Peak oil, flowering curves and the COVID-19 pandemic

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Negative oil prices, the unusual sight of vivid blue skies, the best air quality in decades, gorgeous spring flowers, reduced traffic, reduced traffic noise, what's not to like about the coronavirus lockdown? Well, maybe the highest mortality rate since World War II. "What on earth have these disparate phenomena got to do with geology?" I hear you ask. The article aims to show how a consistent geo-mathematical methodology can be used advantageously in studying many dissimilar phenomena (Fig 1).

More specifically the article describes the pioneering geo-statistical work of the visionary, oil-company polymath, Marion King-Hubbert (1949, 1956, 1981 and 1982). I find it fascinating that Hubbert's maths, in addition to its classic application—of predicting the timing of peak oil and quantifying the total amount of recoverable

Figure 1 ***What do (a) the COVID-19 pandemic, (b) the opening of Montbretia flowers, and (c) the prediction that oil production would peak by the early 1970s, have in common?***

fuels—also performs remarkably well in a wide range of other situations, including modelling the deaths and infections resulting from the COVID-19 pandemic, and in charting the patterns of opening of flowers in the spring.

Briefly the 'peak-oil' story effectively began at about 10 am on March 8, 1956, when King-Hubbert first 'went public' with his bold prediction—that, contrary to conventional geological wisdom, oil production (Lower 48 States, onshore USA) would reach its zenith by the early 1970s and then quickly decline. He chose a conference of the American Petroleum Institute (API), the oil industry's main lobbying outlet, to set out his new geo-mathematical forecasting rules, to describe his "reappraisal of the whole energy picture", and to make his controversial forecast for US production. Quite an agenda for a speaker faced by an audience of some 500 hearty oilmen in a plush venue in down-town San Antonio, Texas, especially as, at the time, America was a supremely confident exporter of petroleum.

Geo-statistical curve fitting

During the COVID-19 lockdown in Scotland (began 23 March 2020) I posted a series of blog pages about the epidemic and how it was likely to progress. To achieve my forecasts I employed Hubbert's curve-fitting approach. I was already familiar with Hubbert's maths, having previously used it in order to delve into the rapidly declining state of UK oil and gas reserves (Thompson, 2017b), but had generalised the underlying equation slightly (see the flowering curve approach of Clark & Thompson (2011) and Box 1 for further details).

Fig 2 shows an example of Hubbert's geo-maths when used to model both Italian and UK deaths trajectories (daily deaths as reported in the database of the European Centre for Disease prevention and Control, ECDC) and to project the future course of the epidemics (dashed lines). The trajectories of the two countries can be seen to have been exhibiting remarkable similarities in general shape, duration and skewness, and to resemble typical curves of oil discovery and production. The maths showed that for any officials formulating UK policy response, Italy was supplying an honest, down-to-Earth foretaste of what was about to befall the UK.

In addition to forecasting 'peak oil' Hubbert also devised a method to estimate the important economic and geological indicator of ultimate recoverable resource (URR). His neat methodology is often referred to as Hubbert linearization. Fig 3 shows

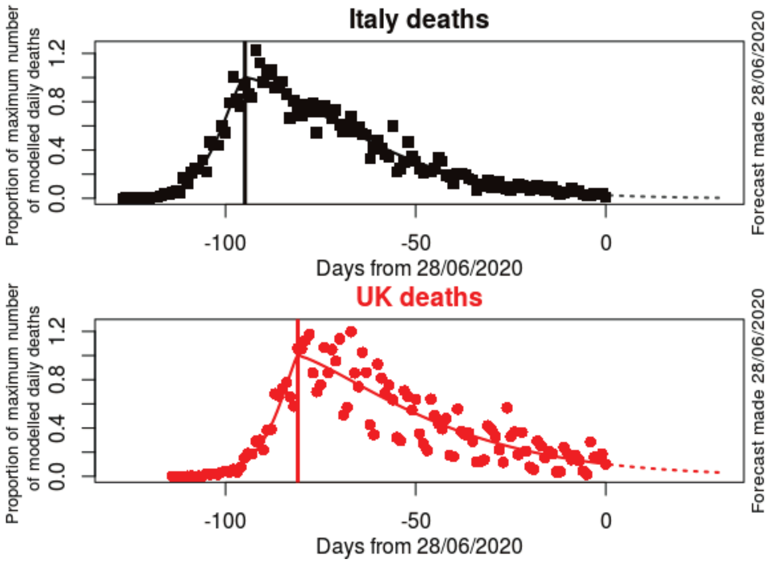


***Figure 2** Comparison of curve fitting of Italian and UK deaths trajectories. Dashed lines: forecasts using skew-normal model. Note the low quality of the UK data, largely caused by under reporting on Saturdays and Sundays and on bank holidays but also by confounding effects associated with a step change in recording procedures in England, brought in for April 29th onwards, when the count included deaths with COVID-19 in all settings for the first time. Nevertheless the trajectories of the two countries remain remarkably similar in general shape, duration and skewness. Italy, on average, was 15 days ahead. Conclusion, from analyses made on 09/05 and again on 28/06/2020: watch Italy if you want advance warning of how the UK epidemic is likely to progress.*

the results of applying this facet of Hubbert's work to COVID-19 deaths as recorded in countries from around the world with high numbers of deaths. The key finding was that expected deaths (per capita) varied widely. The intercepts of the coloured diagonal lines with the horizontal axis quantify the ultimate totals.

Fig 3 is an update to a very similar plot drawn and posted on my blog on April 7th, and yet as late as May 15th the UK government was still claiming it was far too early to compare between countries. They chose to maintain that any such comparison while the crisis was still unfolding was '*premature*'. In my view, Hubbert's

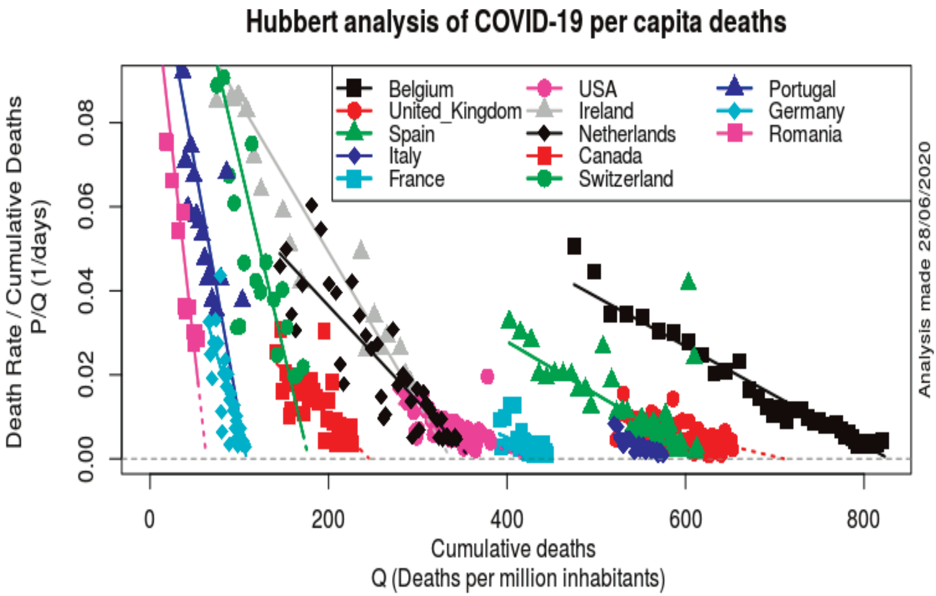


Figure 3 Hubbert-type predictions of final (per capita) death tolls. Countries ranked (see legend) by total numbers of per capita deaths (as estimated on 28th June). All data points are daily. For example the black square in the extreme lower right corner represents the most recent day, for which data was available at the time the diagram was drawn, in Belgium. Hubbert showed that a plot of Q vs P/Q can be used in a straight-line extrapolation (dashed lines) to determine recoverable oil-reserves, or in this example, ultimate deaths. Some of the data sets (e.g. Netherlands and UK) are rather scattered, othersr have occasional unusually high values (e.g. Portugal, Canada, USA and Spain). Nevertheless reasonable projections forward can still be made by employing a robust least-squares line-fitting procedure.

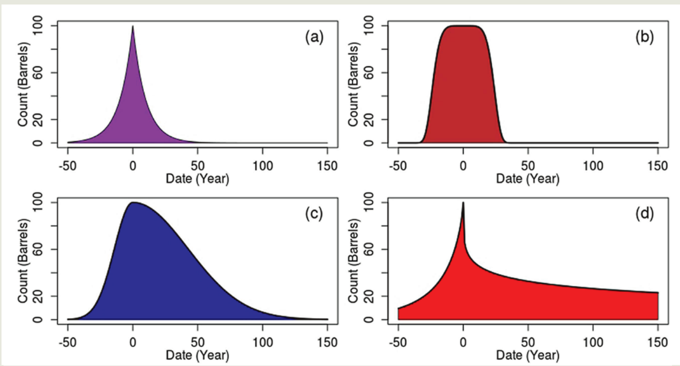
maths were way ahead of the game and already demonstrating distinct between-country differences in late March—i.e. demonstrating the disastrously tardy way in which Britain had allowed the infection to spread, to swamp the NHS and in turn to overburden our care homes. The stringency of the social distancing that countries chose to adopt, the firmness and rapidity with which travel restrictions were put in place, the rigorous implementation of public-health measures used to prevent viral transfer to vulnerable sections of the community (e.g.

Box 1 Generalised epsilon-skew curves

The equation I have been using to make forecasts of oil reserves (barrels), or COVID-19 deaths, or counts of open flowers as based on previous behaviour (x) is:

y = k*exp(-abs(((x-mu)/(sig*(1+sign(x-mu)*eps))))^ (gam*(1+sign(x-mu)*eta)))

The response (y) is a function of six parameters (k, mu, sig, eps, gam, and eta). These are respectively the peak value (k), date of the peak (mu), spread i.e. width of peak (sig), skewness (eps), a flat-topped parameter (gam), and an excess kurtosis parameter—a measure of the fatness of the tails (eta). The classic symmetry of the bell-shaped curve (e.g. Fig 1c) occurs when eps=0, gam=2 and eta=0. Clark and Thompson (2011) developed the equation to model springtime flowering. Pleasingly, as it allows a smooth transition between all four types of curves sketched below, as well as fitting symmetrical curves, it is highly suited to maximum likelihood optimisation and to studying a wide range of phenomena.



Four curves illustrating a range of generalised epsilon-skew fits. (a) cusped, (b) round-shouldered, (c) skewed, (d) fat-tailed, skewed and cusped.

isolation of Covid patients in hospital settings and care homes) and the effectiveness of temperature testing at major airports were all likely to be critical policy-response interventions (Hale et al., 2020). Governments that chose to take no, or tardy, actions or had not prepared in the wake of the traumatic experiences of countries afflicted by the 2015 outbreak of Middle East Respiratory Syndrome, or MERS, ended up with high numbers of deaths on their hands (e.g. Hubbert intersections at the right-hand side of Fig 3) as their health services were overcome and unable to function efficiently. Countries that acted swiftly (intersections towards the left-hand side) had far fewer deaths, returned more easily to free internal movement and achieved a rebounding economy more speedily. Tellingly many of these nations had female leaders (Taub, 2020).

Why should Hubbertian lines (Fig 3) decline so linearly? Why should oil production and epidemics follow similar trajectories? A useful analogy can be drawn with an ecological model. Imagine a piece of newly derelict ground starting to fill up with weeds. In the beginning the weeds are so far apart they are not competing with each other and so the number of plants can grow rapidly. Then as the weeds become more numerous the rate at which new plants materialise starts to be constrained and to depend on the area of unoccupied space remaining. Eventually the previously open ground is fully occupied. In the oil-energy analogy the rate of new discoveries primarily depends on the geology. Fundamentally, to first order, it is controlled by the volume of rock (specifically—porous rock capable of trapping hydrocarbons) remaining to be explored. Oil production follows discovery, but typically with a ten-year development gap. What rates of oil discovery, weed increase, and daily deaths during viral infections all have in common is their dependence on the fractions of the ultimate totals (barrels of oil, gaps between weeds, susceptible people) which remain untouched. Hubbert (1949, 1982) explained how the straight-line trends, of Fig 3, are to be expected for typical population growth, or decline, because in technical terms the logistic function is a good approximation for the cumulative normal.

Hubbert, to my mind, although a maverick was a genius, a visionary, an oracle. It is often claimed that the advent of "fracking" and cheap gas, which today is being won from North American black shales, has undermined Hubbert's predictions (see Box 2). But I would point out that Hubbert, in the mid-1950s, had been the first person to explain correctly how the then-new engineering technique, known today as hydraulic 'fracking', actually worked. It is true that fracking, made possible by the development of horizontal drilling, has revived the fortunes of oil and gas production in the USA and Canada. Nevertheless it will be interesting to see if fracking, post COVID-19 and its by-product of negative oil prices, survives as a major producer. As hinted at in Box 2, it is often claimed (e.g. Helm, 2011and 2017) that "the Earth's crust is absolutely *riddled* with carbon", and that economic behaviour (e.g. commodity super-cycles) dominates over geology when it comes to the oil price; and hence the world is nowhere close to running out of cheap fossil fuels. That is not what Hubbert believed and neither do I.

For references and further details see: https://www.edinburghgeolsoc.org/publications/the-edinburgh-geologist/ and https://blogs.ed.ac.uk/roythompson/2020/04/26/glimmer-of-hope-recap-of-posts-i-to-xv/

Box 2 Super basins and peak oil

The timing and magnitude of peak oil, despite being of enormous significance for future economic growth and for the well-being and lifestyle of billions of people, continue to remain contentious and to be very poorly known.

A wide range of well-reasoned estimates of the volume of ultimate recoverable oil and gas have been generated. Starting at the low end, Hubbert's most recent (1982, 1985) logistic-curve-based evaluation of 2.1 trillion barrels of oil has been confirmed by Campbell's (2015) reworking of 2.0 trillion of conventional oil. Both authors argue for similar quantities of total recoverable gas. Their overall judgement is that, in broad terms, only 1/3rd of oil and a somewhat higher fraction of gas remains for development. Similarly Sandrea (2005, 2020), in a detailed, well-argued report, uses Hubbert's approach, when production data are available, and reservoir modelling when not, to arrive at a URR of 2.3 trillion boe for conventional and unconventional gas alone. In contrast, at the high end, Li (2011) employs geological arguments to conclude that 7.3 trillion barrels of conventional and non-conventional oil are producible from the 1000 million km^2 of sedimentary rocks on Earth. He suggests we are barely 1/5th of the way into the 'Oil Age'.

The modern concept of super basins (Fryklund and Stark, 2016) provides a fresh way of looking at future energy potential from fossil fuels. Sedimentary basins with 5 billion barrels of oil produced, 5 billion yet to be produced, multiple plays, at least one prolific source rock and extensive existing infrastructure are classified as super basins. The world's top four super basins (Central Arabia, W. Siberian, Rub Al Khali and Zagros) dominate world oil production today. These four embrace the world's most prolific fields (> 65 billion recoverable barrels of oil, past and future): Ghawar, Burgan, Gachsaran and the Mesopotamian Foredeep Basin; but intriguingly they do not contain any of the world's top individual wells (>100 000 barrels per day) located in Mexico, California and Oklahoma. Forecasting global reserves using super basins as a basis for a Hubbert-type analysis is an attractive proposition because of the intermediate geological scale between wells & fields and the whole planet. Furthermore the definition of super basins ensures reasonably low lifting costs.

The ever-optimistic American Association of Petroleum Geologists is especially keen on the concept of super basins (Sternbach, 2020). It foresees that the associated paradigm shift will lead to a resurgence of exploration and to an energy renaissance that will lead to a more abundant and affordable energy supply. Technologically the programme will be led by recent improvements in seismic imaging, particularly in deep-water basins, and by the industrial production successes already demonstrated for the black shales in the emerging Permian (W. Texas) super basin.

A word of caution, especially relevant in this era of COVID-19 induced sufferings: energy balance modelling shows that total oil and gas production is closely interconnected to global warming. Production of even the lowest total reserve would lead to global temperatures well above the Paris Agreement's temperature threshold of +1.5oC (See Thompson, 2017a and Additional material). Production of the high-end reserves would in the absence of mitigation technologies lead, by 2150, to 7–8 degrees of warming: a geohistorical, ice-free state not experienced since the Eocene (Burke et al., 2018), some 40–50 million years ago, when sea levels were (roughly) 100m higher than today.