appears to have occurred in recent years, as finally acknowledged by the otherwise conservative International Energy Agency after years of denying that peak oil was of concern or at all imminent. But it does not mean that conventional oil has run out – far from it, since the peak extraction rate occurs about halfway through the reserve pool. Further, as respected commentators *The Economist*, *Time* and *The Guardian* point out, there are immense additional pools of fuels in the form of unconventional oil and gas reserves, such as those being accessed by hydraulic fracturing (fracking). (These additional reserves were included in the data of non-renewable resources for the comparison shown in Figures 1 and 2.) The optimist view being expressed recently is that there could be a new oil and gas glut. This superficially appears to contradict the resource

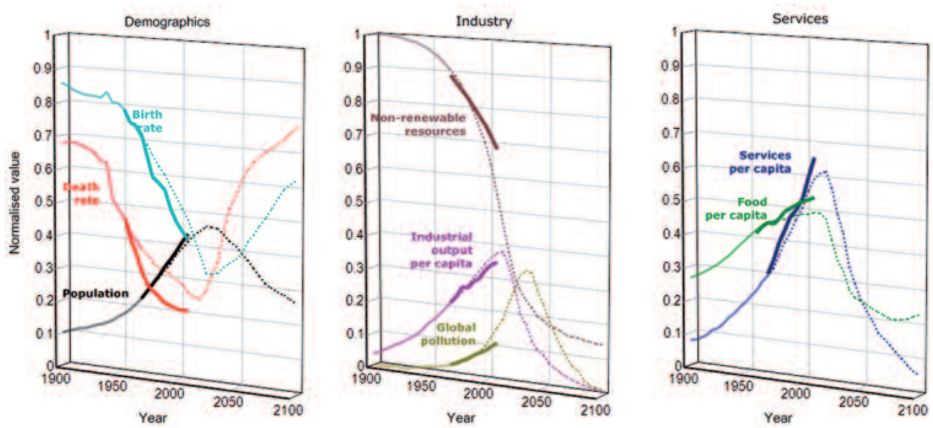

Figure 2. Full time-course of *The limits to growth* business-as-usual scenario to the end of this century (dotted lines), showing the collapse in economic conditions and population that is primarily based on resource constraints. The historical data is also shown (bold lines).

constraint that underpins the collapse in the BAU scenario of the LtG.

But the protagonists of oil and gas gluts have not understood a crucial point. They have essentially confused a stock with a flow. The key, as the LtG modelling highlights, is the rate at which the resource can be supplied, i.e. the flow, and the associated imposts of machinery, energy and other inputs required to achieve that flow. Contemporary research into the energy required to extract and supply a unit of energy from oil shows that the inputs have more than doubled for conventional oil. It doesn't matter how big the resource stock is if you can't extract it fast enough or you use up other scarce inputs needed elsewhere in the economy. Oil and gas optimists note that extracting unconventional fuels is only economic above an oil price somewhere in the vicinity of US$70 per barrel. They readily acknowledge that the age of cheap oil is over, without apparently realising that expensive fuels are a sign of constraints on extraction rates and inputs needed. It is these constraints that lead to the collapse in the LtG modelling of the BAU scenario.

This is where the global financial crisis enters the picture. Although the global financial crisis was clearly driven by excessive levels of debt, high oil prices may have been an important contributor. Economic analysis recognises that recessions are commonly linked to high oil prices; and specific influences have been drawn for the global financial crisis. For instance, national debt of some countries has been substantially worsened due to the cost of importing expensive oil. At the household level, rising costs of essential items such as transport and food only add to mortgage stress and the likelihood of defaulting on home loans. With the global financial crisis still playing out, industrial output per capita is flat-lining, which aligns with the plateau depicted in the LtG simulation of BAU.

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So, not only does global data match the BAU scenario outputs of the LtG, but the mechanism, timing and short-term outcomes of the collapse also appear to be corroborated. If this turns out to be accurate (and there must always be an 'if' with such difficult modelling), then hindsight will say that the sustainability debate was clouded by a focus on climate change rather than the resource issues of peak oil. However, in the event that oil constraints are overcome by technological advances efficiently opening up new resources or alternative fuels, the sustainability challenge is likely to be translated to that of maintaining a stable climate, as the full suite of LtG scenarios show. Given the poor track record of Rio+20, Copenhagen and such, the likelihood of meeting this challenge is low.

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