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From Covid-19 to Zero-Gravity: Complex Crises and Production Revolutions

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Abstract

Historically, pandemics have occurred in the context of complex crises involving other human and natural disasters, including war, rebellion, flooding, and economic collapse. This is because they all derive from increases in population and world connectedness, which produce epidemiological vulnerability, domestic conflict, hegemonic challenge, risky economic behaviour, and environmental over-exploitation. Such complex crises are learning experiences for humanity and, as people solve the attendant problems, they culminate in breakthroughs in social and material technologies that are sufficiently large and abrupt to be perceived as shifts of historical era. COVID-19 is no exception, occurring amidst growing geopolitical, financial and cultural stresses, and points to what is likely to be a deepening crisis over the coming years. As before, it should generate an unmistakable advance in social institutions and human capacities, which can be identified with Leonid Grinin's forecasted Florescence of the Information-Scientific production principle c. 2030–2040. Besides presenting this verbal argument, the paper includes some mathematical explorations to verify the logical consistency of the concepts and their proposed relationships.

Keywords: *COVID-19, pandemics, global crises, connectedness, production principles, historical transitions, AI, space.*

1. Introduction

Pandemics are usually not isolated but occur in conjunction with other challenges like war, climate change and internal unrest. This is because disease is a symptom of and a contributory factor to multiple forces re-shaping the world system, including new trade routes, new geopolitical structures, new technologies, new economic institutions, new climate conditions, new religious-philosophical provinces, and so on. The pandemic is part of a complex crisis or syndrome of interlocking stresses, which can be attributed to an increase in the intensity of human interaction caused by population growth and expansion of socio-economic networks. The problem is not increased interaction as such but the creation of new networks and contacts without the new attitudes, institutions and social technologies needed to manage the resulting stresses. The crisis generates its own solution, as it persuades people of the need for reform and encourages them to negotiate possibly difficult, far-reaching changes in human relationships. Hence, a complex crisis is associated with accelerated progress in social institutions that may subsequently be perceived as a shift of historical era.

This paper shows how pandemics have in the past been associated with complex crises and historical transitions, and presents a theoretical argument as to why this should be the case. It argues that COVID-19 is occurring in the midst of such a complex crisis, and suggests this is associated with a historical era change – predicted by Leonid Grinin (2012: 15–45) – that will transform the nature and location of human work. It includes mathematical explorations to demonstrate that the verbal model produces the indicated dynamics, that is episodic institutional reform, interaction between domestic and global cycles, and tipping behaviour. It concludes that today's generations are in the midst of a wide-ranging transformation of local and global society that will be accompanied by financial crashes, civil unrest, technological upheavals, interstate war, climate change, and further outbreaks of disease, culminating in Artificial Intelligence (AI) breakthrough and massive expansion of activity in space, one or two decades from now.

2. Complex Crises

In the biblical Ten Plagues of Egypt (Ex. 7–12), the Egyptians faced not only human disease but livestock disease, locust swarms, environmental and climatic disaster, and some kind of atmospheric phenomenon possibly related to volcanism. This was linked to unrest among their Jewish sub-population and a military disaster as the pharaoh's army was lost in the Red Sea (Ex. 14).

This is a vivid depiction of a 'complex crisis,' in which a whole series of disasters and social stresses occur together. The timing is probably *c.* 1500–1450 BC during the era of the Thutmose (Marr and Malloy 1996; Bimson 1981; Klenck 2011; Meyers n.d.). This corresponds to what Grinin, in his division of history into four 'production principles,' identifies as the start of the maturity stage of the Craft-Agrarian principle. It is contemporaneous with the founding of the New Kingdom after the crisis of the Second Intermediate Period. (Grinin's production principles are: Hunter-Gatherer from *c.* 40,000 BC, Craft-Agrarian from 8000 BC, Industrial from AD 1430, and Scientific-Cybernetic from 1955. Each is divided into six stages: Transitional, Adolescence, Florescence, Maturity, High Maturity and Preparatory (see Grinin 2012).

While the historicity of Egypt's plagues might be questioned, the same kind of complex crisis/historical transformation characterises the more reliably documented Black Death (1348–1349). Barbara Tuchman called the period 'the calamitous 14th century' (Tuchman 1978), while Bruce Campbell speaks of the 'great transition' (Campbell 2016). Again, there is a link to Grinin's model, since this transition can be equated to inauguration of the Industrial production principle, which was a 'production revolution' shifting humanity to an entirely new socio-technical schema. In traditional terms, it corresponds to the Medieval-Modern transition.

At the time of the Black Death, Europe was experiencing cooler, wetter climate and later, less certain harvests (Le Roy Ladurie 1971). Heavy rain brought famines in 1315–1317 and 1329–1330 (Bray 1996: 59; Campbell 2016: 257). The 'St Mary Magdalene' flood of 1342 was the worst in Central Europe of the last thousand years (Brázdil *et al.* 2012: 147). England and France were fighting the Hundred Years War (1337–1453), there were wars in Italy and Germany, and international trade was stagnating (Bray 1996: 59). GDPs fell, Edward III of England defaulted on his loans, and Italian banks failed (Campbell 2016: 144). The Great Cattle Panzootic of 1314–1325 wiped out herds across Europe (Campbell 2016: 216–217). At the other end of Eurasia, there were plagues of locusts (Campbell 2016: 283). In January before the Black Death, an earthquake was felt from Naples to Bavaria (Rohr 2003). In the decades after the Black Death, there was civil unrest, with France's Jacquerie (1358), Italy's Ciompi (1378), and England's Peasants' Revolt (1381). The disease itself recurred in the following centuries, initially at ten-year intervals, later less frequently (Aberth 2011: 24).

After the Black Death, feudalism disappeared and bourgeois capitalism arose. This is sometimes attributed to the pandemic alone. However, it is better to link it to this wider series of social and natural disasters.

Thus, a simple story is that the Black Death created shortages of workers, which increased their bargaining power vis-à-vis the elite and helped them to negotiate higher wages and lower rents, while gaining greater rights over their own labour. Yet in England, the best-documented nation (Campbell 2016: 25–27), population had been falling since the 1310s and continued to do so until around 1450 (Broadberry *et al.* 2015: 206). The Black Death only contributed to demographic decline that was happening anyway. Furthermore, feudal obligations were lapsing during the population peak up to the early 1300s. In the scramble for workers after the Black Death, some landlords actually tried to reassert their feudal dues, relentlessly pursuing escaped peasants, while penalties for vagrancy were toughened (Cartwright 1972: 44). With respect to feudalism, the Black Death increased stress on a system that was already on its way out.

Similarly, the English Peasants' Revolt has been linked to the Black Death as a clash between the aspirations of newly empowered peasants and the attempts of the lords to maintain the status quo. Yet the trigger for the Peasants' Revolt seems to have been new poll taxes to fund the Hundred Years War, which had been in progress for nearly half a century (Bell, Prescott, and Lacey 2020). The tax fell primarily on the 'lower middle class' rich peasants, who were nevertheless excluded from political representation. Since the relevant laws dated back to 1334, these resentments might have been brewing long before the plague's arrival. This is not to say the Black Death was irrelevant, just that its contribution was mixed up with other factors.

This syndrome of multi-dimensional disasters in conjunction with world-historical change is characteristic of other noted plagues and pandemics.

- The Justinianic Plague, striking the Mediterranean in 541 and lasting until *c*. 750, occurred at a time of climate cooling called the Late Antique Little Ice Age (Campbell 2016: 331; Welford 2018: 21). There were famines and riots, suggesting a system that was already fragile (Welford 2018: 28). This was also a time of war and geosocial reorganisation, as the Byzantines tried and failed to rebuild the Western Roman Empire and the Islamic conquests began.
- The earlier Antonine Plague (probably smallpox) of AD 165 – *c*. 190 struck the Roman Empire at a time of war with the Parthians, Germanic incursions in Gaul, and uprisings against Commodus and his eventual assassination (Aberth 2011: 77). It was accompanied by 'considerable social, economic, and political disruptions,' with fiscal stress and, as after the Black Death, falling rents and rising wages (Hays 2005: 20).
- Plague was resurgent during the 17th century (Biraben 1975 cited in Turchin 2007: 181), which is well known as a time of 'general crisis' (Parker and Smith 1978) that also saw typhus follow armies round Europe during the Thirty Years War (Hays 2005: 97–101).
- In the 19th century, cholera outbreaks went hand in hand with riots and rebellion, both in Europe and in the European colonies (Hays 2005: 214). The Paris outbreak of June 1832 occurred in the context of an uprising against King Louis Philippe and at a time of economic problems, food shortages and inflation (Fortescue 1988).

Again, these crises tended to be linked to some kind of shift of historical era. The Justinianic Plague can be linked to the end of Antiquity and the beginning of the Middle Ages (Little 2007). The Antonine Plague and the later Plague of Cyprian (*c*. 250) coincided with an accelerating shift from polytheism to Christianity. The 'general crisis' of the 17th century was followed by the Industrial Revolution, as the 'calamitous' fourteenth Century was followed by the shift to Modernity. The seventeenth century crisis produced a new understanding of the nation state in relation to its population, through events like the English Civil War and Glorious Revolution, and in relation to other states, through the Treaty of Westphalia (Kissinger 2014). Similarly, the Hundred Years War, depriving English kings of their holdings in France, was in part about a new definition of national sovereignty. The choleras and riots of the 19th century were also contemporaneous with emerging national political consciousness, such as with the United Kingdom Reform Act (1832) and the founding of the Indian National Congress (1885).

To some extent, these shifts can be equated to the stages of Grinin's production principles. For example, Grinin puts the Florescence stage of the Industrial principle as starting in 1730, after the 17th -century crisis, and the Maturity stage as starting in 1830, at the time of cholera, unrest and reform. The timing is not perfect. However, if one drops the specific involvement of a pandemic, there is a clearer correlation between crises and production principle stages. The Craft-Agrarian principle originated in a 'food crisis' (Cohen 1977; Boserup 1965). The Scientific-Cybernetic principle emerged after the catastrophes of the first half of the 20th century, which included the 1918 flu pandemic. The previous Preparatory stage began in 1929 with the Wall Street Crash (Grinin 2012). The crisis is not necessarily a cause of the changing world but an expression of it.

3. A Syndrome of Interacting Stresses and Disasters

That epidemics should be synchronised with other disasters is not really a mystery. They have a common origin in terms of increases in the size and connectedness of human populations. The issues are interdependent in a web of mutual causation. They materialise as problems not because of connectedness per se but because this level of connectedness is reached without there being the institutions necessary to manage such a level of connectedness. The short-term response to a mismatch between connectedness and institutions is retrenchment and fragmentation. The long-term response is learning and socio-technical innovation, making it possible to return to the original connectedness with the appropriate material and social technologies for controlling the resulting stresses. This institutional change and progress manifests as a shift of historical era, typically a change of production principle or a stage in the evolution of a production principle.

Successive revolutions in global connectedness have produced a 'confluence of disease pools' (McNeill 1976: 77), allowing formerly localised pathogens to reach inexperienced populations, and start pandemics across continents and the world. Peter Turchin has linked these 'waves of integration' to the structural-demographic cycle within societies connected by global trade routes (Turchin 2007). During the integrative phase of the cycle, when populations are growing and elites are expanding, societies reach out to each other for material and cultural exchange. During the disintegrative phase, when mass impoverishment and elite competition are producing internal societal disruption and reorganisation, these connections retract and atrophy. Turchin notes that disease is a feature of the cycle since population expansion and increased interaction cause populations to cross the epidemiological threshold, and have other relevant effects such as urbanisation, crowding people into unhealthy cities (Turchin 2007: 177). The result, as Turchin shows, is that instability, trade contraction and disease all pulse in synchrony.

Table 1 links disease events to increases in global connectedness. Those not already mentioned are: the Columbian exchange, when indigenous American populations were devastated by Old World diseases and possibly (Hays 2005: 75–76) transmitted syphilis in the opposite direction; plague in Europe in the 3rd Millennium BC, which led to demographic replacement (King 2019; Callaway 2015); AIDS and expansion of jet travel and American-Caribbean tourism in the 1970s.

Table 1. Increases in global connectedness and associated pandemics

Era	Connectedness	Disease event
Bronze Age	Domestication of horse	European plague
2nd century	Silk route, Indian Ocean navigation	Antonine Plague
6th century	Trade intensification, Islamic conquests	Justinianic Plague
14th century	Mongol Empire from China to Ukraine	Black Death
16th century	Columbus and transatlantic contact	American devastation
19th century	Steamships, railways	Cholera
20th century	Jet travel, US-Caribbean tourism	AIDS

The post-Columbian devastation of America can be regarded as a complex crisis. The Aztecs seem to have been suffering from overpopulation and societal stresses when Europeans encountered them, and the subsequent heavy mortality and breakdown of New World societies must be attributed not just to disease but also to the effects of colonialism, military conquest, mass conversion and forced labour (Hays 2005: 89; Aberth 2011: 80).

The population growth and intensification of interaction networks that allow diseases to multiply also stress societies in other ways. As populations come into contact, conflict becomes more likely, especially as their burgeoning size creates competition for resources. Newly elaborated and complex commercial exchanges and financial structures may be precarious, built during optimistic, fair weather times and lacking safeguards and fallbacks to deal with business failures and contractions caused by changing tastes or new discoveries.

Environmental disasters are another consequence. Even climate change should not be seen as a purely exogenous phenomenon. Flooding, say, is natural and only becomes a 'disaster' when people make their homes in the places where flooding occurs. Equally, earthquakes are a problem when people choose to live in fault zones. Those who have lived in such areas for a long time develop ways of coping. However, demographic expansion causes people to move into areas that were previously avoided as marginal and undesirable, including flood plains and earthquake zones, and such inexperienced populations are vulnerable to these natural phenomena in the same way they are vulnerable to disease. Similarly, climate change is normal and continuous. It only emerges as a problem when overspecialisation and overcrowding reduce societies' scope for adaptation.

This then is why a pandemic is not an isolated event and occurs in the context of a complex crisis involving some mixture of war, economic difficulties, social unrest, natural disaster and so on. If there had been only one plague of Egypt, the story would not be convincing. Since there were ten, it may be a stylised memory of real events.

4. Historical Transitions

Change comes out of a crisis because people learn from their mistakes. In *A Short History of Progress*, Ronald Wright describes the many ways in which progress has led to disaster (Wright 2004). What he emphasises less but is equally important is how disaster has led to progress. Wright, perhaps, expresses the feeling of many people when he characterises this as a pathological merry-go-round, writing that humans 'invent new fixes for old messes, which in turn create ever more dangerous messes' (Wright 2004: 123). Yet optimists, including the present author, would look back over the human story and see general and desirable improvement. The Black Death, for instance, stimulated scientific medicine, as doctors attempted to understand their failure (Aberth 2011: 43), and this paved the way for Grinin's Industrial production revolution, and eventually the discoveries that would eliminate smallpox and produce today's vastly expanded pharmacopeia.

In an ideal world, people would have a clear vision of the problems their activities are likely to cause, and they would anticipate them with perfectly crafted institutions and technologies. In reality, this does not happen because perfect understanding of the social evolutionary consequences of present trends is not available – though the work of mathematical historians and globalisation theorists, perhaps, brings it closer. Societies are complex adaptive systems. It is difficult enough to understand what the problems might be, let alone the solutions – otherwise, humans could have saved themselves much hardship by sitting down at the beginning of the Stone Age and inventing electricity, markets, representative government and all the other things that have made life safer and more comfortable. Obviously, that could not happen; ideas come slowly and in a necessary sequence (Carneiro 1962), and institutions evolve through trial and error.

Even if people were motivated to solve their problems in advance, it is not clear that there is one unique solution. People would have different priorities. They would disagree about the nature of the problem and the conditions a solution must satisfy. The Black Death may have ended the Medieval world but the sequel varied from place to place. In England there arose ‘agrarian capitalism,’ in France an ‘absolutist state,’ in Italy ‘city states’ and ‘merchant oligarchies,’ in Egypt ‘repression’ that destroyed the country's agricultural prosperity, while the Byzantine Empire went into terminal decline until it was conquered by the Ottoman Turks (Roos 2020).

Social change is contested. Whereas the masses desire solutions that are fairer, elites prefer ones that preserve their privileges. Wages rose and freedoms grew after the Black Death but not without a struggle. The first response of the English government was to enact the Statute of Labourers (1351), ordering wages and prices to be kept at their previous levels (Campbell 2016: 310), and ‘sumptuary’ laws, restricting certain products to the elite, reasserted status differences (Hays 2005: 56). The guilds still refused to admit women despite their growing presence in the business world (Welford 2018: 57). Change occurred because of its inevitability, not through the foresight of those responsible for managing society.

For all these reasons – uncertainty, vested interests, forces of reaction – institutional change tends to require a crisis that demonstrates its necessity and where the downside of resistance is clearly seen to be greater than the downside of acceptance.

A classic illustration is the evolution of institutions of supranational governance. These have expanded in scope through a succession of macro-conflicts. The Napoleonic wars gave rise to the Concert of Europe, World War I to the League of Nations, and World War II to the United Nations. In each case, countries felt that there had to be a better way of settling their differences, though the impulse for finding it came after the crisis, not before. Each successive solution has been limited and imperfect, and the search for mechanisms of peaceful co-existence remains punctuated and iterative. While global political unification is the point to which the world is moving, it will likely not be reached until the end of the 4th millennium (Taagepera 1997). People do not like to give up their autonomy, and it will take many more crises to overcome resistance and persuade them of its desirability. The process is by no means one way – witness the European Union's recent experience – yet each failure improves future institutions in a kind of anti-fragility (Taleb 2013).

5. The Present Pandemic

COVID-19 should be understood, then, not in isolation but as part of a complex crisis. It is a symptom as well as a cause of other changes in global society. In light of Table 1, the root cause can be taken to be recent increases in human connectedness. The key development is surely the opening up of China since the 1980s and its emergence as a hub of the world economy. As a key manufacturing centre, operator of the world's highest capacity container ports, and author of the Belt and Road Initiative – as well as many other initiatives, such as the Shanghai Co-operation Organisation – China's contribution to the expansion of global interaction networks is clear. It is to be expected that this has created opportunity for new diseases and indeed that China might be the source.

Today, in the midst of the pandemic, there are many signs of a complex crisis, even as far as floods (Kwok 2020) and plagues of locusts (World Bank 2020). Recent decades have seen animal diseases, such as mad-cow / BSE and the foot-and-mouth outbreak in the UK. There was a global financial crisis, while another severe economic contraction has occurred as a result of the pandemic. Key Western societies are in the critical phase of the structural-demographic cycle (Turchin 2016; Ortmans *et al.* 2017), and the pandemic arrived at a time when there were chronic anti-government demonstrations in France and in Hong Kong, China.

The stress generated by China's expansion of global connectedness is seen in the US sanctioning Chinese companies over alleged spying activities and confronting Chinese activities in the South China Sea, while China conducts exercises perceived as aggressive towards Taiwan and threatens US seigniorage with non-dollar international payment systems. As argued by op-eds in *Le Monde* and *Hindustan Times*, the problem is a world order that was not designed for a powerful China, coupled with China's increasing belligerence in challenging that order (Le Monde 2020; Laskar 2020). There is a mismatch between current levels of human connectedness and the institutions available for managing that connectedness, and this is leading not to orderly renegotiation of international relations but to a global crisis from which a new equilibrium will eventually emerge.

There are signs of the expected first-line response to such a crisis, in the form of fragmentation. These include the UK's departure from the European Union, and a growth of nationalist sentiment around the world (Snyder 2019; Bieber 2018). That this is part of a long-term ‘wave’ (Turchin 2007), therefore not a random fluctuation but consistent with a deeper geohistorical logic, is suggested by Fig. 1. This uses residuals of the volume of world exports as a proxy for global economic interaction. It can be seen that, after rising for much of the 19th century, this fell up to and during the crisis of the early 20th century, rose again afterwards and has recently started falling again. The curve indicates incipient global decoupling.

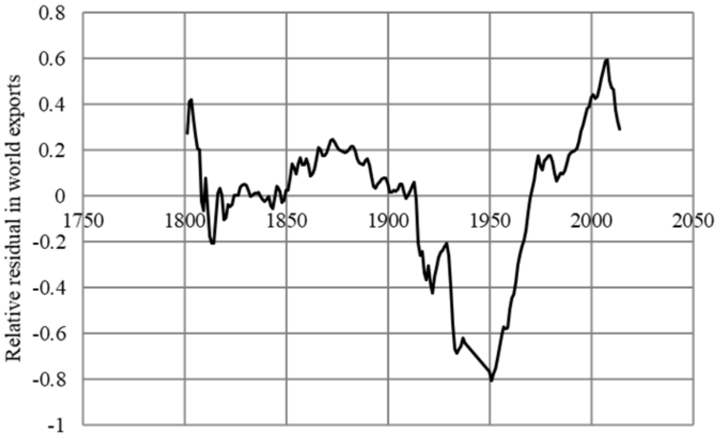

Fig. 1. Residuals of world exports (value in constant dollars) normalised to instantaneous value. The chart shows (*O* – *E*)/*E* where *O* is the observed volume and *E* is the expected volume given the exponential trend (which fits the raw data with R^2 = 0.98)

Source: data from Tena-Junguito and Federico 2016 via Ortiz-Ospina and Beltekian 2018.

This ongoing and perhaps deepening complex crisis ought to be associated with the historical transitions of Grinin's production principles, insofar as they have emerged from crises in the past. If so, this would be the Florescence stage of the Scientific-Cybernetic production principle, which Grinin expects to start around 2030 to 2040.

In the case of the Industrial principle, Florescence involved a great change in the nature and location of work, as people moved from their cottages into the new factories, and as the steam engine replaced human effort, making people operators of machines rather than mere sources of motive power. During the earlier Adolescence, life was mostly still rural, slow-paced and traditional, and a quick glance might not have revealed much difference from the late Craft-Agrarian period. Yet by the Florescence, this was no longer true. Even a quick glance would reveal that a fundamental transformation had taken place, with smoke pouring from factory chimneys and cities building crowded streets of worker dwellings. This is characteristic of Florescence. At the Craft-Agrarian Florescence, when the first urban states emerged around 3000 BC, it was similarly no longer possible to overlook that there had been a radical shift in the nature and location of human activity.

The Florescence of the Scientific-Cybernetic principle should therefore be expected to witness a shift in the nature and location of work as profound as that of industrialisation. This will likely include the vast expansion of AI, replacing humans for many roles, as steam power once did. It will also likely include the move into space. Jeff Bezos of Amazon envisions ‘millions of people’ living and working in orbiting space factories, while plans are being made to regulate mining on the moon (Blue Origin n.d.; Roulette 2020). Today, superficially, the world is not so different from that of fifty or more years ago. One has to look closely to see the laptops and mobile phones. Yet when robots are ubiquitous and visits to low earth orbit are a normal part of doing business, the change of era will be unmistakable.

Today's complex crisis meshes with this forthcoming transformation. Climate concerns are leading countries to eliminate their reliance on fossil fuels, precisely as required for a world leaving the industrial era. Solar power not only supports localised electricity generation – avoiding costly, complex, vulnerable power grids, and so well suited for a fragmented, more conflictual world – but is ideal for outer space. Whether solar panels are truly ‘green’ is questionable (*e.g.*, Mulvaney 2014; Gibson, Wilman, and Laurance 2017; Chen 2019). However, the technological progress stimulated by environmentalism has, as it were, pre-adapted global economies for the coming production revolution. To optimists, confident of human resourcefulness and biospheric resilience (Simon 1996), the claim that climate change is an existential threat may be difficult to take seriously (Lomborg 1998), and the surrounding discourse is, perhaps, more ideological than scientific (Garske 2020). Yet it is as though this movement has appeared on cue to effect a great historical change. Those familiar with the work of Pierre Bourdieu (Bourdieu and Passeron 1977; Bourdieu 1977) will not be surprised if the real logic and motivations are hidden behind an ideological veil.

The COVID-19 pandemic contributes to pre-adaptation. Today's extensive interference in economic and social activities, ostensibly to control contagion, is a dress rehearsal for what would be needed if present geopolitical frictions evolve to a macrowar using all the power of modern weaponry, including anti-satellite – affecting communications, sensing and geolocation services that are now vital to everyday life – cyber and nuclear. The pandemic has witnessed governments assuming responsibility for maintaining people's incomes, and this has led to renewed interest in the idea of Universal Basic Income (UBI), a grant given to all citizens (*e.g.*, Paton 2020). Various thought-leaders have suggested that UBI will be needed when AI starts to eliminate jobs (*e.g.*, Bloch 2018). In fact, despite perennial suspicion of new machinery, technology has always created more jobs than it has destroyed – or population could not have expanded as it has. Nevertheless, there could be transient unemployment requiring a large-scale, if temporary, programme of income support, for which COVID-19 provides a model. Again, the crisis facilitates the change of era by highlighting problems and making solutions more acceptable than before.

6. Mathematical Discussion

Turchin has noted the importance of testing verbal models with mathematics, showing how the verbal theory of 'imperial overstretch' predicts stasis rather than collapse as envisaged by its proponents (Turchin 2003: 17–22). Hence, this section explores the above arguments mathematically.

Crisis and Effect

It was argued that crises produce institutional progress. One suggestion is that social evolution builds up entropy (loss of structure, increase of disorder), which necessitates compensatory absorption of negentropy, that is negative entropy or free energy (Trinn 2018). The punctuated evolution of social institutions results from episodic (rather than continuous) absorption of free entropy through new resource discoveries, contact with other societies or technical innovation.

Suppose that a crisis has a particular *effect*, equivalent to its energy, which measures its capacity to counteract entropy by introducing new structure (*e.g.*, WW2 leading to the UN). In physics, the Boltzmann distribution indicates that the probability of an event of energy E is given by

$$p(E) \sim e^{-\beta E}, \qquad \text{(Eq. 1)}$$

where β is a constant and ~ means 'is proportional to'.

Since effect is hypothesised to correspond to energy, Eq. 1 can be taken to describe the probability of occurrence of a crisis having effect E.

The effect of a crisis naturally depends on its size – a larger crisis should typically generate more institutional progress. The question arises: What is meant by the size of a crisis and how is this related to its effect?

Take war as an illustrative type of crisis. Lewis Fry Richardson measured the size of a war in terms of its fatalities (Richardson 1960). At the same time, he classified wars by the order of magnitude of fatalities, so for example a war of 1,000 fatalities is of magnitude 3. More precisely, the magnitude of a war is the logarithm (to base 10) of the fatalities.

Richardson's decision to classify wars by a logarithmic or geometric scale bespeaks an intuition that the significance of a war – its effect – is a logarithmic function of its size. In other words, if S represents size

$$E = \alpha \ln S, \qquad \text{(Eq. 2)}$$

where α is a constant, and Richardson's $\log_{10} S$ is replaced by $\ln S$ (the difference is a constant that can be absorbed into α).

Consider a war of 10 fatalities and one of 1,000 fatalities. It makes sense that the larger war, with 990 extra fatalities, would have a noticeably larger effect on society. On the other hand, consider a war of 25,000,000 fatalities and one of 25,000,990 fatalities. Here the extra 990 fatalities are 'in the noise' and unlikely to make any difference to the war's ability to effect social change like founding the UN. Thus, it is the relative difference that matters – that is not the *absolute* size difference dS (990 in this case) but the *relative* size difference dS/S (990 compared to 10 or 990 compared to 25,000,000). With dE for the difference in effect

$$dE \sim \frac{dS}{S}. \qquad \text{(Eq. 3)}$$

Eq. 2 is the solution to Eq. 3, so this justifies Richardson's logic.

Nobody actually measures the effects of wars since there is currently no way of quantifying institutional changes. However, the probability of a war of a particular *size* can be related to the probability of a war of a particular *effect* by the identity

$$p(S)\,dS = p(E)\,dE \qquad \text{(Eq. 4)}$$

or

$$p(S) = p(E)\frac{dE}{dS}. \qquad \text{(Eq. 5)}$$

Substituting from Eqs 1 and 2, and performing some manipulation, gives

$$p(S) \sim S^{(-\gamma)}, \qquad \text{(Eq. 6)}$$

where $\gamma = \alpha\beta + 1$.

This corresponds to the well-known observation that the sizes of wars and other forms of political violence obey a power law (Martelloni, Di Patti, and Bardi 2019; Guo 2019). Fig. 2 illustrates this for Richardson's data.

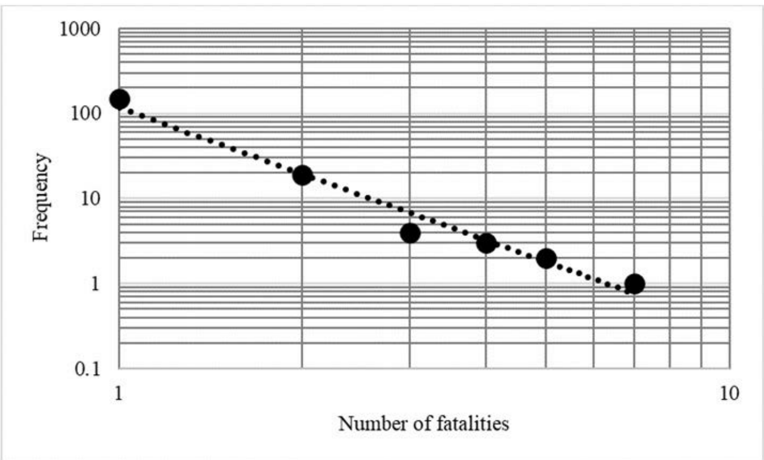

Fig. 2. Power law in number of wars as a function of size (number of fatalities). R^2 = 0.97.

Source: Richardson 1960.

War is just one kind of crisis, used here because it is particularly well studied. Another kind is a financial crash. Fig. 3 indicates that the same principle may apply, since it shows that there is a power law in the largest annual contractions of UK GDP, a rough index of financial crashes.

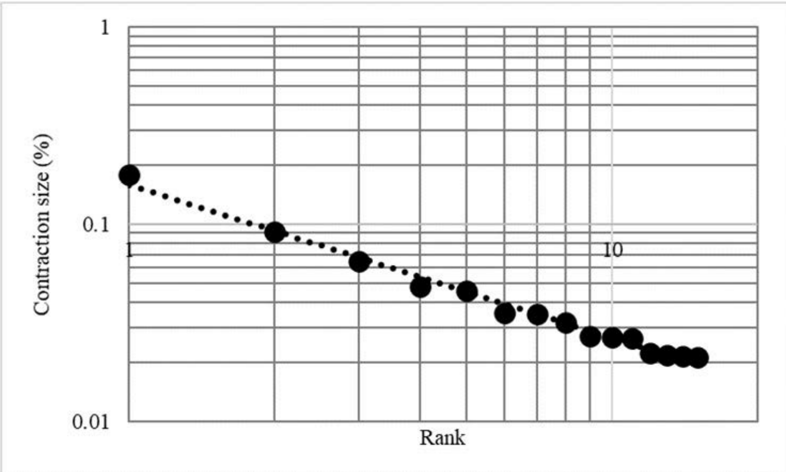

Fig. 3. Power law in largest annual contractions of UK GDP (%), 1870–2014. R^2 = 0.99.

Source: Our World in Data n.d.

While the analysis here is only a sketch, there is a congruence with both existing theoretical concepts and data. This suggests that the principle that crises generate social change in proportion to the size of the crisis is a potentially fruitful one that makes tangible predictions and reflects some underlying social reality.

Integration Waves

This paper follows Turchin's idea of waves of integration, arguing that an increase in connectedness with inadequate institutions generates a complex crisis, which results initially in fragmentation and ultimately in institutional innovation to manage such a level of connectedness more successfully. The tenability of this argument will be tested with a stylised model. It keeps the equations free of clutter, focusing on essential logic, by ignoring proportionality constants, which are important for calibration not for structural properties.

According to Turchin, the engine of the process is the structural-demographic cycle. Since he finds the cycles of the interacting societies to be synchronised, they can be modelled as one cycle.

Turchin's actual structural-demographic model, which exists in various flavours (Turchin 2003: A.3), is relatively complex, in order to represent internal structural changes that are not of interest here. The cycle can be simplified to just two variables, 'happiness' H and population pressure L (the symbol chosen by Graber 1995, standing for 'load'). The essence of the structural-demographic dynamic is that when a society is happy, population grows, increasing population pressure, whereas population pressure causes happiness to fall. In symbols:

$$\dot{L} = H \qquad \text{(Eq. 7)}$$

$$\dot{H} = -L, \qquad \text{(Eq. 8)}$$

where the dot notation is used to represent the time derivative. Thus, happiness increases population pressure (Eq. 7) and population pressure decreases happiness (Eq. 8).

Let population pressure be defined as the ratio of population P to carrying capacity K, *i.e.*

$$L = \ln \frac{P}{K} . \qquad \text{(Eq. 9)}$$

With this definition, when P is below K, population pressure is negative (population is encouraged to expand), and when P is above K, population pressure is positive (population is forced to contract). Population at carrying capacity corresponds to zero population pressure.

This definition has two advantages. First, the model is agnostic about whether a decrease in population pressure is due to a decrease in population or to an increase in carrying capacity – both are allowed and the crucial thing is that population pressure decreases. Second, population pressure can take on negative values and still have a physical interpretation. Even when L tends to $-\infty$, it just means that population is negligible relative to carrying capacity.

This way of defining population pressure (Eq. 9) will be extended to all the variables of the present model, that is they will all be taken to be the logarithm of the ratio of some quantity (*e.g.*, P) to its par value (*e.g.*, K). Thus, H is not an absolute happiness but is happiness relative to some equilibrium level of happiness. To avoid burdening the discussion with circumlocutions, this will involve some looseness of vocabulary. When 'connectedness' and 'technology' are referred to below, this should be understood as the logarithm of connectedness or technology relative to par. Hence the derived 'technology' can fluctuate around zero, even though real-world technology is only positive and increases monotonically through increase in its par value – which depends on other variables in the same way that carrying capacity (par population) depends on technology.

Eqs 7 and 8 can be solved by substituting one into the other to give, for example

$$\ddot{L} = \dot{H} = -L \Rightarrow \ddot{L} = -L \Rightarrow L = \sin t, \quad \text{(Eq. 10)}$$

where the final step uses standard techniques to solve the well-known ordinary differential equation and also simplifies it. Thus, the general solution of $\ddot{L} = -L$ is $L = A\sin(t+\phi)$ where A and ϕ are constants. In the interest of stylisation, these constants are ignored. If $L = \sin t$, then it follows from, say, Eq. 8 that

$$H = \cos t. \quad \text{(Eq. 11)}$$

It is not $H = \sin t$ because, although the absolute phase (ϕ) of L and H is not important for the dynamics, their relative phase is important and of interest.

Eqs 10 and 11 indicate that happiness and population pressure oscillate, with H a quarter cycle ahead of L. This is the structural-demographic cycle (see Fig. 4).

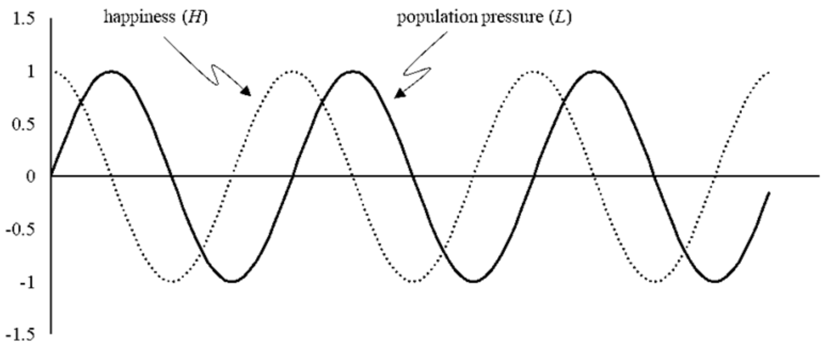

Fig. 4. Relationship of happiness and population pressure in the stylised structural-demographic model

Now let us consider connectedness C. It is proposed that this is related to global 'difference' D. Difference makes connectedness grow – it is when the East has desirable spices unavailable in the West that people make hazardous journeys across Central Asia or around the Cape of Good Hope in order to establish connectedness; if they could only find abroad what they already had at home, they would not bother. On the other hand, connectedness tends to reduce difference through exchange and equalisation. (Recall that this is relative to par values, so that absolute difference may be constant but relative difference falls; for example, trade in spices has fallen in significance compared to, say, consumer electronics, where there is extensive equalisation, so that relative difference has decreased.)

In equations, the above argument becomes

$$\dot{C} = D \quad \text{(Eq. 12)}$$

$$\dot{D} = -C. \quad \text{(Eq. 13)}$$

This is structurally equivalent to Eqs 7 and 8, and yields the same oscillatory dynamics, with *D* for *H* and *C* for *L*.

Next consider institutions, which will here be called 'technology' *T*, referring to both material and social technologies that underpin institutions. The argument is that institutions advance as people seek solutions for problems or 'troubles', which will here be symbolised by *W* (for 'war', an aspect of troubles along with rebellion, bankruptcies, pandemics, natural disasters, *etc.*). Thus, troubles *W* cause technology *T* to increase, while technology (institutions) causes troubles to decrease. In equations

$$\dot{T} = W \quad \text{(Eq. 14)}$$

$$\dot{W} = -T\ . \quad \text{(Eq. 15)}$$

Again, this is structurally equivalent to Eqs 7 and 8, and yields the same oscillatory dynamics, with *W* for *H* and *T* for *L*.

The model so far looks like Fig. 5 and involves three independent oscillators $H \leftrightarrow L$, $D \leftrightarrow C$ and $W \leftrightarrow T$.

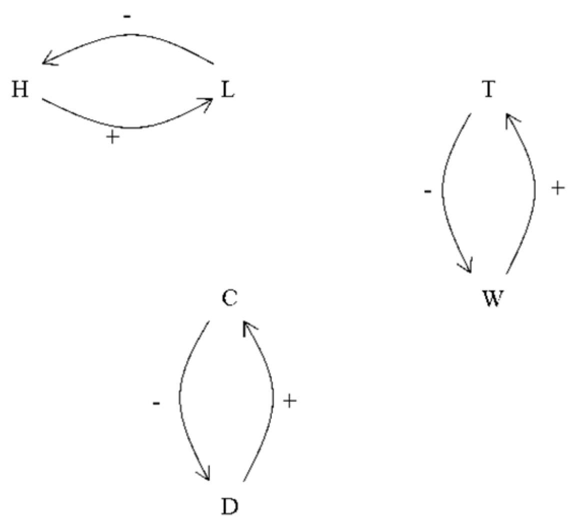

Fig. 5. Stage in the development of the complex crisis model (for symbols, see text)

The next challenge is to connect them together. This will involve the following assumptions:

(1) Population pressure increases connectedness. It is surplus population and resulting competition for social and material resources that makes people restless, adventurous and outward-looking, building long-distance connections. Conversely, connectedness reduces population pressure, which occurs, for example, through gains of trade and importing of foreign ideas.

(2) Population pressure increases technology. This is Ester Boserup's principle (Boserup 1965). It was not that people invented agriculture and population grew, but population grew, people became more careful at managing food sources, and so they invented agriculture. Conversely, technology decreases population pressure, which occurs through increased carrying capacity.

(3) Connectedness increases troubles. This is the core of the complex crisis thesis, that is that increased connectedness produces frictions and risks, like conflict, merged disease pools and migration into marginal areas. Conversely, troubles decrease connectedness, since, as argued above, the initial, easy response to troubles is fragmentation.

With these additions, the model becomes as shown in Fig. 6.

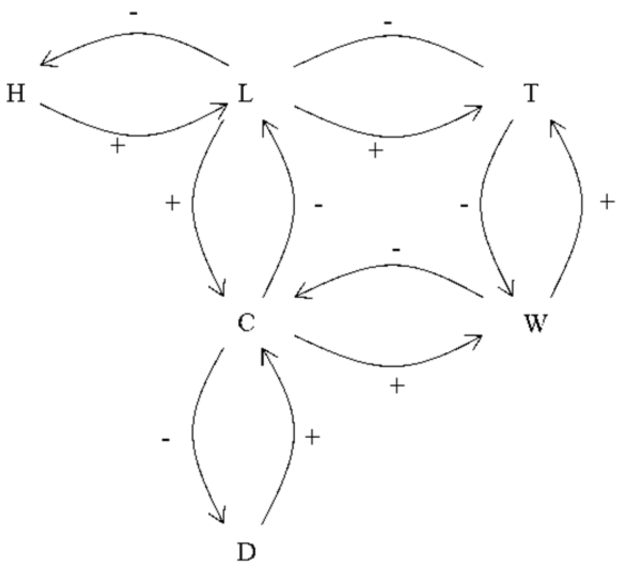

Fig. 6. Completed complex crisis model

The equations become

$$\dot{H} = -L \quad \text{(Eq. 16)}$$

$$\dot{L} = H - C - T \quad \text{(Eq. 17)}$$

$$\dot{D} = -C \quad \text{(Eq. 18)}$$

$$\dot{C} = D + L - W \qquad \text{(Eq. 19)}$$

$$\dot{W} = C - T \qquad \text{(Eq. 20)}$$

$$\dot{T} = W + L \qquad \text{(Eq. 21)}$$

Solving these equations by numerical integration gives the results shown in Fig. 7. All the variables oscillate, with a short period cycle imposed on a long period cycle. The short period cycle can be attributed to the two-stroke oscillators shown in Fig. 5, while the long period cycle can be attributed to the four-stroke oscillator of $L \leftrightarrow C \leftrightarrow T \leftrightarrow W$ shown in Fig. 6. In the curve for H, the long cycle dominates, and this suggests that the period of the structural-demographic cycle, reflected in social mood, may be influenced by global connections rather than by the internal dynamic. The short period oscillations, as seen in the curve for L, may reflect something like the business cycle.

The phase relationships of the variables are not necessarily what might be expected, which is not to say that they are wrong. H is rising as W reaches its peak, and continues to rise thereafter. C also peaks after W, implying that conflict, disease, economic difficulties, *etc*. are already declining before fragmentation becomes obvious.

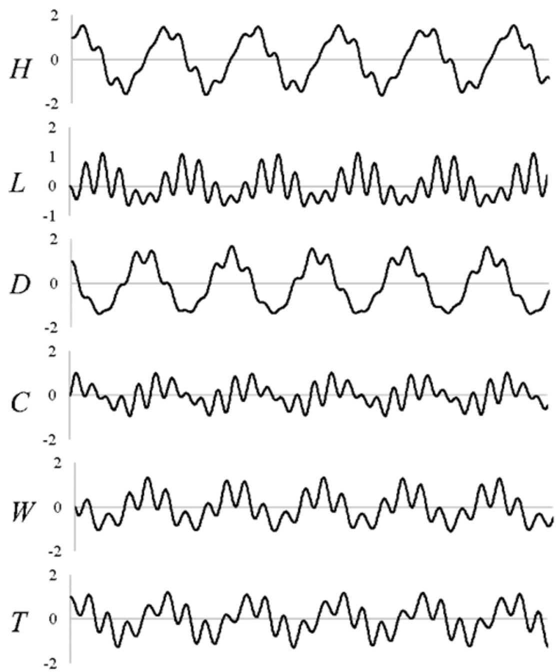

Fig. 7. Numerical solution of complex crisis model

One should not overinterpret Fig. 7. The model is highly impressionistic, and regular oscillations like those of Fig. 7 will clearly not occur in reality. The takeaway is that the variables and relationships of the verbal model generate cyclical behaviour as argued, rather than, say, converging to equilibrium or blowing up unrealistically.

A notable aspect of this model is the assumption that $\dot{L} = -T$. This implies that high technology does not just reduce population pressure by a one-off increase in carrying capacity, but causes population pressure to keep on falling. This only makes sense if it is considered that T represents a global quantity, that is the technology that humanity as a whole has achieved, and there is a lag in the dissemination of technology, so that carrying capacity does not increase everywhere instantaneously, but the overall carrying capacity of the earth begins to rise as individual regions gradually catch up.

If, on the other hand, the world were so small that technology did indeed disseminate everywhere instantaneously, then it would make sense to write

$$\dot{T} = L \qquad \text{(Eq. 22)}$$

$$L = -T \ . \qquad \text{(Eq. 23)}$$

This gives

$$\dot{T} = -T \Rightarrow T = e^{-t} \Rightarrow L = -e^{-t} \ . \qquad \text{(Eq. 24)}$$

Since e^{-t} tends to zero as t tends to infinity, this means that L and T would converge on zero, so that population and institutions would converge on their par values. Realistically, this means that both population and institutions would stagnate (it is unlikely they would increase in exact synchrony, which is a possible but unstable state). Arguably, this is what is seen among isolated populations, such as on remote islands, where socio-technical evolution comes to a standstill. It is only on larger landmasses, where there is a lag in the dissemination of technology, that an oscillatory dynamic, driving a continual increase of par values, can arise. As the world becomes more highly connected and new technology is adopted everywhere instantaneously, institutional progress could come to a halt as it did in populations like those of Australia and New Guinea.

Integration Waves – Increased Stylisation

The above approach to a complex crisis model took inspiration from the work of Andrey Korotayev and colleagues, who show the value of 'compact macromodels' for large-scale historical processes (Korotayev, Malkov, and Khaltourina 2006a, 2006b). Naturally, there is some way to go before this model reaches the level of quantitative agreement with data achieved by Korotayev *et al.* However, the goal here is proof of principle. It will now be shown how the model can be made still more abstract and compact.

Suppose a society's location in the structural-demographic cycle is represented by a complex number ψ whose components are happiness and population pressure. Specifically

$$\psi = H + iL\ , \qquad \text{(Eq. 25)}$$

where $i^2 = -1$.

Then the equation

$$\dot{\psi} = i\psi \qquad \text{(Eq. 26)}$$

can be rewritten as

$$\dot{H} + i\dot{L} = i(H + iL) = iH - L\ . \qquad \text{(Eq. 27)}$$

Equating the real and imaginary parts separately gives $\dot{H} = -L,\ \dot{L} = H$. In other words, Eq. 26 combines Eqs 7 and 8 into one. Hence, Eq. 26, $\dot{\psi} = i\psi$, is a highly compact description of the structural-demographic cycle.

Eq. 26 can be solved directly to give

$$\psi = e^{it}. \qquad \text{(Eq. 28)}$$

Substituting for ψ and using Euler's theorem gives

$$H + iL = \cos t + i \sin t. \qquad \text{(Eq. 29)}$$

Hence this is just a more direct way of deriving Eqs 10 and 11.

Given the structural equivalence of the equations for *D*, *C* and *W*, *T*, the same approach can be applied to them. However, it will be helpful to define the complex quantity for *D* and *C* slightly differently as (notice the minus sign in front of *D*)

$$\gamma = -D + iC \qquad \text{(Eq. 30)}$$

and its dynamical equation as

$$\dot{\gamma} = -i\gamma. \qquad \text{(Eq. 31)}$$

An alternative, avoiding the minus signs, would be to replace difference *D* with its opposite, sameness, but the concept of ‘difference’ is probably more intuitive.

For *W* and *T*, it suffices to define

$$\sigma = W + iT \qquad \text{(Eq. 32)}$$

and require

$$\dot{\sigma} = i\sigma. \qquad \text{(Eq. 33)}$$

The issue now is to derive equations linking ψ, γ and σ. This cannot be done in a neat way using Eqs 16 to 21 because of the piecemeal way in which the components of the three different complex quantities are connected. However, it can be done by introducing some further assumptions as follows:

(1) Happiness is decreased by troubles and increased by difference. The first point should be intuitive enough. The second point reflects the idea that, as in the English proverb, ‘variety is the spice of life.’ People complain that towns are increasingly the same with the same shops on the high streets. Difference is exciting and lifts social mood. Sameness is drab and depresses social mood.

(2) Difference is decreased by both happiness and technology. The first point reflects the idea that more optimistic societies are more receptive to outside ideas – as say Enlightenment Europeans enthusiastically read Chinese philosophers – and reduce difference by taking them on board. The second point reflects the idea that technology speeds the flow of people, ideas and commodities, and has an independent effect in reducing difference, above and beyond connectedness per se.

(3) Troubles are increased by happiness. This reflects the idea that optimistic and exuberant societies are more likely to take risks, for example moving into marginal lands, and so create more opportunities for conflict, crashes and disease.

(4) Technology is increased by difference. This reflects the idea that when societies have different existing ideas and technologies, there are more opportunities for creative recombination, to produce even more technologies, when they come together.

With these extra assumptions, the equations become

$$\dot{H} = -L - W + D \qquad \text{(Eq. 34)}$$

$$\dot{L} = H - T - C \qquad \text{(Eq. 35)}$$

$$\dot{D} = -C - H - T \qquad \text{(Eq. 36)}$$

$$\dot{C} = D + L - W \qquad \text{(Eq. 37)}$$

$$\dot{W} = -T + H + C \qquad \text{(Eq. 38)}$$

$$\dot{T} = W + L + D. \qquad \text{(Eq. 39)}$$

It is now possible to write

$$\dot{\psi} = i\psi - \sigma - \gamma \qquad \text{(Eq. 40)}$$

$$\dot{\gamma} = -i\gamma + \psi - i\sigma \qquad \text{(Eq. 41)}$$

$$\dot{\sigma} = i\sigma + \psi - i\gamma. \qquad \text{(Eq. 42)}$$

By substituting for ψ, γ and σ, and separately equating real and imaginary parts, one can show that Eqs 40 to 42 are equivalent to Eqs 34 to 39. For instance, Eq. 40 becomes

$$\dot{H} + i\dot{L} = i(H + iL) - (W + iT) - (-D + iC) \qquad \text{(Eq. 43)}$$

$$\Rightarrow \dot{H} + i\dot{L} = (-L - W + D) + i(H - T - C) \qquad \text{(Eq. 44)}$$

and equating real and imaginary parts gives Eqs 34 and 35 respectively.

Eqs 40 to 42 can be expressed in matrix form as

$$\begin{pmatrix} \dot{\psi} \\ \gamma \\ \sigma \end{pmatrix} = \begin{pmatrix} i & -1 & -1 \\ 1 & -i & -i \\ 1 & -i & i \end{pmatrix} \begin{pmatrix} \psi \\ \gamma \\ \sigma \end{pmatrix}. \quad \text{(Eq. 45)}$$

Defining the vector

$$\Omega = \begin{pmatrix} \psi \\ \gamma \\ \sigma \end{pmatrix} \quad \text{(Eq. 46)}$$

and the matrix

$$\mathbb{A} = \begin{pmatrix} i & -1 & -1 \\ 1 & -i & -i \\ 1 & -i & i \end{pmatrix}. \quad \text{(Eq. 47)}$$

Eq. 45 becomes

$$\dot{\Omega} = \mathbb{A}\Omega \quad \text{(Eq. 48)}$$

which is then a compact expression of the geodynamics of complex crises.

Numerical integration of Eqs 34 to 39 gives the results shown in Fig. 8.

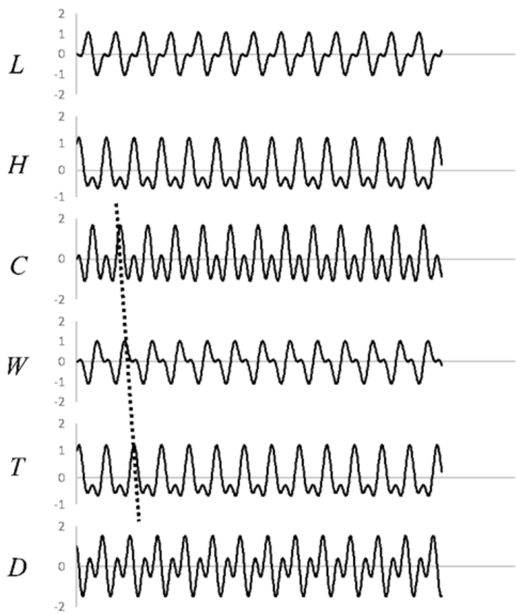

Fig. 8. Numerical solution of revised complex crisis model. Dotted line shows relative lag

These dynamics appear to be less interesting. However, two points are worth noting. First, the peaks occupy a smaller part of the cycle: increases in troubles, connectedness and technology come in short bursts, like sudden crises or technological revolutions. Second, peak connectedness is followed by peak troubles, which is followed by peak technology. This recalls the lag structure discovered by Joshua Goldstein in his study of the Kondratieff long wave (Goldstein 1988) (see Fig. 9, where production and investment correspond to *C*, war corresponds to *W*, and innovation corresponds to *T*).

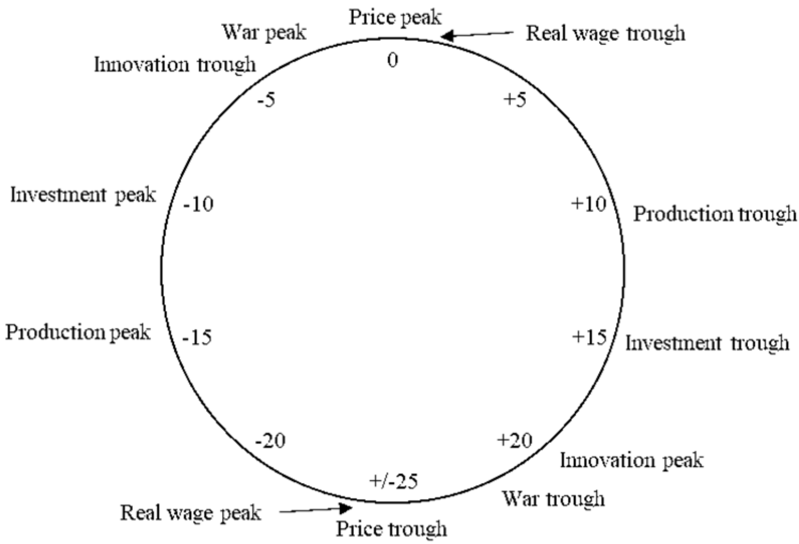

Fig. 9. Empirically revealed lag structure of Goldstein's 'long cycle'
Source: Goldstein 1988: 259; with permission.

Critical Transitions

The above complex crisis model involved smooth oscillation in the variables. In practice, wars, financial crashes, and to some extent pandemics, come on suddenly, as if the world has passed a tipping point. This sub-section will develop a model for sudden crises. Again, the treatment is highly stylised, showing in principle that such a model is possible given the verbal theory.

Suppose that connectedness *C* behaves logistically. At low values of connectedness, it increases exponentially (*e.g.*, because news of profits in foreign lands attracts other adventurers). However, growth slows as connectedness approaches some value, which can be set as 1 or 100 %, representing the maximum feasible connectedness given present population, technology, *etc.* In symbols:

$$\dot{C} = rC(1-C), \qquad \text{(Eq. 49)}$$

where r controls the rate of growth.

Suppose now that r depends on costs and benefits of connectedness. If benefits exceed costs, r is positive; if costs exceed benefits, r is negative. Benefits may be measured by C itself, since connectedness implies economic and cultural interaction, which has intrinsic value. Costs meanwhile correspond to troubles W, *i.e.* wars, crashes, pandemics and other frictions of interaction. A suitable form for r is therefore

$$r = C - W. \qquad \text{(Eq. 50)}$$

The dynamics of C become

$$\dot{C} = (C-W)C(1-C). \qquad \text{(Eq. 51)}$$

This has fixed points $(\dot{C} = 0)$ at C = 0, W and 1, where it will be assumed that W, like C, varies between zero and some maximum normalised to 1 or 100 % (see Fig. 10).

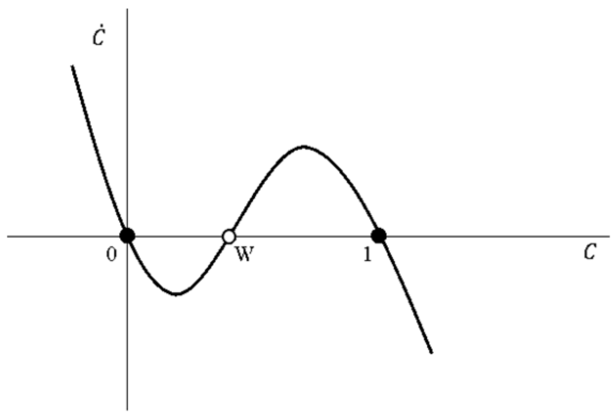

Fig. 10. Dynamics of connectedness

The fixed points at 0 and 1 are stable, while that at W are unstable (*e.g.*, if C rises slightly above zero, $C < 0$ so C will fall back to zero; but if C rises slightly above W, C > 0 so C will keep increasing until it hits 1). Everything to the left of W is in the attractor basin of 0 and everything to the right of W is in the attractor basin of 1.

Such a system, when it is subject to random perturbations, can generate sudden transitions. If C is at 0 or 1, and perturbations are small, the system will fluctuate around that value. However, if a perturbation is large, it may knock the system into the other attractor basin, and C will switch to the other value.

In practice, W is not fixed. It depends on the level of connectedness. When connectedness is low, there is less chance for war, pandemics, *etc*., and troubles decrease. When connectedness is high, troubles increase.

This means that, when C is close to 0, the point W in Fig. 10 will move closer to 0, shrinking the basin of attraction for $C = 0$ and making it more likely that a random perturbation will switch C to the other attractor, $C = 1$. Conversely, if C is close to 1, the point W will move towards 1, shrinking the upper basin of attraction and making it likely that C will switch back towards 0.

A simple way to model such a process is to have W moving towards C with this equation:

$$\dot{W} = \lambda(C - W). \qquad \text{(Eq. 52)}$$

The dynamics generated by this model (Eqs 51 and 52) are shown in Fig. 11. With C subjected to a small, random, time-varying perturbation, there is switching between high and low connectedness.

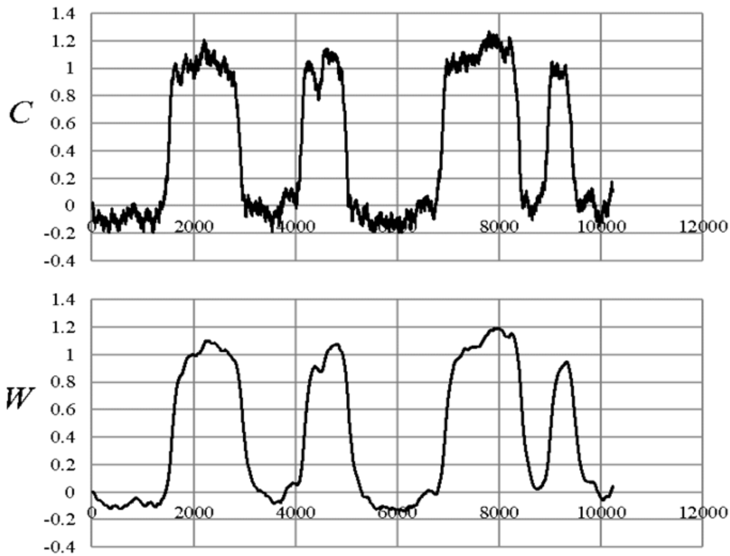

Fig. 11. Numerical solution of critical transition model with small random perturbation

Although Fig. 11 shows C switching back and forth, this does not mean that real world connectedness does the same. As before, C is the logarithm of a ratio relative to a par value. With C representing derived connectedness, let K be real-world connectedness, which will correspond to some physical metric of interaction networks, and let K^* be its par value. K^* will depend on institutions, which determine how much human interaction is 'normal'. These are all related by

$$C = \ln \frac{K}{K^*}. \quad \text{(Eq. 53)}$$

When C suddenly drops, this may be due to a decrease in actual connectedness or to an increase in par connectedness. Par connectedness reflects institutions/technology and, according to the complex crisis model, these should increase when W is high – troubles encourage people to innovate. Hence K^* increases when W is high.

A simple way of modelling the dependence of K^* on W would be to assume that K^*'s rate of increase is proportional to W, that is

$$\dot{K}^* \sim W \quad \text{(Eq. 54)}$$

However, Korotayev *et al.* (2006a: 24) have shown that the rate of increase of technology depends on technology itself – with more technology there are more possibilities for further innovation. Hence a better equation might be

$$\dot{K}^* = \mu W K^*, \quad \text{(Eq. 55)}$$

where μ is a proportionality constant.

Eqs 51, 52 and 55 provide a model for the dynamics of K^*. Real-world connectedness can then be calculated by rearranging Eq. 53 as

$$K = K^* e^C. \quad \text{(Eq. 56)}$$

The resulting dynamics are shown in Fig. 12. It will be seen how real-world connectedness and its par value increase over time while C and W oscillate.

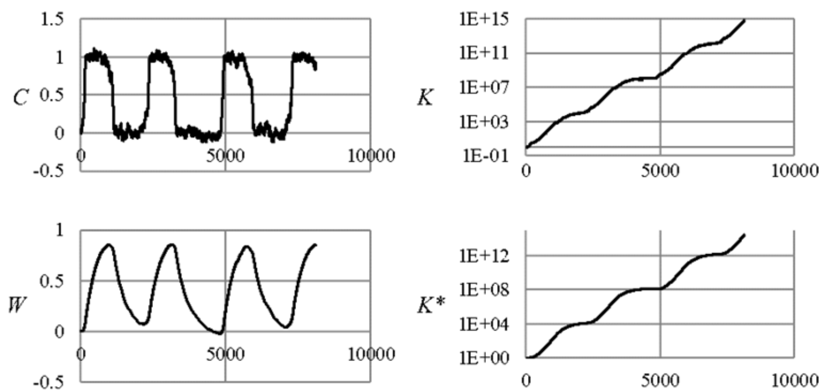

Fig. 12. Numerical solution of model including real world connectedness and par value

This model shows how a switching dynamic, with abrupt crises over short periods, can produce a long-term increase in real-world quantities. Here, K and K^* advance through a series of steps, which are reminiscent of the 'upsweeps' identified by Chase-Dunn *et al.* (2010). Upsweeps are successive increases in the prevailing level of social organisation, from tribes to chiefdoms to states, *etc*., that is what is here called 'par connectedness.'

Conclusion

COVID-19 is part of an unfolding complex crisis that is typical of social evolutionary processes and arises from the way institutions of governance and resource management lag behind growth in human numbers and capacities for interaction. Such crises, by generating the institutions that were originally lacking, culminate in a perceived shift of historical era. In the present case, this seems to be what Grinin has identified as Florescence of the Scientific-Cybernetic production principle, probably involving humanity's first serious move away from a solely terrestrial existence *c.* 2030–2040.

The pandemic has alerted many people to the way the world is changing, and the crisis can be expected to widen and deepen over the coming years. This will likely involve further outbreaks of disease, some of which may be of greater seriousness and lethality than the present one, as well as inter-state war, economic/financial misfortunes, natural disasters, and of course the domestic polarisation and conflict expected by the structural-demographic theory.

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