



Systemic complexity and criticality in economic forecasting

It is, once again, the season of the year when not only are we preparing for Christmas holidays and starting to think about new year resolutions, but economic forecasters are also offering their outlooks for the upcoming year. There are still many hedgehog-type forecasters, who hold fast to their personal models of the world and the economy, never look back, and hence are able to market their forecasts with utter conviction. And of course, they do have their audience, which laps up this kind of forecast, as it satisfies the demand for certainty that is so deeply ingrained in our DNA.

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However, the last two years should have convinced even the most stubborn hedgehog that there is far less predictability, let alone certainty, around us than we like to believe. This applies to events of both categories, the “known unknowns” (such as hurricanes or other weather events) as well as the “unknown unknowns”, which are not even mentioned as tail risks or black swans in those forecasts that take the discussion of risks seriously and not just as a kind of a sophisticatedly-wrapped disclaimer. But lack of certainty affects our forecasts on a much deeper level than the simple “we did not see this one coming”. It applies to the workings of the system itself and the scope of the system relevant for economic forecasts, which is no longer some type of macroeconomic model. Given the pandemic, climate change and digitalisation, it should be obvious that we need to look at the socio-economic-technological system with all its complexity. Some of the relevant interactions are already discussed: will mandatory vaccination cause further tensions in societies, maybe even civil unrest? Will there be an energy storage technology that will make the supply of renewable energies more independent of the whims of nature? The intertwined feedback loops create developments that one can hardly approximate with some kind of linear equation; perhaps they cannot be approximated at all! These issues of “system complexity” are, in our view, not sufficiently appreciated by forecasters and the recipients of these forecasts, alike.



How a global pandemic reveals the complexity that is surrounding us

In January 2020, the Chinese authorities reported that a novel coronavirus was causing cases of pneumonia in the city of Wuhan. What started as a local issue – seemingly far away – has rapidly become a pandemic on a global scale, permanently changing life as we know it. The COVID-19 crisis is the biggest shock to the world economy since World War II. It is a prime example of complexity in action, impressively demonstrating that our globalised world has become a complex system of interacting subsystems. This pandemic illustrates how suddenly changing dynamics can destabilise the world economy and tip it into an unstable state. Furthermore, it shows that system complexity is still vastly underestimated as a contributor to systemic risk.

The emergence and spread of SARS-CoV-2

The emergence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) resulted from interactions between host, virus and several factors at the human, animal, and environmental levels.¹ The dramatic decrease of natural habitats that pushed animals closer to human communities led to hubs of multi-species' convergence with an unprecedented accumulation of people, animals, and pathogens. Following the significant increase in the density of human-wildlife interactions, we have witnessed a drastic shift in the routes of viral transmission, increasing the risk of zoonotic spreads between animals and humans. With approximately 75% of new infectious diseases emerging from a zoonotic origin, the current pandemic has long been predicted and is far from a black swan.² Unlike previous outbreaks of zoonoses, such as SARS, MERS, and Ebola, SARS-CoV-2 caused a worldwide gridlock of economies, because it is unusually difficult to track and control as it is easily spread and can be transmitted even by pre-symptomatic people.³ Global travel further facilitated the rapid spread of SARS-CoV-2 around the world.

Social and economic systems are complex

The emergence and global spread of the novel coronavirus has highlighted that complexity is a crucial feature of our modern social and economic systems. They are complex systems – in the sense that they are characterised by a plethora of mutually adaptive system elements that are either directly or indirectly interconnected. Emergent behaviours within these systems are at the core of complexity theory. They describe the idea that interactions of the individual elements lead to outcomes that are more than the sum of their parts. From birds flocking and individuals self-organising into neighbourhoods in cities, to interactions in multi-species hubs that eventually sum up to a global pandemic – examples of emergent behaviours are plentiful.⁴ The emergent behaviours of complex systems arise from properties that make them hard to predict and control as they challenge humans' analytical capabilities. In fact, one of the "measures" to assess the level of complexity of a system is the size of model to reproduce the system's behaviour.

Nonlinearities and power laws

Complex systems are defined by a high degree of interconnectedness between the individual system elements. The direct and indirect interactions between these

1 Blanchet, K., Lee, K., Levrat, N., Morel, C., Pittet, D., Tediosi, F., Wernli, D., Young, O. (2021). A Complexity Lens on the COVID-19 Pandemic. International Journal of Health Policy and Management
2 Khoday, K. (2021). Rethinking Nature, Crisis and Complexity after the Pandemic. UNDP Global Policy Network Brief
3 Rogers, K. (2020). [Why did the world shut down for COVID-19 but not Ebola, SARS or Swine Flu?](#)
4 Pines, D. (2014). [Emergence: A unifying theme for 21st century science](#)



elements are typically nonlinear. In addition to the emergence phenomena, these nonlinearities are another fundamental component of complex systems. A large number of nonlinear coupled components causes complex dynamics that make the system unpredictable after a certain period. As a result of nonlinear interactions, causes and effects are not proportional. Therefore, complex systems exhibit rich dynamic system behaviours that may lead to random unforeseeable outcomes. A further aspect to consider when dealing with complex systems is that due to strong interactions between the system elements, the statistical distributions characterising their behaviour do not follow normal distributions but power laws that can be illustrated by heavy-tail distributions. As the name suggests, heavy-tail distributions show much bigger tails than normal distributions, implying that extreme events or black swans occur more frequently than expected.⁵

Cascading effects and positive feedback

Complex systems are robust yet fragile: within a particular range, connections between the individual components act as shock absorbers. Beyond this range, interconnections start to serve as gateways for propagating shocks.⁶ The interconnections in highly complex systems provide the transmission channels needed for the system-wide spreading of a local shock. As complex systems are defined by tight interconnections between the elements of the system, each node can have an almost immediate and significant impact on the other components in the system. Hence, local incidents can be easily amplified and turned into systemic events with global ramifications. Due to the powerful forces of globalisation, emerging risks are no longer restricted to a specific industrial sector or region of the world. These cascading effects form the basis of most large-scale disasters. If a small perturbation becomes a destabilising threat to the system, it exhibits positive feedback. The destabilising features of positive feedback amplify the likelihood or consequences of emerging risks and turn them into systemic risks.⁷

Butterflies and thunderstorms

The uncertainties triggered by the COVID-19 pandemic have shown how cascading effects can lead to uncontrollable dynamics and a sudden systemic crisis, by turning a small local event into a massive global issue. In a metaphorical sense, this is the famous flapping of a butterfly's wings in Beijing that triggers a thunderstorm in New York. This idea illustrates the theory of self-organised criticality, which postulates that even marginal events can cause a sudden regime shift in highly complex systems if they are close to a tipping point. While this image refers to chaotic behaviour in nature, self-organised criticality also applies to social man-made systems. It states that the individual behaviour of economic agents based on rational optimisation processes tends to drive the parameters determining system stability towards a tipping point. Beyond this point, the system behaviour becomes dynamically unstable, increasing its vulnerability to shocks.

The COVID-19 crisis pushed our socio-economic systems beyond such a tipping point and caused a systemic shift. System shifts describe a significant change in the feedback and behaviour of a system that renders what is perceived as the status quo obsolete and leads to a "new normal". Because systems exhibit memory and are path-dependent, the sequence of past events influences the order of succeeding events. Movements along the path are irreversible. Therefore, a return

⁵ Helbing, D. (2010). Systemic Risks in Society and Economics

⁶ Carmona, C. U., Kenet, D. Y., Martinez-Jaramillo, S. (2019). Interconnectedness and financial stability. *Journal of Risk Management in Financial Institutions*, 12(2), 168-183

⁷ International Risk Governance Council (2010). *The Emergence of Risks: Contributing Factors*



to a previous state is inconceivable. Even a rebound to pre-pandemic conditions may not shift the affected systems back to their original state.⁸

Is there an economic status quo?

It is important to note that the existence of an (ex-ante) status quo is debatable, at least when interpreted as an equilibrium the system enjoyed before being hit by a shock. As economic variables are in constant flux, there is not only a single static equilibrium in the economy, but rather multiple dynamic equilibria. However, the idea of these economic equilibria is merely a theoretical construct that exists in economic models but such conditions might never materialise in reality. Since economists' typical forecasting models generally do not include structural changes (ceteris paribus assumption), comparing levels before and after a shock implies a false narrative. Similarly, the comparison with a counterfactual scenario, used by central banks to demonstrate the success of their extreme policies is, in that sense, a questionable exercise. In the case of systemic crises such as the global financial crisis or the current COVID-19 pandemic, calculating lost GDP growth based on anecdotal evidence of production disruptions is impossible. To avoid undesirable irreversible structural changes, systemic risks in socio-economic systems need to be better assessed and prepared for.

Examples for systemic crises due to cascading effects in complex systems

Throughout the past decades, globalisation, advances in telecommunication, the strategy of just-in-time production, and financial internationalisation have led to significant increases in complexity, causing tipping points to occur more frequently. As complexity rises, externalities mount, leading to greater economic and social fragility. If these externalities cause feedback effects, tipping points can be reached quickly. During the 21st century, we have witnessed several events whose effects, while not comparable to those of the COVID-19 pandemic, revealed how cascading effects help shocks to spread through the system.

The global financial crisis (GFC): Complexity gone wrong

The most prominent example of cascading effects causing a large-scale crisis is the global financial crisis of 2008. The modern financial system is highly complex with strong nonlinear couplings and network interdependencies that have been created through interbank markets and complex financial derivatives.⁹ In September 2008, the collapse of Lehman Brothers – that triggered a general reassessment of risks in the financial sector, which ultimately formed the starting point of the European sovereign debt crisis – showed how these interconnections can act as conductors propagating idiosyncratic shocks across the system in a contagion effect.¹⁰ Continued strong credit and liquidity growth as a result of excessively low global interest rates had led to a lack of sensitivity to risk, paving the way for the exaggerations before the Lehman collapse. Now, analysis of interconnectedness and contagion has become a substantial part of the IMF's financial stability and risk assessment of a country's financial system.¹¹

From GFC to GVC pre-COVID-19

Events in the real world show that the problem of systemic risk arising from network interactions is not limited to the financial sector. The optimisation of make-or-buy

⁸ International Risk Governance Council (2010). The Emergence of Risks: Contributing Factors

⁹ Helbing, D. (2010). Systemic Risks in Society and Economics

¹⁰ The OFR Financial Stress Index

¹¹ IMF, Interconnectedness and Contagion Analysis: A Practical Framework



decisions through information technology and the globalisation of value chains enabled industrial companies to operate more efficiently. However, events such as the eruption of the Icelandic volcano Eyjafjallajökull in 2010, the tsunami in Japan in 2011, as well as modern piracy in the Horn of Africa and the Strait of Malakka between 2000 and 2011, already foreshadowed the fragility of the just-in-time model. While the volcanic eruption paralysed air traffic in parts of Europe and brought German car production close to a standstill, concerns were high after the tsunami that there would be a global slowdown in growth, as Japan plays a major role in global supply chains, both as a supplier of parts and as a producer of finished goods.

How COVID-19 is paralysing global value chains

What previous events only foreshadowed has been made crystal clear by the COVID-19 crisis. In the age of just-in-time production processes, marginal disruptions can have severe consequences for our highly interconnected global economy. The COVID-19 pandemic has once again highlighted the vulnerability of deeply interconnected global value chains. It illustrates the problem of man-made systems with capacity limits that are driven towards full usage of their capacity (maximum efficiency). As soon as these systems get to their maximum efficiency, they reach a tipping point at which the system becomes dynamically unstable. Shortly after reaching maximum performance, systems may suffer from an unexpected capacity drop. Thus, optimising systems for the full usage of their capacity implies the danger of an abrupt breakdown of their performance. The problem of capacity drops and their potentially severe consequences is only avoidable if the capacity limit of the respective system is known.¹²

Digression: Global value chains

Global value chains describe the process of international production sharing. The production of goods is divided into different sub-steps and distributed to various countries. In this process, individual economies can make significant use of their comparative advantages and thus maximise the gains from global trade. The main drivers in the development towards cross-border production were multinational companies in industrialised countries, which were able to significantly increase their efficiency by optimising make-or-buy decisions and thus securing an advantage over their competitors. In the meantime, small and medium-sized enterprises are also increasingly relying on global value chains. However, the current crisis shows once again that this optimisation is not free of risks. GVCs lead to the synchronisation of the economic activities of the countries involved. If production in one country depends on inputs from another country, their economic activity is linked. The strong links in price-setting enable inflationary tendencies in one country to spread effortlessly to its trading partners, increasing the synchronisation of cross-border inflation.¹³ If we picture countries as nodes in a network that is characterised by its interconnections through trade, a shock in one node can be easily transmitted to the rest of the system.

The disruption of global value chains provides a vivid example of cascading failures through network interactions in complex systems. It demonstrates the interplay of sub-systems that make up our complex world and shows that we humans are often not able to assess the long-term and side effects of a specific event. The combination of port closures in China due to cases of COVID-19 and the running

¹² Helbing, D. (2010). Systemic Risks in Society and Economics

¹³ World Development Report 2020



aground of the Ever Given in the Suez Canal coincided with a sharp increase in global demand, as major economies recovered from strict COVID-19 distancing measures in the summer months. As a result, companies around the world started to suffer from supply shortages. Reinforcing this effect is the human tendency to solve problems in an ad-hoc manner. Companies now try to replenish their inventories to avoid further bottlenecks. What they fail to realise, however, is that this tendency only exacerbates the problem and creates even more shortages, trapping global trade in a vicious cycle with self-enforcing feedback effects. Germany is particularly affected by the supply bottlenecks, as the German economic model is heavily dependent on manufacturing and trade, with about one in four jobs depending on exports.¹⁴

Is nearshoring the new offshoring?

Against this backdrop, more and more companies are moving away from the previously preferred just-in-time model and are starting to review their global production and procurement networks. In doing so, they have to balance short-term productivity gains from further optimisation against the risk of increasing system complexity. A possible way to increase the overall reliability of supply chains could be to move production closer to home. It should be noted though, that the location alone of a supplier does not determine their reliability! A shift towards less complexity often comes at the expense of lower productivity. In the long run, however, welfare might increase, as lower complexity mitigates the impact of such systemic shocks. More importantly, lower complexity reduces the likelihood of so-called black swans that occur more frequently in highly complex systems.

Panacea resilience?

From financial crises to natural disasters, is there anything we can learn from past events to enable better anticipation and early management of the next systemic crisis? One possible way to deal with the more frequent occurrence of tipping points is to increase the resilience of society as a whole, i.e. the ability of a society to recover from a shock and rebound to the previous "normal" state. Increasing the resilience of our physical infrastructure requires the incorporation of redundancies, duplicate structures, and buffers. For societies to become more resilient, flexibility is a crucial aspect. Individuals as well as institutions have to be able to adapt. To achieve this, a society must exhibit a minimum level of fairness and avoid too much inequality (income, education). A stable "social contract" is needed. The promise is that resilience can also increase the willingness to take risks and the ability to adapt, thus enabling higher growth opportunities in the long run.¹⁵

Easier said than done

The concept of resilience sounds good at first glance. However, empowering people, which is the obvious key to a resilient society, is not as easy as it may sound at first, as the German model of "Fordern und Fördern", which has been a key element of social policy in recent decades, has shown. The question remains whether it is even possible to increase the flexibility of an ageing society with rising defensive tendencies. More attention should be paid to the nature of shocks. While most shocks are considered to be exogenous, a large number of them are in fact endogenous. More attention should be paid to factors that contribute to the severity of systemic risks in order to limit their impact in the future. We must be aware of the seeds we plant. By doing so, we can take advantage of the path dependency of

¹⁴ Ewing, J. (2021). Fears of a "Bottleneck Recession": How Shortages Are Hurting Germany. The New York Times

¹⁵ Brunnermeier, M. (2021). The Resilient Society



complex systems and mitigate the probability of amplifying emerging risks into systemic risks.

Key elements of 2022 forecasts are all prone to system complexity

The critical assumptions, nota bene assumptions not predictions, to a large extent driving the GDP and inflation forecasts for the next one or two years are the future development of the COVID-19 pandemic and the – hoped for – gradual easing of supply bottlenecks, both almost textbook examples of system complexity. But the same probably applies to inflation forecasts, which commonly apply some variant of the Philips curve approach, i.e. the relationship between economic slack and inflation. Until recently, the widely held belief was that globalisation has resulted in a flattening of the Philips curve, i.e. that a change in output gap or the unemployment rate causes a comparatively smaller inflation response. Looking at the drivers of labour supply, one can easily come up with a plethora of factors likely to impact the Philips curve: demographics, but also more early retirements as seniors might want to reduce their infection risk, less potential competition from overseas as globalisation is progressing at a slower pace, or even psychological factors as the pandemic might have prompted people to reconsider what is important in life, which could affect their work-life balance choices, as well as political developments, which seem to improve the bargaining position of labour unions (for example minimum wage increases). This is not to forget technological disruptions, which AI might herald for use in the coming years. Let's face it, believing in inflation forecasts with exact numbers behind the decimal point for several years out is little different to believing in Santa Claus.

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Appendix 1

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