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Policy Brief

Adapting to Uncertainty:
Complexity Science and COVID-19

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Key Takeaways

- Both human society and the COVID-19 pandemic are complex adaptive systems. That is, they are dynamic networks of independent and interconnected agents that adapt to their environments.
- Complex systems exhibit emergent behavior – the whole is more than the sum of its parts – which makes them hard to study, predict, or control with conventional analytical tools.
- Complexity science offers clues for how society can fight this virus while minimizing the risk of cascading failures. In periods of high uncertainty, we need to prioritize adaptability over efficiency, distributed processing over hierarchical processing, evolution over design, and experimentation over mandates.
- During this adaptive period, central governments should focus on facilitating innovation and the free flow of information and resources across society.
- Complexity science also offer lessons for solving other stubborn problems that have long plagued society.

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Preface

"Complexity is the science of the 21st century."

– Stephen Hawking

The COVID-19 pandemic is sweeping the world. Many are blaming our political leaders, and they certainly haven't done much to distinguish themselves or to protect us. Whether it was the Chinese leaders hiding the outbreak until it was too late to contain it or Western leaders failing to quickly flatten the curve, political leaders everywhere have shown remarkably poor judgment. Shouldn't we expect better? Actually, probably not. In "Expert Political Judgment," Philip Tetlock (2005) documents that political experts everywhere consistently fail to accurately predict the outcomes of various policies. Why should this time be any different?[1]

Tetlock attributes some of this failure to ideological bias. He finds that experts with strong political ideologies (whom he calls "hedgehogs") have the least accurate forecasts, probably because they see the world through partisan lenses: They see what they want to see, not what's actually there. But the poor quality of political judgments goes far beyond partisan bias. Both society and the COVID-19 pandemic are *complex adaptive systems* that are hard to study, predict, or control with conventional analytical tools (i.e., *reductionism*). Believing otherwise is what Hayek (1991) called "the fatal conceit."

What are complex systems, why are they so hard to predict, and what can *complexity science* (or *complexity theory*) tell us about how society can respond to this virus and ultimately defeat it?

A Brief Introduction to Complexity Science

Complex systems are networks of independent but interconnected agents (or nodes) that give rise to emergent system-wide behaviors. Complexity science studies how this happens. Complex systems are dynamic, nonlinear, multidimensional, and adaptive. They learn and evolve over time in ways that

[1] For those who would point out that leaders in South Korea and Taiwan did accurately predict and respond to the pandemic, this is a bit like saying some investors beat the market last year. Yes, but can they do so consistently over time? And more importantly, can we identify them in advance? Probably not.

are hard to predict or anticipate and even harder to control. Complex systems are found in many disciplines, from astrophysics to zoology. Examples include the internet, the climate, the human brain, a viral pandemic, the economy, human civilization, ant colonies, and the biosphere. Complexity science studies the similarities in these systems across disciplines in order to uncover broad generalities. This discussion focuses on social systems, but the conclusions apply to all complex systems.

Complex systems are defined by *emergence* – the whole is more than the sum of its parts. Examples of emergent behavior include: physical reality emerging from quantum uncertainty; life emerging from chemical reactions; consciousness emerging from neural activity; and the economy emerging from human interactions. These are all examples of *spontaneous order*, or order that mysteriously emerges from seemingly random and chaotic interactions with no overriding guidance or design. This makes it hard to predict the behavior of complex systems based on knowledge of their properties and underlying components – i.e., conventional reductionist techniques simply don't work (which explains Tetlock's results).

A complex system can be *nested.* American society, for example, is composed of many interacting subsystems – the medical system, the financial system, the transportation system, the communications system, the political system, the legal system, and so on – which themselves are composed of various organizations, which are composed of individuals, who are composed of muscles and organs, which are composed of cells. Each of these subsystems is itself a complex system, making American society a *Complex Adaptive System of Systems (CASoS).*

A key finding of complexity science is that there is a tradeoff between *adaptability* and *efficiency*. As a general rule, simple systems are more efficient and less adaptable; complex systems are more adaptable and less efficient. For a system to be effective, however, its complexity needs to at least match the complexity of its local environment. This is known as *complexity matching*, or the *law of requisite variety*. To successfully adapt to a variety of environmental challenges, the system needs a range of responses that at least matches the range of challenges. Thus, simple, efficient, centralized systems work well in stable and predictable environments, where the challenges are few, known, and unchanging. Conversely, complex, adaptive, and distributed systems work best in uncertain and dynamic environments, where the challenges are many, unknown, and constantly changing.

Complex systems rely on the *evolutionary algorithm* (variation and selection) and *distributed processing*. Local agents are autonomous and use local knowledge to solve local problems (variation). The best solutions then get copied and proliferate across the broader system (selection). In this way, the system learns, adapts, and evolves over time. The best solutions, however, can vary across subsystems and over time, so dynamic systems like the economy are constantly adapting. This is why central planning doesn't work for large, dynamic, and complex economies.

In a nested CASoS, the complexity of each subsystem must match or exceed the complexity of its local environment. In many cases, one system is the environment for another. For example, the legal and tax systems are (part of) the environment for the economic system. If either of these systems becomes more complex, the economic system will need to become more complex as well, forcing it to sacrifice some of its efficiency for adaptability. Economic agents will need to expend time, energy, and resources adapting to changes in the legal or tax system, leaving them less time, energy, and resources to adapt to changing technologies and human preferences. In addition, the results of these adaptations are hard to predict and may result in perverse or unintended consequences. Thus, some subsystems, like the legal or tax system, should be simple, stable, and efficient, while others, like the economy, should be complex, dynamic, and adaptable.

As a general rule, complex systems are more adaptable when there are strong connections between agents. For human societies, these agents are subsystems, organizations, and individuals; the connections between them are flows of information and resources. Because information and resources are widely distributed across society, society adapts more quickly when the connections between agents are strong and information and resources can flow freely among them. Just as the human brain is more intelligent when it has lots of specialized neurons and strong neuronal connections, society's *collective intelligence* is greatest when there are lots of specialized subsystems with strong connections within and among them. Strong connections are the lifeblood of collective intelligence.

This interconnectedness has one major drawback, however: it can lead to *cascading failures.* If one or more nodes fail, it can trigger failures in other nodes, which can trigger further failures, and so on in a cascade of failures. For example, the failure of one part of the electric grid can overload other parts, leading to widespread blackouts. Similarly, when many borrowers default, it can lead to bank failures, which can trigger the failure of bank counterparties, and so on, leading to a systemwide financial crisis. Possible solutions to cascading failure include flexibility (nodes that can better absorb stress), circuit breakers (isolate failing nodes), and redundancy (replace failing nodes with backups).

All systems reside on a spectrum between simple to complex. Table 1 summarizes some of the important differences between simple and complex systems.

Table 1: Simple versus Complex Systems

Simple Systems	Complex Systems
Reductive	Emergent
Efficient	Adaptive
Predictable	Uncertain
Designed	Evolved
Hierarchical	Distributed
Rigid	Flexible
Static	Dynamic
Mandates	Experimentation

Complexity Science and COVID-19

Perhaps the primary lesson of complexity science for COVID-19 is that we need to weaken connections for the viral pandemic and strengthen connections across society and its critical subsystems. For the virus, this means weakening its ability to spread, both within infected individuals and among them and everyone else. The first goal requires treatments that can either deactivate the virus or stop it from spreading to other cells. These treatments can include drugs or the body's own antibodies. To slow the spread between individuals (i.e., the transmission rate), options include vaccines, lockdowns, social distancing, and herd immunity. (Herd immunity occurs when enough people have caught the disease, and developed antibodies, that the virus can't find a new host.) What are the best ways to accomplish these objectives?

The COVID-19 pandemic presents society with dueling prospects for cascading failures. If we do nothing, the virus will spread rapidly and we'll reach herd immunity sooner, but it will also overwhelm the medical system, and many will die. Conversely, if we go into lockdown, it will slow the transmission rate, but it will take longer to reach herd immunity and we'll have cascading failures across the economy. Both of these cascades (medical and economic) have already started. How do we minimize their damage? Complexity theory can't answer this question, but it can offer a process for finding solutions.

The current situation is highly uncertain and the problems are complex, both in terms of the pandemic itself and the policy response. This calls for a complex, adaptive, and distributed approach.

Pandemic uncertainties:

- What are the rates of infection, transmission, hospitalization, and death?
- Do they vary across the population?
- What percentage of hospitalizations require ventilators?
- What is the asymptomatic rate among those infected and do their transmission rates differ?
- What is the distribution of the transmission rate (i.e., are there super-spreaders who are responsible for an outsized share of transmissions)?
- What percentage of the population is currently immune?
- What percentage of the population needs to be immune to achieve herd immunity?
- How long does immunity last?
- How does the virus operate and what treatments might reduce the hospitalization and fatality rates?
- Is the virus mutating, and if so, how quickly and in what ways?

Policy uncertainties:

- How do mandatory lockdowns compare to voluntary social distancing for reducing the transmission rate?
- What are the most cost-effective ways to protect both the economy and the medical system from cascading failures?
- What are the cheapest and fastest ways to increase the supply of essential equipment (tests, masks, PPE, sanitizers, ventilators, treatments, etc.)?
- What are the social and psychological consequences of extended lockdowns (e.g., higher rates of depression, drug abuse, suicide, divorce, and domestic violence)?
- Which treatment and vaccines are likely to be most effective, and how long will they take to develop?

According to the law of requisite variety (complexity matching), we can't solve a complex, uncertain problem with a simple, efficient, and centralized response. Just as it would be a mistake to put all of society's resources behind a single treatment or vaccine option, it would also be a mistake to impose centralized, one-size-fits-all policies on the whole population. If these policies prove to be ineffective, or make matters worse, everyone suffers. For example, if the federal government imposes mandatory lockdowns, but it turns out that extensive testing-and-tracking (i.e., the South Korean model) or voluntary social distancing (i.e., the Swedish model) would produce similar medical results over the long term with far less economic damage, then the whole nation suffers. At this point, we just don't know. (If you think you do, please refer back to Tetlock's study, mentioned earlier.)

When one is faced with a complex and uncertain environment, the law of requisite variety demands a complex, adaptive, and distributed response. We need lots of subsystems, organizations, jurisdictions, entrepreneurs, and scientists trying lots of different approaches (variation) so we can quickly discover the best ones and implement them more broadly (selection). We need more labs developing different tests, treatments and vaccines; more companies and entrepreneurs exploring different options for manufacturing critical medical supplies; more do-it-yourselfers coming up with creative ideas (crowdsourcing); more tech companies developing disease tracking apps; and more local jurisdictions trying different approaches to slowing the transmission rate while minimizing economic damage. Fortunately, much of this is already happening.

What can central governments do during this adaptive process? Plenty. Perhaps their most important role is to encourage innovation and expedite the flow of information and resources across society. This means both eliminating barriers and creating incentives. Table 2 lists some options, many of which are already being explored. It is meant to be suggestive, not exhaustive or definitive.

Table 2: Government responses to enhance adaptability in a pandemic

Eliminate or relax unnecessary regulations and red tape
Patent reform to encourage information sharing
Tort reform to encourage innovation
Permit telemedicine and practicing medicine across state lines
Expand scope-of-practice laws for medical professionals
Offer monetary and public-service awards for significant achievements in fighting COVID-19
Remove tariffs on imported medical supplies
Eliminate certificate-of-need laws that limit supplies of new hospital beds and medical equipment
Conduct random testing on the population to get better estimates of the transmission, infection, hospitalization, and fatality rates
Develop logistical systems to quickly move scarce resources to where they are most needed
Provide safety net programs that encourage labor mobility
Offer guaranteed high prices for critical medical equipment and supplies
Collect and share information on which treatments, policies, and approaches are most effective.

Finally, with its unparalleled borrowing power (at least for now), the federal government is in a unique position to support people and businesses that have been idled by the pandemic. But what is the best approach? Should the government guarantee some portion of last year's revenues for idled businesses that continue to pay their employees? Or provide enhanced unemployment benefits for laid off workers? Or simply send checks to everyone? What about providing loan guarantees to failing businesses? Or maybe just let companies fail and have creditors take over? What about extended paid leave? How will different policies impact labor mobility and the risks of cascading failures? We just don't know.

When uncertainty is high, the best approach is to promote adaptability and distributed processing. We need to try different policies on small samples (variation) then implement the most effective ones across society (selection). Unfortunately, there wasn't enough time for this. But the CARES Act is a kitchen-sink approach that is rife with waste and cronyism. It is neither efficient nor adaptive. A better policy might have been to issue block grants to states so they can try different approaches simultaneously. This way, every region gets help now even as we experiment with different policies.

Complexity Science Beyond COVID-19

The global economy is extraordinarily complex: It is both adaptive and efficient. It has produced vast increases in wealth and income around the world while simultaneously reducing the frequency of armed conflict (trading partners rarely go to war). Unfortunately, greater connectivity has also left the world more vulnerable to cascading failures. Strong interconnections mean that viruses can spread faster. They also mean that the failure of one or more economic systems can quickly spread globally (e.g., the 2008 global financial crisis). How can complexity science help us enjoy the benefits of globalization while limiting the risks of cascading failures? By promoting flexibility, circuit breakers, and redundancy.

Complexity theory offers clear guidance on how to avoid future pandemics. The best strategy is to break viral connections before they can form (i.e., circuit breakers). This means ending wet markets and taking other steps to keep viruses from jumping to humans from other species. When a new virus does emerge, authorities should isolate infected individuals immediately before it can spread. If it does escape, society needs to be ready with a complex, adaptive health care system. This means a flexible one with distributed processing and few centralized mandates — one that can adapt and respond quickly to new problems and that is not hindered by unnecessary regulations and artificial supply constraints. To the extent that the policies in Table 2 improve the adaptability of the medical system, society should make them permanent. Like any good complex system, society will learn from this experience and adapt going forward.

Flexibility, circuit breakers, and redundancy can also help society avoid cascading economic failures. Some factors that make an economy vulnerable to cascading failures include: high debt levels; high fixed costs (operating leverage); low savings rates; dependence on a few suppliers or clients; and restrictions on the flow of capital and labor. Accordingly, government policies should encourage: equity over debt financing; more savings; diverse, redundant supply chains; and better mobility for capital and labor. We can debate the specific policies that would best achieve these goals, but as with any new policy idea, it's always best to test them on small samples before implementing them more broadly across society. Because the economy is a complex adaptive system, it is hard to predict exactly how it will respond to any given policy.

Finally, complexity science also provides guidance for many other stubborn problems that have long plagued society, including climate change, inequality, poverty, housing, education, and health care. First, per Tetlock (2005), we need to admit that we just can't accurately predict which policies, if any, will solve these problems. If we knew, they'd be solved by now. The law of requisite variety (complexity matching) demands that we attack complex problems with equally complex systems that prioritize adaptability and distributed processing. This means encouraging innovation and facilitating flows of information and resources across the system. We can then test the best ideas on small samples (variation) before implementing them more broadly (selection). Conversely, a simple hierarchical approach is much less likely to solve these complex problems (which is why they remain problems today).

Conclusion

Strange as it may seem, humanity actually owes a lot to viruses. By some estimates, 40 percent to 80 percent of the human genome had viral origins.

Some of these viral segments are critical for fetal development and the immune system. A merger between a simple (prokaryotic) cell and a virus likely produced the first complex (eukaryotic) cell, resulting in all complex life on earth, including humans (this is called *viral eukaryogenesis*). The *evolution of sexual reproduction* (and thus the two sexes) was also likely an adaptation for fighting viral infections. There is even evidence that human consciousness resulted from a viral infection.[2] Unfortunately, viruses can also cause pandemics and widespread death.

Both humanity and viruses are complex systems that are constantly adapting to each other in an arms race that neither side can ever really win (see the *Red Queen hypothesis*[3]). Eventually, humanity and the new coronavirus will reach a state of mutual equilibrium where we develop antibodies (herd immunity) and complex medical and social systems that make us more resistant to viruses. Until then, however, complexity science offers many suggestions for how we can minimize the impact of the twin cascading failures – medical and economic – that currently threaten society.

About the Author

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[2] Rafi Letzter, "An Ancient Virus May be Responsible for Human Consciousness," Live Science, Feb. 2, 2018, https://www.livescience.com/61627-ancient-virus-brain.html.

[3] Francis Heylighen (2000): "The Red Queen Principle", in: F. Heylighen, C. Joslyn and V. Turchin (editors): Principia Cybernetica Web (Principia Cybernetica, Brussels), URL: http://pespmc1.vub.ac.be/REDQUEEN.html

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