Augmenting the Toolbox

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The failure of traditional policy-making

When asked in a 2005 Senate hearing about the US Federal Reserve's ability to face a financial crisis, then-Fed Chairman Ben Bernanke had a confident reply for his audience: "I think, in fact, that the financial system has benefited over the years from the meetings of a variety of financial crises, including 9/11, for example, which has led to hardening and providing additional back-up facilities and the like and other experiences that the Federal Reserve has had. The depths, the liquidity, the flexibility of the financial markets has increased greatly" (Washington Post 2005). What's more, Bernanke was far from the only one to be so optimistic. Aside from some rare early warnings by a handful of academics,[2] few had correctly predicted the 2008 financial meltdown, let alone the scale of its economic and social impact.

The failure of mainstream macroeconomic models played a key role in this forecasting fiasco. In 2006, worried about a potential housing bubble, the Fed used its main macroeconomic model to test what would happen to the U.S. economy if housing prices dropped by 20 percent. Going through the results, the Fed concluded that such an event would not prove all that problematic. As pointed out by Eric Beinhocker (2012), the Fed's position was that "[g]rowth might soften, or there might even be a mild recession, but nothing that a few small

2 Such early warnings came, for example, from Keen (1995), Baker (2002), Roubini (2006) and Talbott (2006). Other academics often credited with having warned of the crisis early on include Joseph Stiglitz, Paul Krugman and George Soros.

interest rate cuts couldn't handle." The model simply assumed that, were housing prices to collapse, markets would behave rationally, and that, after some time, the system would gently move back to its full-employment equilibrium.

Ultimately, these models failed, and their failure extended beyond their forecasting role. When policymakers had to deal with the global banking panic, mainstream macroeconomics and traditional models were of little use to them. Beinhocker (ibid.) cites a report of the *Economist* claiming that the Bank of England's macroeconomic model was not of much help because it didn't have banks in it, noting that it "is hard to make policy in the middle of a banking crisis" under such conditions. Adair Turner (2015), appointed chairman of the UK's Financial Services Authority on September 20, 2008 (i.e., only five days after the collapse of Lehman Brothers), recently compared taking office in the midst of a financial meltdown with little guidance to "being appointed captain of the Titanic after you've hit the iceberg, but before we'd actually sunk."

Indeed, at the height of the financial crisis, it became clear that the central bankers' toolbox was outdated. The tools being relied on were familiar from past use, but they were no longer able to help maintain a global economy profoundly altered by decades of digitalization, financial integration, market deregulation, global mobility and trade liberalization.

Beyond financial markets: An urgent need to adapt

Such limitations of policymakers' tools are far from being constrained to the world of finance. While advancing globalization and fast-paced technological change have generated immense wealth and improved living conditions worldwide,[3] such progress has come at a cost.

3 The United Nations claims that the global share of people living on less than $1.25 per day was more than halved between 1990 and 2010. Moreover, figures provided by the World Bank show that the world's annual GDP rose from $9.2 billion in 1960 (constant 2005 prices) to $56.5 billion in 2013, with the final 15 years accounting for a roughly 50 percent increase. All over the world, people are enjoying longer and healthier lives than ever before.

The past decade has witnessed not just a global financial crisis (which eventually morphed into the still-ongoing debt crisis in the euro zone), but also a series of other severe crises. To name just a few, there has been the nuclear accident in Fukushima, triggered by a tsunami; climate change, spurring droughts and floods alike and resulting in mass migration; a data-privacy crisis revealed by the NSA scandal; the outbreak and spread of Ebola; a massive shift to populist parties in European elections; and, more recently, geopolitical conflicts and terror in the Middle East, Ukraine and elsewhere.

Technological and economic integration have made us more vulnerable to widespread crises. Owing to an unprecedented level of global interconnectedness and interdependence, a single financial asset can bring our economies to a sudden halt, a single infrastructure failure can throw a wrench in entire production chains, and pandemics are ever harder to contain. These crises have three things a common: They appear in a vulnerable system. They have unexpected triggers. And, once they have materialized, they are incredibly hard to contain effectively.

The nature and source of these new "systemic risks" can be captured by a single term: complexity. With the technological progress and the advances of globalization of the past few decades, our world's complexity has increased dramatically. Indeed, the global systems that policymakers now deal with have become very large, interconnected, heterogeneous and changing at an accelerating pace, resulting in emergent phenomena, instability, unpredictability and fundamental uncertainty.[4] In short, we live in ambivalent times: Although great progress has been made on many fronts, today's world appears to be tremendously fragile and vulnerable.[5]

Traditional policy-making rarely takes into account this rising complexity. The speed of systems adaptation is lagging behind the pace of technological advances and their consequences. As a result,

4 See Arpe (2012) for a more detailed assessment of these structural changes and their implied challenges to economic policy.

5 This view is supported by Paul Ormerod, who argues in his chapter that "[s]ystems of interconnected agents [...] are both 'robust' and 'fragile.'"

complexity alienates policymakers and the general public, leaving them in dire need of orientation and unable to adequately prevent looming crises. Such unpreparedness could have tragic consequences. As emphasized by Ian Goldin in his chapter, "[t]he fragility of our outdated institutions in the face of these new vulnerabilities challenges the core benefits that globalization has produced." Policymakers must augment their toolbox if they hope to cope with both immediate risks (e.g., financial crashes and infrastructural collapse) and more long-term threats (e.g., demographic change, urbanization, jobless growth, global competitive pressure and rising inequality).[6]

Successfully facing systemic risks will require policymakers to radically adapt. If they are to make systems less prone to failure and improve their capacity to contain crises more effectively, decision-makers should specifically be equipped with the means to:

- better understand the systems under consideration
- better and more intelligently monitor the crucial components of these systems
- implement a more effective risk management focused on both multidisciplinary approaches and multiple future scenarios, and
- carefully redesign these systems to make them more stable and resilient.

A historic opportunity

There has never been such a need to adapt, and – thankfully – we have never had such an opportunity to do so. Owing to recent advances in our understanding of complex systems as well as in our ability to harness the power of the digital revolution, policymakers have the means to augment their toolboxes and tackle the countless challenges of a complex world.

6 In the "Outlook on the Global Agenda 2015," the Global Agenda Councils of the World Economic Forum find that 86 percent of respondents "think that there is a leadership crisis in the world today," and that 87 percent agree or strongly agree with the statement "We need to develop new structures for global governance" (WEF 2014).

For example, breathtaking advances in information technology have allowed us to collect, store, disseminate and process ever-growing volumes of data. In less than 20 years, Google, YouTube, Facebook and Twitter have revolutionized the way we access information and social networks. We have deciphered the human genome, invented the smartphone, explored the surface of Mars and entered into a new era of digital education.

International organizations have recognized that it is high time to harness the power of these advances for policy-making, too (PARIS21 2015; Data Revolution Group 2014; WEF 2014). For example, in his synthesis report on the post-2015 sustainable development agenda (U.N. 2014), U.N. Secretary-General Ban Ki-moon stated: “We are on the threshold of the most important year of development since the founding of the United Nations itself.”

The editors of and contributors to this book share this optimism. As Ian Goldin puts it, “[T]he opportunities for cooperative solutions have never been greater.” Eve Mitleton-Kelly states that “humans are able to co-evolve, to self-organize and to create something new that is emergent in the sense that it could not have been predicted at the outset.” On the technical side, James B. Glattfelder speaks of “a new era of analyzing the complex and interdependent world surrounding us,” ushered in by the “increased influx of data” and “a paradigm shift in the analysis of complex systems.” And Paul Ormerod concludes his article by saying: “The potential gains from more effective policies built on better scientific understanding of how the world operates are enormous.”

With these encouraging words in mind, let us now look at what a toolbox “upgrade” may look like.

From old tools and mindsets to new ones

What exactly do we mean when we speak of “augmenting the policy-maker’s toolbox”? Of course, this is first and foremost about adding to the box tools that are new, tools that are suited to dealing with the complexity of today's (and tomorrow's) challenges, tools that draw on the technological and intellectual capacity accumulated over recent decades. But providing new tools is not enough. Indeed, if you already have a hammer and you now add, say, a screwdriver, you might be tempted to put everything into the category of either a nail or a screw, even if you are dealing with a tomato.[7] Policymakers and their organizations need to change not only *what* they act with, but also *how* they act.[8] They need to be trained to look at a problem from the right angle (or, even better, from multiple angles), to choose the right tool to address it, or even to realize and acknowledge that no appropriate tools are currently available.

In the latter case – that is, if the policymaker is facing a challenge that does not permit any direct solution – it might be time to "redesign" the environment in which the policymaker is working. By making clever changes to the building blocks of a complex system and to their arrangement, the system may become amenable to steering or even self-correct in a desired way. Redesigning complex systems, however, is clearly a complex challenge in its own right, so it should be handled with the utmost care and caution. Brian Arthur (2014), a leading complexity scientist at the Santa Fe Institute, warns that "[a]ll systems will be gamed" and suggests that "[w]e need to stress test our policy designs, to find their weak points and see if we can 'break' them. [...] Such exploitation-mode analysis, applied to the world of policy, would give us economic and social outcomes that perform as hoped for, something that would avert much misery in the world."

In what follows, we describe how the contents of the policymaker's toolbox should be changed in order to better cope with these new challenges. Since new tools must come with new instructions, the focus will be on describing both the features of our new tools and the intel-

7 As Dirk Helbing notes in his contribution: "[I]f wrongly used, a powerful tool can be very destructive."

8 As Eve Mitleton-Kelly writes: "Complexity, however, is not a methodology or set of tools. Complexity theory provides a conceptual framework, a way of thinking, and a way of seeing the world."

lectual underpinnings that policymakers should adapt to. An overview is provided by Table 1.

Table 1: Characteristics of old and new tools

From old to new tools	
From…	**To…**
Simplistic models	Models of complexity
Spreadsheet analysis	Data science
Isolated objects	Networks
Disconnected micro and macro theories	Smooth and evidence-based linkages between micro and macro theories
Overregulation	Patterns and rules of thumb
Future projections and planning	Accepting uncertainty
Pillarization	Enabling environments

From simplistic models to models of complexity

Since the late 1970s, economic policy has largely been driven by the neoclassical doctrine that takes as its theoretical underpinnings such concepts as rational actors, market efficiency, Pareto-optimal equilibria, stable and homogeneous preferences, and a tendency to aim at optimizing simplistic macroeconomic measures, such as GDP per capita. Across the world, this has resulted in strong efforts toward market liberalization and reductions in government intervention.

Such assumptions hardly fit with today's realities. For instance, Paul Ormerod observes in his contribution that the prevailing consensus on the rules that govern economic agents' decisions – a consensus at the heart of microeconomics – is increasingly invalid. As he sees it, this consensus includes the assumptions that agents "have stable tastes and preferences between alternatives," that such tastes and preferences are "transitive," that "people make choices independently," and that an agent is "able to both gather and understand all the information available about the various alternatives on offer." He then goes on to argue that all of these assumptions have come under scrutiny in recent decades by several prominent scholars, including Joseph Stiglitz, George Akerlof and Daniel Kahneman, and that "in the cyber society of the 21st century," we are confronted with "quantum leaps in both the accessibility of the behavior, actions and opinions of others, and in the number of choices available," all of which are not at all captured by standard economic theory.

Taleb (2007: 303) defines the problem of "Platonicity" as "the focus on those pure, well-defined, and easily discernible objects like triangles, or more social notions like friendship or love, at the cost of ignoring those objects of seemingly messier and less tractable structures." Although it has been clear that the simplified assumptions of standard economic theory were only meant to be approximations of real-world phenomena (as every model naturally is), the hard-core traditional economist's stance was to steer actors as much as possible in the direction of being rational. Modern science, however, suggests that this is impossible, and that the "invisible hand" succumbs to irrational behavior, heterogeneity and the consequential instability of multiple equilibria in complex environments.

Similar incompatibilities between prominent features of complex systems (such as emergence, non-linearity and repercussions) and common policy practices can be observed in many fields other than economic theory. Mainstream forecasting (traditionally based on projections of past experience into the future), planning (usually built on mechanistic, waterfall-like successions of actions), evaluating (traditionally focused on reductive measures or aggregates, such as GDP) and managing (conventionally involving the assessment of performance indicators and standard procedures) can all prove useless when applied to a complex environment.

To make the right decisions in the face of complexity, we must revise the assumptions of the models we use so that they more closely match the realities. Likewise, the analysis of a system should take into account all of the system's aspects and features that are relevant to the decision. This, in turn, requires policymakers to choose their tools wisely. Indeed, there is no "super-hammer," no Swiss Army do-it-all multi-tool. Instead, every challenge may require a different choice of tools.

In her chapter, Eve Mitleton-Kelly notes that, “[i]n a human context, the social, cultural, technical, economic, political and global dimensions may impinge upon and influence each other.” In other words, we need to admit that the world is often not as simple as we would like it to be. Owing to this insight, which is crucial for good decision-making, she calls for holistic analyses of complex systems.

Graham Room makes the case for evidence-based policy-making in his chapter, but he emphasizes that “[i]mpact must be judged with reference to the various interests involved” and that the weighting of these interests “involves a political judgment.”

And, in his chapter, César Hidalgo discusses how we should cast economics in the language of *information* and *computation*: “Under-the-hood products are made of information, which is better measured in *bits* than in *dollars* or *euros*. This means that the actions we use to make products are acts of *computation*.”

In a similar vein, Hanauer and Beinhocker (2014) have recently suggested that one can view capitalism as an evolutionary system for enabling people to cooperate and make new solutions available. Economic growth may then be viewed as the rate at which new solutions become available rather than as the monetary increase in arbitrary goods and services.

From spreadsheet analysis to data science

In recent years, there has been a lot of buzz around “big data.” The breathtaking advances in information technology have allowed us to collect, store, disseminate and process ever-growing volumes of data. Indeed, with a fresh 2.5 quintillion (i.e., 2.5×10^{18}) bytes of data produced every day (according to IBM estimates), this represents a treasure trove of opportunities. Mayer-Schönberger and Cukier (2013) explain how these new opportunities are revolutionizing how we can analyze and forecast based on real-world evidence. Recent developments, such as "deep learning," allow us to work with huge amounts of fuzzy data (i.e., data that is extremely heterogeneous in format, with lots of missing or inexact values) and to extract from them future predictions that surpass all classical approaches in terms of accuracy and speed, without even having to wonder whether or not correlations can be taken for causations.

However, as James Glattfelder notes, "[t]he buzzword 'big data' is slowly being replaced by what is becoming established as 'data science,'" and "collecting and storing raw data is futile if there is no way to extract meaningful information from it." In a similar vein, Dirk Helbing writes that "more data does not necessarily imply better decisions" and points to potential problems of fitting to irrelevant features, identifying meaningless patterns and making classification errors. Thus, even if more and more promising new "big data"-based tools emerge, we should take them with a pinch of salt while firmly placing our focus on thoughtful data *analytics*. In the words of Gary King (2013), director of Harvard University's Institute for Quantitative Social Science: "Big data is not about the data!"

Several international public institutions (e.g., the U.N., IMF, World Bank and OECD) have realized the potential that data science holds for addressing their respective challenges, and they have taken two major approaches to it. The first one is to use big data analytics to gather meaningful information more quickly, cheaply and reliably than through traditional procedures of "by hand" data collection, official reporting, aggregation over various levels and publications in unwieldy books with significant time lags. The second approach is to not only store the data for one's own use, but to also make it publicly accessible. In other words, many global institutions are gradually turning into proponents, and sometimes even champions, of the open data movement. Making data freely accessible to the public increases transparency and enables data scientists, statisticians, analysts, journalists and many others to advance evidence-based analyses, reporting and policy-making and to build tools for the public good.

From isolated objects to networks

When trying to make sense of the world, we often look at its various obvious parts and assess "things," such as countries, companies, merchandise goods, stocks or even soccer clubs. Assessing the performance of these "things" in terms of numbers, we can rank them and determine which is "best" and which "worst." But as James Glattfelder discusses in his chapter, this "reductionist approach" has meant that traditional problem-solving has focused "on things in isolation – on the tangible, the tractable, the malleable." He continues, "[u]nderstanding the structure of a system's components does not bring insights into how the system will behave as a whole." In the words of the old saying, the whole is more than the sum of its parts. But whenever we encounter a whole that does not equal the sum of its parts, we can in fact be sure that we have missed something. Making sense of the whole then means that we need to *identify the missing parts*. This "more," Glattfelder concludes, is the *patterns of interaction* of these objects. Thus, instead of looking only at "things," we also need to look at connections between these "things" and how they interact with each other. The structure embedding the things turns out to be the missing part of the whole.[9] This shift – taking us from analyzing objects to patterns of interaction within systems – represents a "true paradigm shift" that has been impacting a still-growing number of fields.

There are several new tools that help us do this. In *network analysis*, the "things" under consideration are modeled as *nodes,* and the connections between the "things" are modeled as *links*, which may be directed or undirected and carry a weight indicating the strength of the connection. There is a huge arsenal of mathematical methods

9 In his chapter, César Hidalgo invokes the example of a Bugatti worth millions being crashed against a wall, which destroys its value immediately. He writes that "the value of the Bugatti evaporated when you crashed it against the wall because this was not stored in its atoms, but rather in the way in which these atoms were arranged. And that physical order is information." Thus, the missing part that makes the Bugatti more than just the sum of its atoms is this physical order (and, to add to Hidalgo, value induced by social constructs).

available to study such networks and gain insights into their global structure, critical parts, dynamics and so forth. In particular, network analyses may provide insights that are impossible to obtain by looking exclusively at "things." For example, Google's PageRank algorithm ranks web pages according to their centrality, but the most important factor in determining a web page's importance is the importance of other web pages that link to it.

The same methodology is applied in the *DebtRank* analysis of major financial players that Glattfelder describes in his chapter. The analysis strongly supports the idea that, since centrality turns out to be of major importance in the propagation of financial distress, the original notion of being "too big to fail" should be replaced by the notion of being "too central to fail."[10] As another example, Glattfelder reports that an analysis of the global network of transnational corporations (TNCs) reveals that global corporate control is highly concentrated, with only 730 top shareholders controlling 80 percent of the total revenue value of all TNCs in the network.

In a more qualitative vein, Paul Ormerod explains in his chapter how "network effects can dwarf the impacts of policy based on the standard economic model of decision-making, even in its modern behavioural guise." This is because "[t]he views of each individual agent are potentially influenced by what the agents directly connected to it are thinking."

Further support for this idea is found in Eve Mitleton-Kelly's chapter. "Complex behaviour of systems arises from the inter-relationship, interaction and inter-connectivity of elements within a system and between a system and its environment," she writes, adding that "a decision or action by any individual [...] may affect related individuals and systems."

A variety of interactions between actors of different types is taken into account by *agent-based models*. In these models, companies, pub-

10 In fact, one might at first be tempted to term them "too connected to fail." It turns out, however, that a high degree of connectedness does not necessarily imply a high centrality. Quite to the contrary, as Liu, Slotine and Barabási (2011) show, the nodes driving a network tend to avoid the nodes of high degree.

lic institutions, households, individuals and so forth are modeled as *agents* equipped with different preferences, capabilities, access to information, financial resources, geographic locations, decision rules, etc. The evolution of such systems can then be studied under several initial conditions by computer simulations that have the agents interact with each other according to predefined rules. For example, Herbert Dawid et al. describe in their chapter the Eurace@Unibi model and discuss its potential uses for informing policymakers.

Trade is an obvious example amenable to network analysis, as it is about exchanging goods and services. However, economists have recently realized that looking at bilateral trade relations may not suffice to capture the essence of trade imbalances. In light of ever more complex international value chains, it has been proposed that we should consider all the multilateral contributions to a traded good and extract the true "trade in value added."[11]

From disconnected macro and micro theories to smooth and evidence-based linkages

To understand a complex system, we must at least be aware of its micro-structure. A fundamental critique of macroeconomic theory is that is not "rooted" in microeconomics – in other words, that it makes predictions about a system's global behavior without looking at the system's components. As a consequence, market outcomes predicted by macroeconomic theory may differ significantly from actual market outcomes (see, e.g., Beinhocker 2006).

The question then is: Just how detailed should our analytical models be? The obvious answer appears to be: The more detailed, the better. But building *too much* complexity into the models by trying to incorporate as many aspects of reality as possible won't help for three reasons. First, this would require us to be able to capture every rele-

11 For example, the OECD and the WTO have joined forces to start the Trade in Value-Added (TiVA) initiative (http://oe.cd/tiva).

vant aspect of the world, which is obviously impossible. Second, and more fundamentally, this would require the world to work mechanistically and deterministically, which is a matter of much contentious debate in fields ranging from sociology and philosophy to theoretical physics. Third, even if we had the means to build extremely detailed models of reality, we would still have to be able to interpret them. Of course, the “best” (in the sense of the “most accurate”) model of reality is reality itself. So, if we chose this very best model as the one to work with, we wouldn’t gain any benefit from such a choice in terms of reducing complexity to eventually come to a decision.

In addition, the more complex the model, the more difficult the task of reaching decisions based on it. To make things easier, we can use algorithms. But since algorithms (no matter how sophisticated) are just standardized computational procedures invented by human beings, we still need to take into account the danger of relying on them too much. This has been highlighted, for example, by the 2010 Flash Crash, which saw algorithm-based trading trigger a 9 percent nosedive in the Dow Jones Industrial Average within just a few minutes.

So, how should we proceed in specific situations? It depends, of course, on the situation. In some cases, a bird’s-eye view of the global state may suffice, as macroeconomic theory makes reasonably good predictions in many situations. For example, as Bridget Rosewell points out in her chapter, if time scales are too short, then “[s]ignal is dominated by noise.” In other cases, it is reasonable to descend to a meso level, as is done by the technique to characterize an economy’s ability to produce products developed by César Hidalgo (see his chapter and the references therein). In this case, one takes into account the diversity of countries with respect to their exported products as well as the ubiquity of products with respect to the number of countries producing them, without having any more detailed knowledge on which capabilities are actually needed to produce a specific product or which capabilities are available in which countries. However, in other cases, it makes sense to look very closely at the micro level of individual actors.

In short, we have to find the right focal length for the lens we use to analyze the world. And, importantly, changes to the focal length should ideally be consistent – in other words, if we aggregate our lower-level findings to higher levels, the derived findings should agree with observations at higher levels.

A particularly delicate case for finding the right focal length appears to be the recent public debate about the growth of social inequality worldwide. Much of the debate revolves around assessments of total measures for income or wealth inequality in countries as a whole, such as the Gini coefficient or the so-called 20:20 ratio. Given the heterogeneity of societies within and across countries, it is obvious that such simple measures cannot capture much relevant information that could be used to derive adequate policies. However, much of the expert debate revolves around precisely such oversimplified measures. Instead, policymakers should find a way to simultaneously analyze inequality dynamics both holistically and at a decent level of granularity.

From overregulation to patterns and rules of thumb

While the last three sections focused on the *analysis* of complex systems, we will now turn to their *control*.

If systems are getting increasingly complex, don't the mechanisms to control them have to become more complex, as well? On first sight, this idea appears to be supported by W. Ross Ashby's oft-cited "law of requisite variety," which posits that the number of states of a system's control mechanism must at least match the number of system states being controlled if the system is to remain stable (Ashby 1956). Recent developments in financial regulation appear to take this insight into account. For example, when trying to illustrate the increasing complexity of the global financial markets a few years ago, Bank of England chief economist Andrew Haldane (2012) noted that the volume of the Basel regulatory framework had grown from 30 pages in 1988 (for Basel I) to 616 pages in 2010 (for Basel III).

However, after checking the performance of complex regulatory frameworks against much simpler "rules of thumb," Haldane determined that the latter can dramatically outperform the former in risk-weighting capital, predicting bank failure and modeling financial risks. One reason for this is that, in order for the complex frameworks to work reliably, one would need access to much more historical data than has been collected so far. According to Haldane, the big difference between policy responding to risk and policy responding to uncertainty is that the former is "fine-tuned," while the latter should be "coarse-tuned." "Complex environments," he concludes, "often [...] call for simple decision rules [...] because these rules are more robust to ignorance."

Further evidence for the potential superiority of rules of thumb is their omnipresence in less rationalized decision-making processes of everyday life. In fact, the Eurace@Unibi model introduced in Dawid et al.'s chapter has rules of thumb built into its agents' decision-making.

Still, doesn't the idea of replacing complex rules with simpler rules of thumb contradict Ashby's law? It doesn't. The reason is that complex systems don't necessarily have to follow complex rules, but can actually (though perhaps paradoxically) follow very simple ones. In this case, the number of components *driving* the system's behavior can be surprisingly small. Controlling just the states of these individual drivers may then be accomplished by mechanisms far less complex than one might expect given the complexity of the system as a whole.

Of course, the challenge is to find "good" rules of thumb. Haldane (2012) explains that in order to catch a Frisbee, dogs and humans alike have been observed to follow a very simple rule: "run at a speed so that the angle of gaze to the Frisbee remains roughly constant." The angle of gaze to the Frisbee is the reduction of a complex system to a single parameter that is amenable to control (by varying one's speed and direction). If the angle of gaze is kept constant, the system will automatically arrive at a state in which the Frisbee is caught.

In more artificial complex systems, such as financial markets, finding *patterns* can help in identifying good rules of thumb. While the sheer variety of complex systems suggests that very specific analytical tools are required to find such patterns in each of them, Barzel and Barabási (2013) have shown that there are universal characteristics of network dynamics that apply to a broad range of networks, "from biochemical dynamics to epidemic spreading." The Santa Fe Institute, in fact, runs a project on "finding the hidden laws that pervade complex biological & social phenomena."

Thus, to summarize, we do need complex tools to analyze what is going on in our complex world and to be able to find the patterns that help us make sense of that world. But when it comes to identifying specific risks, to predicting systemic failures or to designing regulatory rules, it can make better sense to not fight complexity with complexity, but rather to concentrate on relevant patterns and to base one's decision-making on appropriate rules of thumb.

From future projections and planning to accepting uncertainty

When faced with a set of policy choices, we tend to use the following standard approach:

1. Decide on a target variable (or a set of target variables) to be optimized by our choice (e.g., GDP growth, jobless rates or average transit times) as well as on a set of variables that drive the target measure and that can at least partially be influenced by our choice.
2. Define a model that specifies the qualitative relations between several variables that can somehow be measured, including the target variable and the driving variables. This usually involves a set of free parameters. For example, the model may specify that, in any specific year, annual GDP can be expressed as a linear combination of a set of "explanatory variables," plus a residual term.
3. Calibrate the model, that is, derive values for the free parameters by fitting the model to satisfy data of past observations. The quality

of explanation is commonly expressed in terms of statistical significance.
4. Estimate the impact of the policy choices on the driving variables based on past experience, theoretical considerations or even informed guessing.
5. For each choice, run the model with driving variables altered accordingly, giving results for the target variable.
6. Decide on a choice that in some way optimizes the target variable.

This process can have a number of pitfalls. First, the chosen target variable can be a poor choice. As Bridget Rosewell discusses in her chapter, the focus on transit times as the target variable has delayed the UK's Crossrail underground railway project for decades. Only when a new report considered its potential to create production growth, it became clear that the benefits would probably go far beyond shortened transit times. In a similar direction, the model may well miss some of the truly driving variables on which the different choices can have equally strong effects.

Second, the relations specified typically involve assumptions about causalities even if we can only observe correlations. Sometimes models are chosen because of their mathematical elegance or their resemblance to physical laws. For instance, assuming that trade flows follow a law resembling Newton's law of gravitation may look appealing, but there is no reason why a similar law should apply to international economics.[12]

Third, the derivation of the free parameters can be obscure. If there are too many of them, there can be large degrees of freedom in determining them – sometimes so as to fit predetermined results. If there are too few of them, the model may become unsatisfiable.

Fourth, to produce statistically significant results, sufficient amounts of data are needed. Hence, if data availability is limited in the first place (as is often the case for consistent time series), this also

12 The majority of leading trade researchers will likely object to this by pointing to empirical evidence that appears to confirm this assumption.

limits the number of variables to be admitted in the model, forcing it to be much cruder than would be acceptable.

Fifth, the estimated impact of the choices on the driving variables can be subject to much debate. This is particularly true if the analyses involve shaky estimates of the probabilities of future events, and even more so when probability theory doesn't apply due to true uncertainty (Knight 1921).

Sixth, deriving values for the target variable from computations with altered driving variables assumes that the qualitative relations among variables as well as the established parameter values will not change in the future or under different choices. It is commonly taken for granted that the model itself and its parameter values are by no means affected by the choice to be made.[13]

Seventh, if several target values are chosen, how to determine an "optimal" solution may become a matter of dispute. This can be avoided by aggregating the values into one variable, but different ways of aggregation may of course still lead to different notions of optimality. Moreover, in some situations of social choice, it may even be provably impossible to aggregate individual preferences into sensible community-wide rankings of options (Arrow 1950).

Haldane (2012) argues that modern macroeconomics and finance are heavily based on the assumption that the probability distributions for future market risks are known, with the most popular framework being that of rational expectations. The latter assumes that "information collection is close to costless and that agents have cognitive faculties sufficient to weight probabilistically all future outcomes." In contrast, Haldane also notes, decision-making under uncertainty is "occupying a small corner of the profession," although it "yields powerful, and in some cases surprising, insights."

All this tells us that trying to base policy-making on precise future predictions is often futile. As Bridget Rosewell comments in her chapter, "hindsight is no substitute for foresight, and foresight is often impossible in a complex world." In his chapter, Paul Ormerod seconds

13 If the latter change, they do so according to a fixed relation specified in the model.

this stance, writing that "[t]here is *inherent* uncertainty about the impact of policy in a world in which network effects are important, and no amount of cleverness can overcome it." Thus, we need to acknowledge the fundamental limitations on forecasting in complex systems and to let go of the idea that every system can be (or even needs to be) controlled. As Graham Room suggests in his chapter, when planning becomes guessing, agile policy-making may be a more fruitful approach.

Moreover, as Bridget Rosewell points out in her chapter, regardless of the framework in which decision-making takes place, "[t]hings do go wrong." This calls for more risk awareness and willingness to invest more energy into crisis prevention. Indeed, good decision-making is not just about the decisions themselves, but also about preparing for things that could happen should the decisions (or other circumstances) ultimately lead to undesired outcomes. Providing general frameworks, but then adapting them to specific circumstances, could allow regulations and state-of-the-art practices to co-evolve with each other (Beinhocker 2012).

In short, we need to prepare for the future – and as Ian Goldin reminds us in his chapter, in light of looming systemic risks, to prepare for it better than ever before. But that isn't enough. We should also prepare for *multiple* possible futures as well as for the unexpected, which requires us to build resilient systems and to be ready and willing to adapt. For example, in explaining why experimenting is more important than predicting, Beinhocker (2012) suggests that we "create a portfolio of small-scale experiments trying a variety of solutions, see which ones work, scale-up those that are working, and eliminate the ones that aren't."

From pillarization to creating enabling environments

Governments, companies, universities and NGOs alike have traditionally been structured into pillars (e.g., ministries, units, departments or programs), each of which deals with some more or less specific issue. This “pillarization” often results in redundant structures, parallel work efforts and a lack of communication between those pillars, whether due to a lack of institutional infrastructure or even of incentives for exchange.

While it can sometimes be desirable to build parallel structures into a system and thereby increase its robustness, we more frequently observe a waste of resources and disincentives to sharing information across pillars, for example, due to internal resource-assignment schemes.

The more interconnected the issues an organization faces, the less appropriate such pillarization is. This makes it necessary to create additional structures that enable and incentivize various units to exchange, to learn from each other, to cooperate and to co-evolve. Dealing with complexity requires one to be open to new ideas, to interdisciplinary approaches, to multistakeholder processes and to participatory processes. Data and information have to be made accessible, and one needs to introduce holistic approaches that take into consideration multiple trends as well as cross-sector challenges and opportunities.

Above, we have argued that our analytical focus needs to be “upgraded” from assessments of isolated components to ones of dynamical networks. In the same way, our organizational focus must transition from a “one separate unit per issue” arrangement to flexible problem-solving networks with appropriate information-sharing architectures and processes. But, as Paul Ormerod rightly asks in his chapter, this leaves (at least) one question, namely: “How do we induce [...] a genuine change in behaviour by harnessing the potential power of networks?”

In his chapter, Dirk Helbing favors what might be called a “systems design approach.” He is convinced that “instabilities in complex systems and the large-scale cascading failures often resulting from them [...] result from faulty system designs and flawed management approaches, which in turn lead to uncontrollable outcomes, despite massive amounts of data, modern technology and the best of intentions.” He then goes on to suggest that “a paradigm shift in the way we are creating and managing these systems could solve our problems."

Looking more closely at the challenge of organizational restructuring, Eve Mitleton-Kelly comes to the conclusion in her chapter that "the *design* of a new organisation needs to be considered from a new perspective." Drawing on her vast experience in applying her methodology with various corporate and non-corporate organizations, she lists the crucial conditions for building an enabling environment. These comprise cultural conditions (e.g., showing readiness for change, distributing leadership and providing a reflective space for sense-making), social conditions (e.g., valuing staff and co-ordinating objectives), technical conditions (e.g., having an integrated IT system) and political conditions (e.g., fostering clarity of vision and strong leadership).

She also suggests that "clarity of vision and direction are essential" for establishing "multiple micro-strategies." Under changing conditions, this then allows an organization to adapt to the most successful of such strategies. A necessary requirement for this is having a "no-blame" culture that explores alternative solutions and thereby facilitates self-organization. In addition, Mitleton-Kelly writes, this principle has been found to work best if the "three Cs" are present: Communication, Collaboration and Co-creation. Taken together, organizations should create enabling environments that allow every involved individual to unfold his or her full potential and to contribute as much as possible to the organization's greater purpose.

These ideas apply not only to organizations, but also to societies as a whole. It was the need for public goods – such as protection against intruders; provision of cross-country roads, railways and other infrastructure; or public access to education, healthcare and social insurance – that drove the rise of the nation-state in the 18th and 19th centuries. With societies of growing complexity as a result of an increasingly sophisticated division of labor, higher mobility and growing heterogeneity, the task of providing public goods has become a Herculean one for the modern welfare state, particularly in the face of rising debts and societal ageing. For this reason, other players – including corporations, unions, cooperatives and civil society in general – must take on stronger roles, and strengthening corporate social responsibility, social investments and volunteerism are certainly a good start.

Furthermore, as Martin Wolf (2012) convincingly argues, globalization produces the demand for *global* public goods, such as the stability of financial markets, protection against internationally active terroristic groups, cybersecurity and a stable climate. So far, however, there are no satisfactory global structures that could reliably provide such global public goods. Due to the highly interconnected nature of these global public goods, the design of such structures should adhere to the ideas of preventing pillarization and fostering the creation of enabling environments to tackle the world's most pressing challenges right from the start. In almost every discussion of economic globalization, one hears mention of "global competitive pressure." But it is time to recognize that there is also a "global cooperative pressure."

Conclusion

Decision-making ultimately must reduce a complex reality to a finite number of choices and often even to a single "yes" or "no." The more complex a decision-maker's environment, the more difficult the task of reducing complexity in a way that it eventually results in an optimal or at least a reasonably good decision. This task becomes even more challenging when uncertainty abounds. It requires not only more effort and more resources, but also new approaches that may differ substantially from what is commonly practiced.

When surrounded with apparently boundless complexity and uncertainty, policymakers may feel overwhelmed and unable to see the forest for the trees. While the demand for orientation is huge, supply is often of insufficient quality. For example, it can be driven by leftist or rightist ideologies, overly simplistic, based on inadequate models or sometimes even preying on people's fears by being extremist, populist, anti-democratic or racist. The proposals presented in this book on how to augment the policymaker's toolbox will hopefully contribute to providing orientation of much higher quality. They may even contribute to overcoming the age-old right-versus-left debate, namely, that of "markets versus states" and "individual rights versus collective responsibilities" (Beinhocker 2012).

It is important to remind ourselves that there is a clear, simple and compelling goal: to improve the life of all people as much as possible, now and in the future. In fact, many paradigm shifts have started with a return to this universal idea, as has been shown by the U.N. Universal Declaration of Human Rights, Amartya Sen's capabilities approach (Sen 1985), the foundational ideas of Germany's social market economy or the French commission on measuring well-being beyond GDP (Stiglitz, Sen and Fitoussi 2009).

Achieving social justice, equal opportunities and good living conditions for as many people as possible inevitably requires us to acknowledge our world's complexity, to augment our toolboxes and to adapt our mindsets accordingly. As Beinhocker (2012: 144) notes, "widespread use of new economic approaches to policymaking may require some education of citizens, the media and politicians themselves on the risks of overconfident top-down solutions, and the importance of small-scale failure as a way to learn and prevent large-scale disasters." Independent non-state actors, such as foundations, think tanks and NGOs, share the responsibility to assist in doing so.

The promising ideas, insights and examples presented in this collection of contributions prove that a wide selection of new tools is already available for inclusion in the policymaker's toolbox, and that the technical, intellectual and procedural capacity to deal with complex systems is steadily increasing. We are optimistic that there is a lot more of this to come, and that – gradually and with a lot of commitment, effort and courage – policymakers around the world will successfully adapt to a world of abundant complexity.

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