Luohan Academy

Exploring Complexity and Complexity Economics

Symposium Summary

December 2021

Luohan Academy Frontier Dialogue #8

Exploring Complexity and Complexity Economics

FEATURED SPEAKERS

W. Brian Arthur	*Emeritus Professor at Santa Fe Institute*
Long Chen	*President of Luohan Academy*
Katherine Collins	*Head of Sustainable Investing at Putnam Investments* *Chair of Santa Fe Institute Board of Trustees*
J. Doyne Farmer	*Professor of Mathematics and Director of Complexity Economics at Oxford*
John Geanakoplos	*Professor of Economics at Yale*
Alissa Kleinnijenhuis	*Research Scholar at Stanford Institute for Economic Policy Research*
Simon A. Levin	*Professor in Ecology and Evolutionary Biology at Princeton*
Andrew Sheng	*Distinguished Fellow at Asia Global Institute at HKU*
Stefan Thurner	*Professor of Complex Systems at Medical University of Vienna*

Disclaimer: *This symposium summary features transcripted excerpts from the event. It has been lightly edited for clarity and length. The full video of the event can be accessed at the Luohan Academy's website and our Youtube channel.*

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Executive Summary

On December 6, 2021, the Luohan Academy convened its 8th Frontier Dialogue - ***Exploring Complexity and Complexity Economics****. The event was moderated by Katherine Collins, Head of Sustainable Investing at Putnam Investments and Chair of the Santa Fe Institute's Board of Trustees.*

Advances in digital technologies have made the world more connected. Society's actors are linked and affected by each other, making the world an increasingly complex system. Complexity studies probe how elements interacting in a system create patterns, and how these patterns, in turn, cause the elements to change or adapt in response. Whether it is cars in traffic reacting to adjacent cars, or cells in an immune system reacting to other cells and viruses, complexity asks how individual elements react to the current pattern they mutually create, and what patterns result. Panelists in this symposium discussed both theory and real-world applications.

Simon A. Levin, Princeton University Professor of Ecology and Evolutionary Biology, launched the discussion with several crucial points. First, many challenges in both ecological and socioeconomic systems are of complex adaptive systems (CAS). Second, these issues cross scales – macroscopic patterns come from microscopic interactions of heterogenous individual agents. Third, outcomes are often unpredictable with traditional linear tools because these systems have feedbacks, path dependence, hysteresis, etc. His own paper "Ecology for Bankers" (2008) used complex networks, inspired by ecological models, to show financial markets on the verge of collapse. While the paper was unfortunately proven prescient, it showed the capabilities of complexity models for seeing real world problems. Levin noted two important areas of work for complexity sciences. The first is to identify "critical transitions" or early warning indicators of systemic issues. The second is the research begun by Elinor Ostrom, the first female Nobel Laureate in economics, to study how pro-sociality behavior in small local groups can contribute to preserving the Commons globally. This work supports a polycentric governance model, in which multiple governing bodies interact to make and enforce rules in complex social-ecological systems, even without centralized global coordination. This is often a good way to achieve collect action in high uncertainty – key for environmental challenges such as climate change.

Santa Fe Institute External Faculty Member W. Brian Arthur followed by first explaining the history and impetus for his groundbreaking work in complexity economics, which began at the inaugural meeting of the SFI's first research program – the Economy as an Evolving Complex System in 1987. This convened top thinkers in different disciplines, including Kenneth Arrow, Philip Anderson, Doyne Farmer, Tom Sargent, Larry Summers, John Holland. 'Standard' economics was trying to come up with models for problems that required well defined problems, which was *often not possible. Holland, a computer scientist studying AI, suggested a more intuitive "agent based" approach where agents do not have perfect knowledge, but rather intuitions and rules that can learn and evolve. The application of computer simulation to these concepts allowed them to run models. Arthur related an early success simulating investors in a stock market. This model did not assume perfectly rational investors as in Robert Lucas' standard model. While many results were in line with Lucas, additions were periods of bubbles and crashes, exactly like the real world. These early experiments showed the promise and much work has followed. Arthur sees complexity economics as a form of non-equilibrium economics that relaxes the overly strict assumptions of standard economics to improve on the latter.*

University of Oxford mathematics professor J. Doyne Farmer described applications of complexity economics to addressing climate change, household savings, leverage in the financial system, economic impact of pandemic lockdown policies – all situations where the probabilities of events, or even the set of possible outcomes, are not known by individual agents. Farmer underscored the need for micro-level data collection to power the bottom-up models that he works with, which government and statistical agencies are not yet collecting. Finally, he touched on the persistence of mainstream resistance to complexity thinking, which challenges foundational assumptions and orthodoxy which have reigned over the past 150 years.

Yale economics professor John Geanakoplos served as discussant to review the presentations by Levin, Arthur, and Farmer. To Geanakoplos, complexity economics is drawing excitement and he cites two reasons for this. First, it is interdisciplinary and pulling in the brightest minds from various disciplines. Second, it arose by using modern computational methods, which has led to potentially powerful real-world results. Geanakoplos contrasts Farmer's work accurately predicting Covid's impact on employment, with the inability of many economists to predict the effect of Covid and stimulus on inflation, suggesting that complexity bottom-up models may have done better. Geanakoplos concludes by lamenting the loss of talented non-economists to the economic discipline. He calls for all economics, standard or complex, to be open and cross disciplines to absorb and germinate new ideas.

Opening the second session on operationalizing complexity, Stefan Thurner, a complex systems professor at the Medical University of Vienna, introduced real world research using complexity tools to quantify systemic risk in Austria's financial system. Looking at data such as banks contract networks, books, and leverage ratios, Thurner was able to discover that even some very small banks can have outsized systemic importance. Actors who introduce more systemically risky transactions can eventually shoulder a higher price, perhaps by paying a systemic-risk tax. Based on his research, Thurner found that de-risking solutions to prevent cascading effects in a system can be accomplished without making it smaller or less efficient. These models could be applied globally as well to see which country defaults would be most significant from the perspective of global stability.

Asia Global Institute Distinguished Fellow and adviser to China's banking regulator Andrew Sheng warned against the old reductionist ways of regulating specific products and within siloes, when modern innovations like platform economies and crypto-currencies are breaking down traditional barriers, supply chains, and networks. In a world where the markets are linked to the real economy, which is linked to foreign exchange and politics and national security, interdisciplinary complex thinking is required. Traditional remedies based on simple rules, as when governments flooded the world with liquidity in the aftermath of 2008, have only created asset bubbles that leave us with risks of instability, Sheng said.

Stanford Institute for Economic Policy Research scholar Alissa Kleinnijenhuis presented her research on bail-in mechanisms and their effect on the "too big to fail" problem. She used a complexity-based model because systemic risks arise from networks that are interactive and lead to amplification or dampening of crisis. Her research shows how that effective bail-in designs can break harmful deleveraging cycles, and provide recapitalization support for institutions to preserve banking system stability. This has critical impact on stability of the system. Modeling the European bail-in mechanism, the research suggests mechanism does dampen risks, but still far from optimal. Such research can help policymakers to improve on these mechanisms.

Long Chen, president of the Luohan Academy, closed the operational session as discussant by leveraging his deep experience with digital platform, presented modern firms as much more interconnected. Chen illustrated how digital technology facilitates close feedback loops with consumers and suppliers, allowing firms to adapt their behaviors in response to information. While scholars usually study networks after the fact, firms enabled by connected real-time information can design systems that react to change, to support positive outcomes or dampen negative ones. For example, algorithms used by digital lenders can dynamically adjust loan issuance to respond to shocks. The adaptability of firms to external environment is only growing more critical, especially in rising expectations of firms to be involved in environmental, social and governance (ESG) issues.

During the open-floor discussion, Harvard economics and mathematics professor Eric Maskin suggested that complexity economics remains outside of the mainstream because it needs not only to show that standard economics fails, but have in place a solid framework that performs better. Maskin pointed to prospect theory, advanced by behavioral economists, as an example.

Doyne Farmer agreed with Maskin that complexity economics should be challenged to show that they've been superior in understanding the real-world implications of policies. But Farmer believes complexity needs a "fair hearing" from mainstream journals, who have been less willing to publish the work of complexity economists.

Kleinnijhenhuis suggested that ideas from complexity economics have taken hold and are already well-understood within the profession especially in her focus of modeling financial crisis. Many mainstream papers use complexity models even if not explicitly referencing it. Columbia Business School professor Neng Wang noted that while he is very open to complexity economics, he still believes any form of economics needs to assume an optimizing rationality. Wang would like to see more precise definitions of complexity economics. That said, he notes Alissa's point that mainstream economics is already incorporating complexity tools.

Peking University economics professor Chen Ping, one of China's most followed economists, points to how mainstream economics continues to turn a blind eye to more atypical models because of its reliance on the idea of unlimited growth. In the current climate crisis, the need to recognize resource limits is putting pressure on economic foundations.

Finally, the Santa Fe Institute's Arthur predicted that complexity economics will coexist with neoclassical economics in the same way that nonlinear mathematics never replaced linear mathematics. Just as relativity theory and quantum physics exists alongside Newtonian ideas, both economic schools are needed.

Session I: Panel Presentations

1. Complexity and Complexity Economics

Speakers	Discussant
Simon A. Levin Professor of Ecology and Evolutionary Biology at Princeton	**John Geanakoplos** Professor of Economics at Yale
W. Brian Arthur Emeritus Professor at Stanford and Santa Fe Institute	
J. Doyne Farmer Professor of Mathematics and Director of Complexity Economics at Oxford	

Speaker presentation by Simon Levin (Princeton)

Katherine Collins

Welcome, everyone. We're delighted to be here for this Frontier Dialogue today. It promises to be a terrific and curiosity driven discussion. So we're very much looking forward to exploring some new ideas together. I'm Katherine Collins, your moderator for the day. I'm an investor by profession, and I work on sustainable investing at the intersection of societies and ecosystems and markets. All of these are complex, adaptive systems, very much aligned with the topic of our discussion.

Today, we will be exploring complexity and complexity economics. And again, the spirit here is one of curiosity. We are exploring some new questions, some new ideas, some new models for thinking about issues in a different way. So thank you all for bringing your curiosity.

The second note I'll make is that a number of our speakers today have affiliations with the Santa Fe Institute, myself included. This is no surprise since the Santa Fe Institute has been deeply involved with questions of complexity since its founding. Again, I think the spirit of Santa Fe is to bring this ethos of curiosity and intellectual rigor to investigating the big questions of our time. Thank you all for aligning with that spirit of curiosity and intellectual rigor. The last thing I'll note before turning over to our first speaker is that we have a very ambitious and energetic agenda for this morning. Thank you in advance to all of our speakers for giving very short and provocative highlights within your talks so that we can preserve time for discussion at the end of our session here today. I will give each speaker a little bit of a signal when you have a few minutes left in your presentation so that we can stay on time. Thank you to all of you in advance for keeping that in mind.

With that, I'm delighted to turn to our first speaker. Simon Levin is Professor in Ecology and Evolutionary Biology at Princeton, External Professor at the Santa Fe Institute. And I'll note that all of these introductions are a single line to describe many decades of amazing experience. Please excuse the shorthand. I'll turn it straight over to you, Simon, to kick us off.

Professor Simon A. Levin

Thank you very much for the introduction. I'm delighted to be here. I thank the Luohan Academy for inviting me and I thank all the funding sources that have contributed to my work. So sustainability of the biosphere, which Katherine alluded to in terms of investing, is the ultimate global challenge.

A crucial feature is that this sustainability really is focusing on macroscopic features. This is similar to if you're going to boil water to make tea, what you are interested in is whether the water boils while recognizing that control of those features rest at lower levels of organization. Just as if you were boiling water or putting the liquid or gas under pressure, you would know that the phase transitions would depend on lots of interactions that were taking place, but you wouldn't attempt to account for each one of those in your analysis.

This implies that there's a need to relate phenomena across scales, for a biologist from cells to organisms, to collective ecological social, technological systems, in which they are embedded. There's a need to ask: How robust are the properties of those systems? How does that robustness of the macroscopic properties relate to the individual dynamics on finer scales? The sort of agent-based approaches that Doyne is going to talk about. Are systems at critical points about the transition, just like the water that's boiling? And how do we manage the Commons across scales and conflicts of interest? Ecosystems in the biosphere, which is what I work on primarily, are complex adaptive systems. The term originated by John Holland at Santa Fe. They are heterogeneous collections of individual agents that are interacting with each other on a local scale.

The whole system evolves based on the outcomes of interactions and then feeds back to affect them. Not only the ecological systems, but socioeconomic systems, with which we are concerned today and with which they are interlinked. They are complex, adaptive systems, from an ecology, from microbial systems, like the slime molds on the left to the large animal herds that you see on the right (those are wildebeests), to socioeconomic systems. Macroscopic patterns emerge from microscopic interactions. Market dynamics depend on individual traders. Can we learn how to deal with those systems from what we understand

about nature? And what can we add? Because we have the capacity to make models, to build predictions, which is not what's going on during the course of evolution.
The challenges of managing these complex, adaptive systems are, first of all, that the dynamics play out on multiple scales; multiple spatial, temporal, and organizational scales. And the systems self organize. That leads to a consequently unpredictability of outcomes. That is the system may have multiple stable states. There's path dependence and hysteresis, meaning if the path from A to B is not the same as the path getting from B back to A.

Now, this is an idea which is illustrated very graphically by CH Waddington's famous landscape of a developing organism, a ball rolling down the landscape, reaching certain decision points in which it goes one way or the other. That's the path dependence of something that Brian Arthur in his seminal work at the Santa Fe Institute through Brian and Kenneth Arrow's leadership began to develop its economics program. Brian emphasized the importance of path dependence in the economy. And associated with that is the potential for sudden flips from one state to the other: contagious spread and systemic risk, and the potential for the destabilization and shifts of regimes through the evolution of variables that are operating on slower time scales.

As an example in 2008, 6 months before the financial crisis and collapse, Bob May, George Sugihara and I wrote a paper in Nature called Ecology for Bankers, in which we say if we analogize from ecological systems to financial systems, we see an increasingly interconnected system. And one, which if we were monitoring an ecological system, would be on the verge of collapse. In fact, we said, who knows, for instance, how the present concern over sub-prime loans will pan out. Unfortunately, we know how that panned out, and we know what we can learn from thinking about complex adaptive systems from one discipline to another, or from the sort of higher level viewpoint that Santa Fe explores.

Critical transitions are widespread and complex adaptive systems. Often they are early warning indicators, Marten Scheffer's book covers the landscape of this topic from natural systems, to economic systems, to physiological systems. When you go to a doctor and the doctor performs an electrocardiogram or some other measure, she or he is trying to anticipate the potential for catastrophic changes in the system. This raises the question more generally of whether we can read the tea leaves. Are there early warning indicators of critical transitions? Marten Scheffer has led a series of working groups. One I happen to have been part of, was on trying to identify what some of the early warning indicators might be in anticipating the transition of a system, like critical slowing down. There are some caveats in over-interpretation of the signals, but these are very promising and exciting areas.

Having covered all those topics in the black dots, I turn now to the last topic which is involving a lot of my energies: what does all this mean for the conflicts between levels? And how do we achieve a sustainable future? How do we sustain public goods and common-pool resources? How do we get the cooperation and collective decision making that's necessary? Public goods problems are widespread in socioeconomic and ecological context, from the sharing scene between oil rigs and fishermen that you see on the left to tumor cells, whose rapid growth leads to the breakdown of the commons. These are all public goods problems. These are all problems that have to do with complex, adaptive systems. On the right. it's the tumor cells of the individual agents that are proliferating without regard for the ultimate demise of their hosts. So the latest challenges we know about, of course antibiotics and their overuse is a problem for society.

In terms of the latest pandemic, we're seeing this problem in terms of individual perceived liberties versus the collective goods in areas like social distancing, vaccination and mask wearing. And interestingly this has been, surprisingly to many, strongly divided along political divisions. And the degree of political polarization in our systems has made it much more difficult to deal with public goods problems. You see the differences here, for example, between Republicans and Democrats in terms of the willingness to get vaccinated.

The maintenance of cooperation, in general, and sustaining the commons was highlighted by Garrett Hardin three-quarters of a century ago, building on the work of William Forster Lloyd, when he talked about the tragedy of the commons and in which the solution had to do with mutual coercion mutually agreed upon. But Hardin was thinking strongly in terms of the need for a government authority to impose those agreements. Lin Ostrom who was involved in Santa Fe, a Nobel Laureate who passed away a few years ago, showed that this could arise from the bottom up, from shared and mutually agreed upon norms. And social norms are crucial to understanding how we achieve cooperation. They are not only problems. They may be the solutions to many of our problems. Social norms can change rapidly: attitudes towards foot binding, smoking in public places, racial equality, gender equality. Maybe we're seeing it now with regard to attitudes towards climate change, sustainability, and the current pandemic. Norms can change rapidly. Can we build on the local, pro-sociality and norms to achieve agreements at the global level on climate change and other environmental problems.

In some of her last work Lin Ostrom talk about what you call the polycentric approach for coping with climate change in which smaller scale agreements would serve as building blocks for the global agreements. This is a problem in complexity economics. With Avinash Dixit and my student Andrew Tillman, we published a paper recently in which we built on the Elinor Ostrom ideas. Divided the population up into sub populations in each of which individuals had concern for each other, and asked whether the pro-sociality in those local groups at least and the leakage of the public goods or public bads from one sub-population to another, could lead to global cooperation and show the conditions under which it could.

In conclusion, I’ve tried to show you that ecology and economics are two sides of the same coin. Therefore, advances in each can inform problems in the other. If you go back to the early work of Charles Darwin or Adam Smith, you'll see very similar themes. Andy Lo and I edited a volume less than a year ago, a special issue of the Proceedings of the National Academy of Sciences, called "Evolutionary Models of Financial Markets". These are adventures in complexity and economics. I think they show, the papers in this issue, the great potential for interfaces across disciplines from complexity theory to economics.

In conclusion, in dealing with complex adaptive systems, we need to understand the multiple scale nature of those systems. We need to develop approaches, I call them statistical mechanics, to identify the potential for multiple stable states and critical transitions to understand what makes these systems resilient and robust. And most crucially, how do we manage the commons across scales and conflicts of interest. So I think we'll see these topics explored in the lectures that will follow. Thank you very much.

Speaker presentation by W. Brian Arthur (Santa Fe Institute)

Katherine Collins (Moderator)

Awesome. Simon, thanks so much for a wonderful start we're off to. We have some big ideas already on the table, some reference to the arc of development that already has happened in research and other circles. And a terrific stage setting, also fantastic time management skills.

So thank you for all of the above. With that, we'll move straight to our second speaker Brian Arthur, known to many of you already， external professor at Santa Fe Institute, visiting researcher at Parc and many other accolades that I will leave for you to read on your own time so as to leave the most time possible for his presentation. Brian, over to you.

W. Brian Arthur

Good morning everybody, it's early morning here in California and late at night in China. I'm delighted to be here. Thank you Simon for a wonderful talk. And I want to emphasize something that Simon has said. A complex system is really a system with multiple elements that create some pattern. They react to the pattern. They're creating, maybe they change their behavior, and then the pattern itself reacts. There's a recursive move. Very simple example I'm fond of is thinking of cars as the elements. They created pattern that we call traffic. And the cars are adjusting to the traffic all the time, but the traffic is the outcome of cars adjusting. What if we looked at the economy this way? Is the economy an evolving complex system of that sort? My answer would be yes. Physicists are always telling us economists that we borrowed these ideas from them. I like to point out that since time of Adam Smith, economists have been looking at individual players in the economy, be they firms or producers, creating some market pattern that they're reacting to and change, and thereby the market itself is changing.

Quite a long time ago in 1987, Kenneth Arrow the economist and his counterpart in physics, Philip Anderson, Nobel Prize winner in Physics. They convened a meeting in the Santa Fe Institute in 1987 on this topic: Is the economy an evolving complex system? By the way, present at that meeting were Doyne Farmer, who will speak next, Tom Sargent, who's with the Academy, Larry Summers, John Holland and so on. I was there as well. This became Santa Fe's first research program. And I was asked to lead it. We discovered when we were trying to convene at Santa Fe to do long term research on this, it was not quite easy to say how the economy might be an evolving complex system.

But we began to realize that in reality, firms in any market differ. They're not all the same. I happen to live in Silicon Valley. So if you're launching into some new industries say, fleets of driverless trucks doing some new activity coming up. And you're trying to launch a firm to do that. You simply don't know what resources the other players have. You don't know what technologies are used. You don't know their intentions. It's not just a matter of putting probabilities on these things. You simply don't know what the other players are going to do. There's certainly a good area of fundamental uncertainty.

So this means that problems, if you want to be rigorous in economics, are in general not well defined. There's no optimization you can perform if you don't quite know what the problem is. We decided economics itself had got stymied on that, and our group got stymied as well. John Holland was a member, and John quite rapidly pointed out that people do act in situations that are not well defined. That's research he had done all his life. John was a computer scientist, interested in what we would now call AI, teaching computers to get smart playing chess or checkers. John told us that individuals, people in the situation that is not well defined, tended to try to make sense. They formed hypothesis. They tested these out, they continually changed their hypotheses, dropped ones that weren't working, adapted new ones. So we began to ask, how can we do economics in that spirit? We decided that we would construct models where each agent could use a range of rules. The rules and hypothesis might differ from one agent to another in our models. The rules might not be very smart to begin with. It might be randomly chosen. And over time in our models, agents could learn which hypotheses and rules worked for them, which were accurate or which were getting better results. They would generate new ideas or rules from time to time. They would throw out the ones that weren't working. And over time, an intelligence would emerge. At first sight, I want to point out that looking at problems this way is very much the ancestral strategy to the current one that trains computers to play Go very well. So this is a kind of ancestral thing for Alpha Go Zero.

But if you look at problems that way that immediately lands in a world where forecasts, strategies, actions are getting tested. Within a situation, I call that ecology, the forecast strategies or actions are together mutually creating. So immediately, we're in a more biological looking situation. Evolution, survival, ecologies come up, appear out of this logical thinking. Also, you can't quite keep track of all of this in your mind. Maybe you can, most people can’t. And so you have to track all this using computation. It turns out that's the backbone, but I just described the logic of agent based modeling.

One thing we wanted to do is to see if we carry this out on some real economic problem, would it give us any different results? So by 1988 and very much with the help of working with John Holland and others, in particular, with visits from Tom Sargent, we began to think we might be able to model a stock market or what's called asset pricing. Robert Lucas had a wonderful mathematical model of asset pricing in 1979. It's a classic paper in standard economics, beautifully done, very elegant solution. Looking at identical investors, using as equilibrium strategy that on average their forecasts are correct. And that produces bids and offers of a single stock where the forecasting method is in equilibrium, obviously called a rational expectations equilibrium. The problem of Lucas's model, there was a lot of phenomenon in real markets, whereas a lot of trading that gets ruled out if all investors are the same. There aren't bubbles and crashes like seen in the real markets are on periods of high volatility and no volatility.

Lucas had a beautiful model which I think is still classic, but it left out phenomenon you see in real markets. What we decided to do is to see if we could replace Lucas' very mathematical, identical investors with differing what we call artificial investors. And these would be small, intelligent computer programs that could differ from each other, each one representing an individual investor in our arbitrary computerized world. And rather than start them with forecasting methods, that on average, were the same and always correct. We set them the task of discovering forecasts that will work very similarly to what I was showing you. Agents might start off a random forecast. So for example, prices have being falling, I forecast that tomorrow prices will rise by 1.2%. This might be a totally random forecast, but they quickly figure out which forecast in their sweep of forecasts, which hypotheses are working.

We created this artificial market. Remember, this is 1988, 30 years ago. All of this sounds very familiar now, but it was an early model then. I was disappointed. We managed to, feeding in a random dividend series, actually solve mathematically for the Lucas solution. That's the top graph. Our model was producing the bottom graph for the same random series. You can see they're almost identical. At first, I was very disappointed that there is no difference between our complexity approach and the standard approach. And then we started to notice. That's if you look at this little bubble here, the yellow bubble here, you can actually, it's a little crash that appeared, as we looked at differences between the neoclassical solution and our solution, we managed to see several things happening. There was a phase change. They're, very much like what Simon was talking about. We found that if the rate of people trying out new ideas, new strategies, new prediction methods, if the rate of change of trying out new things was low, the market would indeed hover around the rational expectations solution. So Lucas's solution was an attractor. But if we dialed up the adjustment rate, the rate of expiration, not very much, suddenly, there is a phase change. Technical trading would emerge. That is investors would start looking at the past pattern of prices and base their forecasts on those bubbles, and little crashes would appear. Random periods of high and low volatility would appear. There be times when the market wasn't doing very much other times when it was going crazy.

My explanation for that last phenomenon, you can explain all these phenomenon by the way, But my explanation is that perhaps one of the investors or a few discover some highly effective new forecasting method. Then that's they will load and invest into the market more than they had previously. That would change the market very suddenly. That might outdate other investors prediction methods. There might be a ripple or avalanche of change of investment methods getting used right across the economy. So success or gross failure would cause a lot of readjustments that could ripple across our little investor economy.

I want to make a remark on this. A lot of people looked at us and said, these are departures from rationality. No, they're not. Let me remind you that rigorously speaking, the agents are all in a state of fundamental uncertainty. They don't know what other agents are doing in this particular model. They're discovering behavior. Each agent is discovering behavior. It works temporarily. In the context of other agents, discovering behavior that works temporarily. Bottom line here is that there are what we would call in complexity circles, emergent phenomena: bubbles, crashes, arch behavior - behavior as high volatility and randomly giving way to low price volatility.

Let me summarize at this stage. I believe complexity economics is a form of non-equilibrium economics. Nobody is quite clear if non-equilibrium economics goes beyond complexity economics, but think of the two as roughly in parallel. In general, in complexity economics, we don't assume that problems are well defined. In general, agents explore and hypothesize, bringing new methods, bring in new decision rules, et cetera. That creates an ever-changing ecology in which beliefs, strategies, or behaviors are trying to survive, given other agents, beliefs, or strategies or behaviors. Outcomes may not necessarily be an equilibrium, our little stock market never ever settled down. Grand Master players at chess, John Holland used to assure me, have never settled down. People are always discovering new strategies. So this is what we would call perpetual novelty in general and sometimes an equilibrium does emerge. And randomly there is an attractor, although there might be random behavior. And computation is necessary, things have come complicated enough in these models that you need computation to track what's happening. It's not that fundamental to the method. I think computation, be it agent based modeling or some other form of computation is not always necessary, but it tracks behavior. Often as I was pointing out, novel phenomena emerge and novel patterns that you haven't seen emerge. Perpetually, there's this question of, does this negate standard economics? Is this a bold addition to standard economics? I would say neither. It widened standard economics by relaxing some of its assumptions. Sometime around the 1850s and 1860s, mathematicians started to experiment with geometries that didn't fulfill all the Euclidean conditions. Those are called non-Euclidean geometries. And that gave a new set of interests or new branch of interests to mathematics and different types of non-Euclidean geometry.

So basically, what we're trying to do here is relax some of the standard assumptions. Agents may differ, and they don't have common knowledge. Problems may not be that well defined and may be fundamentally indeterminant. Equilibrium is not assumed and if it is present it has to emerge. I see this as a widening of standard economics and certainly not in competition with standard neoclassical economics, but rather it can widen and lead into new areas. Thank you.

Speaker presentation by J. Doyne Farmer (Oxford)

Katherine Collins

Thank you so much. Incredibly timely and I'm thinking of the many hours this weekend I spent pouring through current market commentary, and it would have benefited tremendously by some of the concepts that you just introduced us to.
And you ended by making an eloquent note about the mathematics of all of this. So it's terrific that we have Doyne as our next speaker. Known to many of you, Doyne Farmer is a Professor of Mathematics and Director of Complexity Economics at Oxford. Also an External Professor at Santa Fe. Doyne, we are delighted to have you with us to extend the conversation further. Please take it away.

J. Doyne Farmer

I'm going to go on and present some applications for my own work, and then the applications will be developed more in the second session today. I think everybody is probably familiar with the way standard economic theory works. You have agents with utility functions or something like it. Each agent has a model of the world, and each agent selfishly maximizes their own utility, we use this framework to derive first order conditions. And that's essentially the script that every theoretical economics paper almost everyone follows. I think of complexity economics as a revolution. That is, it's if you compare it with a standard method, uses a very different, radically different methodology.

First of all, rather than writing down utility functions and driving first order conditions, we model behaviors directly. There is good evidence from the psychological literature that this is a sensible thing to do. It's what real people tend to do. It's not that we don't have goals, but we use heuristics and learning algorithms. And when we have goals, they're fairly explicit goals. They're not generic goals, like log utility. I think the key aspect is using feasible information. That is, agents act with information that agents could plausibly have. And then we're in a world of non-linearity so we model dynamics through simulation. The simulations might or might not converge to equilibrium. In fact, as we've shown in a paper, in the context where we've exhaustively studied normal form game theory, that's very unlikely if the game is competitive and complicated, the players are using bounded rationality based algorithms. Cars Hommes has also shown that it becomes unlikely when the setup is too unstable. There's a general philosophy of trying to model things from the bottom up as far as that makes sense.

Now, I think there's several clear advantages of this approach. It's got what I called verisimilitude. That is, it as is rather than as if. It easily incorporates information from behavioral economics. Endogenous dynamics often emerges. It doesn't always emerge, but sometimes it does. And this approach copes with uncertainty, as opposed to risk, that it's operatable in a world where we don't necessarily know the probabilities of all events or even know the set of possible outcomes.

And most importantly, perhaps it's scalable. That is, you can take a real world situation that might be pretty complicated where the first order conditions are likely impossible to solve if you put all the elements that were essential into the problem and it gives you a set of heuristics for just plunging forward and modeling the real world. There's disadvantages. There's less formal structure. Different set of skills are required. Calibration can be challenging. These kind of models crave micro data. You really want data about what's happening at a finer scale than aggregate data. And there is a huge task to properly develop what's going on.

Maybe to contrast the two approaches and standard economic theory, as Jimmy Savage called. He said standard economics was suited for what he called "small world problems", where possible outcomes and their probabilities are known. An example being designing an auction versus complexity economics, the latter would be overkill for those kind of problems, but it becomes useful when the outcomes are uncertain or when you have complicated structure. An example might be climate change.

And now I'm going to go through and just illustrate first with some more conceptual examples, a few of these points. I'm going to begin by talking about cycles and endogenous dynamics, and then just present a few other more applied applications. One of the things you often see when you have bounded rationality is that you begin to get cycles. A metaphor that I like to use for this is someone balancing a pole with their hand. If you take a pole in your hand, think of, say, a mop handle, as long as the pole is longer than about a meter, you can maintain it more or less vertical, more or less, but not exactly vertical. Then the question is: why is that pole oscillating? Think of the pole as the economy. Why is it oscillating? If you were a standard rational expectations DSG modeler, you would write down a model that assumes that the pole balancer is a perfect pole balancer possibly constrained by some frictions of some sort or another, and that there are shocks hitting the pole from the room that are making it move around. Then the pole balancer is always responding to those shocks to bring the pole perfectly back to vertical. And so that's a good approximation. Even then we know real pole balancers aren't that way. But that's not the essence of what causes the pole to oscillate. In reality, poles oscillate even in a room that's perfectly still, because real pole balancers are not perfect. And they overshoot and undershoot. And they do so in a way that, interacting with a pole, they tend to fall into oscillations that are at the resonant frequencies of the pole. It's a completely different way of looking at it, and it gives rise to endogenous oscillations.

Now, I'm going to give a couple of examples where that happens. One is a model that we made, we started with a standard economics model, the RCK model, for savings rate. The standard model, you assume there's a rational representative household, a single one that chooses a savings rate to maximize discounted consumption. That household invests savings in some represented firm and the household decides the right compromise between consumption and investment. You can derive a golden rule. In our version, we have heterogeneous households that have a social network, and at intermittent intervals each copies the savings rate of its neighbor that happens to have the highest consumption at that point in time. And it holds on to that savings rate for a while until the household wakes up again, and repeats the copying operation.

So when you do this, you instantly get oscillations in GDP. You get oscillations in the savings rate. In fact, in that particular model, you see a divergence as the population tends to self organize into rich and poor, with the rich having high savings rates and poor having low savings rates. And interestingly, you can get remarkably close to the golden mean, even though this is a really stupid algorithm. All the agents do is copy each other. Nobody's doing any thinking. And yet you can get remarkably close to the golden mean, but you oscillate around it. That's just a conceptual idea. We're not saying that's a great model for business cycles.

Here's another model of financial crisis that builds on equilibrium work that the discussant John Geanakoplos did, but takes it in a different direction. We set out to model the great financial crisis in a very schematic way. In the plot that I'm showing you here, which is real data. We see the dash blue line, which is S&P500 stock index over time. We see the rust colored curve, which is the VIX that it's a volatility index for the stock market. And we see the solid black line, which is the leverage of broker dealers.

So what you see is there's this long period where the stock market makes a nice, smooth run up, where volatility gets very low, where leverage gradually creeps up until it spikes. And then following the spike, there's a big spike in volatility. Things go into a different mode for a while. We set out to make a simple model that we do that. Actually, we started with a complicated model. And we had different banks playing the stock market and lots of complicated things, happen and we said, now let's give them better risk management. That is the Basel protocol and the whole economy started to oscillate. And we said, wait a minute, what's going on? We began stripping it down until we created the simplest thing we possibly could to capture what was going on.

So that led to two papers both led by Christoph Aymanns. In this model, we have two agents, a bank and a fundamentalist, one risky asset plus cash. We make four assumptions. Banks use an exponential moving average of historical volatility to estimate through expected volatility. They use Basel II risk management. That's value at risk to set their leverage target. They assume supply equals demand, and uh. We assume fundamentalists buy undervalued assets and vice versa. Very simple. What do we get? Well, if the banking sector is small enough, or the amount of leverage they're using is low enough, - and this is without any noise since the general model has noise in it - we get the economy settling into a steady state. But if we turn up the leverage or we turn up the size of the banking sector, this destabilizes and you see spontaneous oscillations. And I just want to mention that the X axis here is not arbitrary units. Those are years. And this model, if you put in an exponential moving average of 2 years, it gives you a kind of great moderation like run up of 10 or 15 years, and then followed by a crash. And that repeats itself not periodically, but chaotically, in an endogenous motion.

Now, going on to a more practical application, I'm going to say a bit about couple of models we made or a model we made to analyze the economic impact of Covid. We began by predicting the shocks a priori. We constructed a remote labor index. We made a list of essential industries. We used a hypothetical study of what would be the reduction in demand if we had a flu pandemic from 2006. And then we use that to make fine grained predictions for the supply and demand shocks for 450 occupations and 55 industries. So just to give you a feeling, this is what things look like at the occupation level. We could predict the size of the demand shock on the X axis or the supply shock on the Y axis for all of these 450 different occupations from just characteristics of the occupations compiled by the Bureau of Labor Statistics. Then we made a dynamic disequilibrium input output model that we used to make conditional forecast of the UK economy. We had 55 industries. We had assumed there was an inventory associated with each industry that we could calibrate against government statistics. We ran the model on a daily time scale. We created a bespoke modified Leontief production functions that differed for each industry based on a survey of industry analysts, which, by the way, we managed to do in a few weeks. And we tested several possible lockdown policies, including one like the one that the UK went into or transitioned into after initial very hard lockdown. This is a real-time prediction. We predicted 21.5% reduction in second quarter GDP in 2020. In reality, what happened was a 22.1% reduction. This model is micro calibrated without any regressions against target data. And this shows our predictions at the sector level. You can see they're not as accurate as the aggregate level. We did have some luck of things averaging out. But we still had a pretty high correlation industry by industry between what happened and what we predicted would happen.

Flying along to try and stay on time. We built a model for the financial stability of the European banking system that looks at detailed balance sheets of banks, and simulates what banks will do when they come under stress. We have a model of occupational mobility that looks at the factors that cause workers to change occupations and tracks the diffusion through the occupation space, through time, based on a simplified earn model for hiring and firing workers.

So just to wrap up and make a few concluding remarks, complex economic models have very different data needs. That is, we really crave, as I said, micro data for calibration. Unfortunately, that's not the philosophy that data is currently collected and distributed by government statistical agencies. That's something we really hope will start to change. I want to stress that all of the models I've mentioned - I can give you a long list of others - are models that don't have utility functions. They don't have rational agents. There are no perfect maximizers. In general, we're not limited by how much realism we can put into them. On calling the approach that we're taking, where we're trying to build models from the micro level up to the global scale, "global microeconomics", the idea is to let macro emerge from micro taking advantage of heterogeneity rather than assuming it away.

Taking advantage of the fact that ultimately there is a lot more data at the micro scale, even if it's difficult to find. That actually allows one to get better statistical significance and models. If you're appropriately parsimonious with other things, it lets endogenous dynamics merge, and it can predict more things because you have both a micro model and a macro model in one package.
I want to emphasize that complexity economics is young. We're talking about something that's been going on for 30 or 40 years. Maybe you can say it reaches back to Herbert Simon. Or maybe you can even say Leontief already started things in motion or maybe even out of it, but it's still not a well-developed field like dynamical DSG models are. There's a lot of work we need to do, like building standard software libraries and coming up with more systematic methods.

And my final slide, there's certainly been some resistance to this from the mainstream. Those I tried to stress. I think the two things are dealing with different problems and are just better at doing different things. But it's not surprising. There's a lot of resistance, because what I'm talking about really requires abandoning foundation assumptions that have been used for a hundred and fifty years. We should be cautious about abandoning such assumptions. We're talking about activity with very different skills in a very different toolkit and whole different attitude toward the way science is done. If you'd like to find out more about my view on this, I have a popular book whose introduction can be found on my website at that link, or you can look on the website of the complexity group at the Institute for New Economic Thinking at the Oxford Martin School.

Discussant talk by John Geanakoplos (Yale)

Katherine Collins (Moderator)

Thank you so much! What a terrific comparing and contrasting of different use cases for the different models that we have very much appreciated. Now we're going to wrap up our first part of today with our discussant, John Geanakoplos, in addition to really deep domain expertise, John is one of the greatest weavers together of ideas that I know of. So we're thrilled to have him with us. John's primary affiliation is as Professor of Economics at Yale. And John, I will turn it straight over to you from here.

John Geanakoplos

I'm going to talk about in a word, what is complexity economics? We've just had a great introduction to the subject. I'm going to find that a little difficult to define so I'll switch to an easier question. Why is it thriving? So I attended the opening of the Indian Game Theory Society 15 years ago, just after the movie A Beautiful Mind came out. Nash, the beautiful mind himself, gave a speech along with others, and there’s a gigantic press conference afterwards. A reporter - a young woman - said, we've all seen the movie, but really could you say in a word what is equilibrium? Everybody tried to give an answer. They all went much more than one words thinking about what the other person's thinking about you. Until it came to Robert Aumann, the last speaker, and he said that reminded him of the first press conference Premier Nikita Khrushchev gave to Western reporters and A reporter got up and said, could you say a word about the health of the Russian economy? And Khrushchev said, good. And the reporter said well, I didn't really mean one word, take two words and tell us about the health of the Russian economy. He said, not good. And then Aumann said, in one word, equilibrium theory is interaction, in two words, rational interaction. So these presentations have attempted to describe complexity theory.

Brian Arthur, I will begin with him because he was the starter at Santa Fe of the complexity program. In his talk, and the surveys he's written that I've read, wonderful surveys. He gives a sweeping account of the many facets of complexity economics that almost all got raised while he was director about the precursors historically who actually used the word complexity and the stunning growth of the field after SFI's beginning. So kinds of facets and concepts that are mentioned are more than one or two. There's the recursive loop, agent based, heterogeneity, ecology of actions, adaptive system, evolution, and perfect information, learning forecasts, undefined problem, computation, non-linearity, emergent phenomenon, noble phenomenon, complexity from simplicity, scaling, phase transition, tipping points, increasing returns, path dependence, new technologies. It's all a messy, vital world like life. I'd say that summarizes Brian.

So now, Simon Levin, a distinguished university professor at Princeton, MacArthur winner and ecologist and evolutionary biologist. He has a complete mastery of the standard tools of economics, of Nash equilibrium, of what Doyne said of all the first order conditions and what it means and so on. Yet he brings interdisciplinary questions to the field, like sustainable growth, or a sustainable environment, social norms, the idea that with strategic complementarity, one person doing something makes other people want to do it more. That's the strategic complementarity. You're going to reach the key tipping point where all of a sudden behavior is going to switch. That's a very important policy implication that you can just push a few people in the right direction. You don’t have to push everybody to tip the whole economy, into having better manners, into wearing masks, things like that. He's written wonderful papers on pro-social preferences as he alluded to. So the question is, if you only have a limited amount of caring by some people for others, when can you get the optimal outcome which might involve a lot of public goods? It's a perfectly coherent, moderate economic model. One of the answers is that if it's expensive to solve the problem yourself with an individual solution, you're going to be more likely to do the socially optimal thing, contribute to the public good provided you have just a little bit of social preferences. He's very interested in system collapses in nature and in finances. The paper he alluded to that he wrote with two others in 2008 was exactly, as he said, couldn't have been more timely. It was spot on and was exactly asking about shouldn't we worry in economics about fragility like we do in ecology, in other fields, just before the collapse in 2008.

Now, Doyne. He's Mister everything. He was a professional gambler who built a computer to put in a shoe. He's an expert on dynamical systems. He ran the complexity lab plus he founded a prediction company to invest in the stock market. He's a long time resident of SFI, one of the founders of the econophysics. He's now on the Oxford faculty, mathematics faculty. So he's interdisciplinary. He alluded to his book on the complexity economics revolution. I can't help but mention that the executive vice president of Knopf is my old college roommate Erroll McDonald. And when they were considering the book for publication - I haven't told Doyne this - I got a call out of blue from my roommate who said, who is this guy Farmer? He seems like a very unusual, maybe slightly crazy person. What have you to say about it? I'm sure the work would have been published anyway, but I mention it for a second reason because I'm going to a dinner tomorrow night, a big dinner that Erroll is giving in honor of the many Nobel prize winners that he's published.

So Doyne’s talk, fascinating talk in which he gave many examples of simulations based on using very specific data about the stability of the banking system based on individual bank information about job transitions. The effects of Covid on unemployment. You contrast that work and that kind of prediction with what is standard in macroeconomics, such as the Phillips curve. The whole discussion lately has been about if you have a little boost to demand, what's going to happen to employment? What's going to happen to prices? It's all derived from very aggregated models that have proved completely wrong. Economists were totally wrong in the US about predicting the effect of the stimulus package on inflation, completely missed the mark. You think they might have done a lot better if they had a kind of a bottoms up model of, the kind that Doyne has been building in many different areas. I'm very glad to see that he's been building on the leverage cycle with Stefan Thurner, as well in putting the idea that the endogenous thinking can create the cycle itself without an external shock. Why is it that complexity economics is thriving? So many aspects to it. I think there are two main reasons. It's interdisciplinary, it's exciting, it's open, it's collaborative. And it represents a return to the origin of economics, which is a very new field and was interdisciplinary when it began. It depends on computation. And complexity economics emerged not coincidentally at the same time the computing power machines became exciting. It also allows for exciting data, Doyne said, and because it's interdisciplinary people focus on classical subjects that are somewhat neglected by modern mainstream economists.

So computation raises the question. The whole approach Brian outlines raises the question. What is intelligence? And I remember very well, Brian and Richard Palmer using these neural networks to solve simple problems with reinforcement learning. And as Brian said, it's exactly the same kind of approach Demis Hassabis has used in Deep Mind, and I never thought it would happen. Actually while I was at Santa Fe I wrote a paper that it could never happen that they would play chess so well. So it's challenged my whole view of what it means to understand. The whole model of the Cowles Foundation of creative mathematics, the leading institution that pushed mathematics into economics. They changed the model from "Science is Measurement" to "Theory and Measurement". There was no measurement without theory. And yet, we sidestep the theory in the Santa Fe Institute with the kind of behavior that the Doyne and Brian has described. It's also based on simulations. With simulations, when you don't have to compute an equilibrium, if you see the freedom to have hundreds of millions of agents.

Yeah, there's still the hope of general properties. "Self organized criticality" was one of the most exciting things I've ever heard about where a system pushes itself naturally to the point where it's critical. It makes phenomena visible before they prove to be there and it enables more detailed data like Doyne said. And both things benefit from the expertise of non economists.

So the biggest challenge, I think for the complexity economics, is simply its strength. Can I really believe that understanding, as I understand understanding, has no role in agent behavior? And Brian says it is rational in some way, but it's not rational in the way that that we typically mean - not old fashioned rationality. Put in another way, rationality of the old fashioned kind seems incredibly improbable and too complicated, but bounded rationality even more complicated.

So I'll just say one more thing about interdisciplinary. Many of the founders of complexity - Murray Gell-Mann, Ken Arrow, spiritual founder, they were polymaths. David Krakauer, who's the head of the Santa Fe Institute, he is a polymath. Economics needs to be informed by other disciplines as it used to be. There was a time when mathematics played a big role in economics. Irving Fisher, one of the greatest economists in the first half of the 20th century, he wrote dissertation with the great physicist J. Willard Gibbs in the physics department, because there was no economics department. Ramsey, von Neumann, and Wald. These are first rate mathematicians, who did pioneering work in economics. In my department, there were three, they just all retired recently, three PhDs in mathematics with tenure as Economics professors – Scard, Bewley, Brown. Berkeley has two of them: Debreu and Anderson, who won the Nobel Prize. You don't see that anymore. Now that this generation has left, there are no mathematicians who are tenured in economics departments, no other scientists tendered in economics departments. Economics has gotten complacent and overconfident. Economists are big part of business school faculties, law school faculties, is getting a foothold of political science departments and sociology. Economics is at its zenith that it seems to be expanding, but because it's expanding, it's giving and not receiving, like it used to be. Pure economic theory is shrinking in most economics departments. And it's time for economics to make a return to its roots and to embrace interdisciplinary and the new methods of computation. These three speakers have brilliantly, I think, made the case and displayed the variety of ways in which complexity theory is affecting economics.

Katherine Collins

John, thank you. We will pull you back in the discussion later and really appreciate your weaving together the themes from phase one here. As you just noted, there's a time and a benefit to specialization, and there's a time and a benefit to cross pollination of all sorts. So really glad that we have set that foundation in session one.

2. Operationalizing Complexity

Speaker	Discussant
Stefan Thurner Professor of Complex Systems at Medical University of Vienna	**Long Chen** President of Luohan Academy
Andrew Sheng Distinguished Fellow at Asia Global Institute at HKU	
Alissa Kleinnijenhuis Research Scholar at Stanford Institute for Economic Policy Research	

Speaker presentation by Stefan Thurner (Medical University of Vienna)

Katherine Collins (Moderator)

Thank you everyone for setting the stage so well in session one. We're going to shift now to session two, which is titled **Operationalizing Complexity**. Looking at some of the concepts that we've just introduced in a somewhat more applied set of circumstances. And I'm delighted to note that our first speaker was just alluded to by John, Stefan Thurner. Many of you know Stefan is Professor of Complex Systems, Medical University of Vienna, President of Complexity, Science Hub Vienna, again, has an external faculty affiliation with SFI. So Stefan, welcome. And we will leave it to you to launch us into session two, with thanks.

Stefan Thurner

Thank you so much for having me. I'll take a little bit of a different angle, not much different to complexity economics, especially I want to show you a little bit what you can do if you have access to data, and if you can more and more watch the economy as it works, as it unfolds. Show you maybe a couple of new questions that can be asked then.

This is a statement that's almost true, not always true. A lot of complexity emerges from networks and the dynamics of networks. We have heard this now from Brian and Doyne in different ways, what I mean is that the concept that we have also heard, like emergence, self organization, path dependence, the existence of power-laws, the ability to set to adapt to new situations, resilience, efficiency, tipping points, et cetera.

This is all understandable in framework of co-evolving networks. Networks that look like something like this. But they are dynamical. So our network is composed of nodes. This could be banks or firms in an economy, banks in a financial system, and they are linked by certain types of interactions. If we are thinking of the financial system, these nodes could be banks and their properties. The colors are shaped here, could be the entries in the balance sheet, the wealth or the risk aversion level, or however you could describe a bank. And the interactions which are different type would be transactions between banks, can be of different type, can be different asset classes. The essence here is that this is not static, but constantly changing, that the states of the nodes are updated according to what the network looks like now, and that the network itself also changes very often as a function of how the states of the system are right now. This is very much what you can say about a theory of complex systems. If you understand how these states change as a function states, sigma here, how they change as a function of how nodes are connected by these matrices or networks M. And if you know at the same time, how these networks change over time as a function of how the networks look now and how the states of the nodes look like then, you know a lot about how complex systems work, how and where they get their characteristics from the typical behavior from, et cetera. What is fascinating about complex systems nowadays is that all these things in the what you can see in this equation, namely, the networks, and the states of the nodes, say, the balance sheets of companies, you can all find and seeing data time resolved, what this T here shows.

So it's always like this. If you want to understand the system, what it's composed of, what its parts are and how these parts interact. Interactions are given by the networks, temporal networks, and networks you find in the databases that you find. Namely, what is the economy? The invention, the realization, the finance, the production, the distribution, consumption, and finally, the recycling of goods and services. This all happens on networks, on dynamical networks that change the states of its components and they change the networks. It is a chicken and egg problem. That's also what makes these complex systems so complicated and hard to handle. It's a mathematical monster, this type of equation. Economics on the other hand the, invisible hand, equilibrium, market efficiency, rationality, concept of complete markets, or game theory. We’ve all heard these and they’re ways to not talk about networks. Economics, traditional economics is kind of or has been since Adam Smith an “art of aggregation”. Which is fine whenever networks play no role, but very often networks do play a role.

I'll show you now two examples, one in financial networks and one in production networks. In these two cases, networks do play a role, and it's obvious. So networks are necessary if you want to understand something beyond a direct interaction between two agents or between all agents. If you want to know how the next agent is coupled to your neighbor, you need networks and they are essential in understanding cascading phenomena. This systemic relevance is something that is quantifiable. As soon as you know these networks and of course you have to know about the nodes and properties of these nodes. And this allows you completely new look on what efficiency is, what resilience is, what systemic risk is, and what collective behavior is, all these are classics of complexity science.

If we want to quantify systemic risk in financial networks, what we want is a number that quantifies the effect of the initial default of, let's say, a bank or one player. We want to compute the effect of this defaulting agent on the entire system as a fraction of the total economic value of the system. So the inputs you have to provide is you need the contract networks between banks, you need the books of the banks, you need the leverage ratios of banks. You need knowledge of how default spreading occurs and how banks are resolved. Once you know these mechanisms, you can try to come up with an algorithm or with a measure, or with a quantity, that serves as a systemic risk index for every individual bank, called it R for risk.

If you're given a banking network, here is a banking network of a tiny nation of Austria. This is one time spot of all the 700 banks or so. The links between those banks are the credits, the net credits, and the size of the nodes is the size of the bank. The color is this systemic risk quantity, this effectiveness or let's call it systemic risk index. What you see is that very small banks, tiny banks can be very red. Red means high systemic risk. Can tip over the system, should they default. In other countries, you might have these better results. In Mexico, for example, for every trade, for every asset type, you have these exposure networks ready every day. This is, I don't know, derivative exposures, security exposures, FX exposures, interbank loan exposures, and in the lowest panel, everything combined.

Just to show you this this kind of data exists, even in many countries. What you can do immediately is that you compute this index and you draw a profile of a country, the systemic risk profile, for the different banks so ordered the left most bar here is the most systemically relevant bank. Should that default, 80% of the financial system will be immediately directly affected and up to 80% of the financial flows would no longer happen if no one was to intervene, which would, of course, happen. Left is the systemic risk profile for Austria, which is completely different from the systemic risk profile of Mexico, for example. Mexico is much less systematically risky. Once you know this systemic risk index of individual banks, and if you know how likely banks default, you can compute the expected systemic loss. It's a quantity that tells you what the cost of a crisis of a systemic banking crisis would be. That is, it looks like a very simple relation, but the outcome of a very complicated combinatorial computation that takes into account every possible a scenario that you can think of every possible collapse scenario.

And you can compute the cost of a banking crisis within a region. For countries that have such data, you can compute that. You can do more. You can compute the systemic risk of individual assets, of individual loans in a network. Left, you see what the loan size is in an interbank credit network and on the Y axis, you see the marginal systemic risk or the systemic risk increase that this individual loan brings into the system. You can measure loan by loan. What on right hand side you see is the systemic risk as a function of a contract size for the Mexican system. You see that systemic risk is well above the diagonal that you see here, meaning system systemic risk is more can be or is typically larger than what the asset is worth. So someone else is paying for systemic risk should systemic event occur. If you accept the systemic risk is an externality, meaning not those are paying for it who created it. And if you know which transaction is risky, you could tax it. What that means is you make systemically risky transactions more expensive. What you're doing there is you create an incentive to avoid systemically risky contracts and by this you are reshaping the network. And that's fantastic thing. If you are able to reshape the network, you can make a system much safer. If you make more risky transactions more expensive, you are restructuring networks that cascading failure practically goes away. You can prove this with an agents based model. That's what we did first. But you can also prove an existence theorem that there exists a 'systemic risk'- free equilibrium under a systemic risk tax.

Let's discuss the agents based model and say some words about the agent based model. In the agents based model, you have a banking network which is coupled to the real economy and to firms which are coupled to households. You model more or less realistically, the loans between firms and banks and households and banks, and wages and dividends between firms and households. If firms collapse and they hold bank credit, the bank takes the loss. And if a bank takes too much loss, it can also turn bankrupt, then might or might not cause systemic collapse in the financial network. And if you plot, if you do these many times and show the histogram of losses to banks from these simulations, what you see on the left side is that if you do nothing, you have to focus on the red curves. You see these fat tails, these famous fat tails of losses to financial institutions, which we now all know about that they exist. If you would turn on a Tobin tax, that's the blue bars, you don't see much changing. If you turn on the systemic risk tax, restructuring the network, you're cutting this tail of large losses completely off. You're getting rid of all the systemic risk. You're not reducing market volume. That's important. You're not making the system less efficient. That's important. You can always make a system safer if you make it smaller or less efficient.

You can ask more: what would an ideal network look like that carries for given efficiency level, the minimum systemic risk. So it's a hard problem to compute an optimal network, but you can do it if the systems are not too large. For 100 node this is not a problem. If it's 1,000 nodes, it is a problem. For the Austrian banking system, you see the risk profile again from a different date. That's the red profile. If you optimize the system, if you rearrange the contract such that no bank is worse off with its portfolio, you get the blue curve. What that tells you is, if you just rearrange the networks, keeping everyone the same in terms of value of their portfolios, you can still get more than half of systemic risk out of the system for free without making the system any less efficient.

You can generalize this kind of thinking to the real economy, to production networks. This is 200,000 firm. You can generalize these and compute these risk profiles now for companies. You find from these 200,000 firms, there's only 30 firms that bring your country down should they collapse. This is data from Hungary.

It opens new ways for monitoring basic supplies of the country. It's a way to do strategic risk planning. How much systemic risk do you want to have in a country? You can quantify that, you can open it up and start debating about it. You can avoid systemic risk concentration, and you can make supply risks visible. I will leave it here.

One more thought I would like to say. One can also take one step further and ask how systemic risk is flowing around the globe. How is the country affected if a firm in country A is defaulting? So you can show flows of systemic risk around the globe, and that, opens even a geopolitical aspect to do this kind of new things you can do with data in combination with complexity economics. Thank you.

[Speaker presentation by Andrew Sheng (University of Hong Kong)]

Katherine Collins

Stefan, thank you. So much more to explore. Really excited to see the links that you've drawn between thinking about risk efficiency size of a network in a way that is more open ended than some of us have been trained to do. So thank you for that. For our next speaker, I'm delighted to welcome Andrew Sheng, known to many of you already. Andrews is a distinguished fellow at Asia Global Institute, University of Hong Kong, a chief adviser to the China Banking Regulatory Commission. So Andrew, we will turn straight to you with thanks.

Andrew Sheng

Thank you very much, Katherine. I'm afraid that some of my comments are not as structured as I would like. As many of you know, I'm neither a mathematician nor an academic. I come from the policy background. Operationalizing complexity is where I come from. Being a former central banker and financial regulator, I have regulated banks, insurance companies, securities markets, foreign exchange markets, and also asset management. The problem with complexity is that life is extremely complex and becoming more so.

The real issue is that financial policy and supervision has changed dramatically since the 2008 global financial crisis. And in the pre-2008 situation, financial regulators were fundamentally reductionist. They had a Newtonian perspective, which was an atomistic, linear, mechanical view of systems. They focus on institutions and jurisdictions. They had a very siloed view. Regulation was product and institution based. And the DSG model, which many of you know, was completely blind to financial balance sheet effects, because financial assets and financial liability net off to zero. So you can model the real economy.

Post 2008, I think all the previous speakers showed that we are moving towards complex non-linear network views which involves system entanglements. Doyne Farmer and others are working on agent based bottom-up models, which is very, very good. But the game has changed because QE has changed the game, and cyber currencies are changing finance.

Now let me say what the earlier speakers have said. Financial systems are networks. Complexity comes from the networks, and I think Brian Arthur was absolutely right. It is really about recursive loops, because systems change through interaction between different parts of the systems, across very different networks. So the problem is that in the last 15 years when the platform economies emerge, they straddle multiple markets, entangling markets and supply chains and networks. Whereas the markets are regulated as silos, a single regulator for one product area: banking, securities, insurance all regulated separately. And yet, the technological evolution of money and information has changed the speed, scale, and scope of financial and real sector markets completely entangling them, making things even more complex. So the fundamental problem is that if economists are having problems understanding the complexity of the evolution of the system as a whole, regulators are even worse off, right? They don't understand the technology. I mean they are certainly behind the curve in that area. So they're learning it from the people they regulate. They're learning from banks. And banks are way behind the platform networks. So how do you coordinate very different siloed regulators not just at the domestic level, but at the international level. It is a fundamental problem how we deal with this issue. So essentially, if you really think about the network issue, it's about the complexity of nested networks, interacting through adaptive cycles of growth and renewal. It's not just a complete, massive network. But it's like a Russian doll. A complex system is nested in another complex system, nested in another complex system. So the old Greek atom idea that you can reduce everything down to one rational man is nonsense. Because when you get down even to the atom, you suddenly find the atom itself comprises of neutrons, protons, et cetera, interacting each other with non-duality, non-local situations.

The physics shows that the world is interconnected and interrelated and interactive simultaneously. And the Newtonian perspective is look for the cause, look for the inter relationship between the cause and effect. Whereas actually, the cause and effect is not either or but and. So we need to understand and manage complexity, but we do this through reductionist method. Right? And when we have too much information, we have to decide. When Stefan says we have to bail in or bail out, you don't have time to ring up Doyne Farmer and say: do me an agent based model of what the hell is happening in the situation. Because the whole market is melting down. So you have to make certain very quick reductionist, simple decisions.

Now, the problems of our time are systemic problems, right? They are systems within systems. They are interconnected and interdependent. We are getting emergence. But how we get collective action is what we just talked about, so we know about this. But slide seven basically says, if we think about systems and climate change shows that, and in financial systems and economic systems, we are dealing with four factors: the Meta which is the way we think about it. This about this as algos, the heuristic of the system. Then the big picture Macro, then the Micro, and then the Mezo. The Mezo are the social institutions that we build to link the macro with the micro.

How do we manage top down or bottom up? The problem is, when things go wrong, it's wrong with the Meta, it's wrong with the Macro, is wrong with the Mezo and is wrong with the Micro or interacting with each other. So the Western scientific paradigm is under the Newtonian system is linear, logical, and evidential. And now we're dealing with massive uncertainty, with massive interactions, with each other, even on an organic basis. We're dealing with nonlinear self organizing, operationally closed, self generating cognitive systems. Therefore, we need to integrate specialists, not just multiple disciplines or the addition of disciplines. We are not talking about just inter-discipline and the interaction between disciplines. We need to transcend these disciplines. How do we see the patterns as different systems interact with each other in sometimes chaotic, nonlinear manner? And they interact through basically recursive loops, exactly as Brian says, right? And whenever we look at a picture, we suddenly realize, is it the two faces or is it a vase? And that perception is simultaneous. But we need to reduce this picture and make a decision. So the Chinese see this but the issue is that a reductionism is having serious problems when systems are becoming more and more complex.

Now, I've been working with Stuart Kauffman. He's come up with this the theory of the “adjacent possible”, which shows that when different things are invented, they interact with each other, and eventually it's quite stable, and then slowly becomes exponential, hyperbolic. If you look at the central bank, on the right hand curve, that's exactly what has happened. Slide 12. Now, on slide 14, Stuart Kauffman in the theory of the adjacent possible derived this equation. Now, I'm not a mathematician so I don't fully explain this, but it does explain the great acceleration. That's where we are and that is what's happening to QE. Let me now show you what's happened. One of his students, Abigail Devereaux, showed that if you have an exponential explosion of something, if you don't intervene carefully, and the later you intervene it could lead to a collapse.

So now central banks and securities regulator cannot just worry about your area, because your area is completely linked to other areas. The capital market is linked to the real economy, linked to the banking system, linked to the FX market, linked to the futures market, linked to politics and today linked to national security. They interact in ways far too complex for us to deal with. So what the central banks did in 2008 was to reduce all this to one simple rule, which started with the Walter Bagehot: in a financial crisis lend freely but against collateral at market interest rates.

But in 2008, it was lent freely at zero or near zero interest rates. We flooded the whole situation with liquidity. And we simplified, we had a one silver bullet solution to all this. It is simplistic. But we created a second, third, fourth order problems with asset bubbles and a huge debt. We solved a debt problem with more debt. And now we have a huge productivity trap, possibly an explosion of inflation. We don't know yet. And huge moral hazard. So what is the complexity approach? The complexity approach obviously says, maybe exactly like dealing with the pandemic, we should think about this in terms of interconnectivity, interdependence. We can't have a top down solution. There's no super regulator possible. We should build immunity in the system. We should increase capital. We should get the atoms to follow Basel III, de-leverage right? We should avoid excessive imbalances. But in the world, in which there are huge imbalances both at the fiscal level, social inequities, climate change issues, complexity economics will help us think about this issue.

But we are struggling, therefore, the regulators, exactly, as Keynes says, are still stuck in the Newtonian way of thinking with tools that is moving fast, but with the markets moving even faster, particularly with the invention of cyber currencies and all that.

So let me say this. I totally agree with all the previous speakers, complexity economics is the way to go, but we need a holistic approach. We really need to think about complex systems as interactive recursive loops. But we need to reduce it to a form in which the policy guys know how to deal with the collective action traps and how to deliver a common public good, both challenges we are currently struggling with.

Let me stop there. Hopefully, we can have a good discussion afterwards. Thank you very much.

Speaker presentation by Alissa Kleinnijenhuis (Stanford)

Katherine Collins

Andrew, thank you so much. This question on regulation for complex adaptive systems is a fascinating one, both formal regulation (big R regulation) and small R regulation, influence of the system. So thank you for bringing that into focus for us.

I'm delighted to say our next speaker will round out this discussion. Alissa Kleinnijenhuis from the Stanford Institute for Economic Policy Research is our next speaker and our final long form speaker before we have some closing comments from Professor Chen Long. So, Alissa, over to you.

Alissa Kleinnijenhuis

Regina, thank you so much for inviting me to speak at the Luohan Academy, Frontier Dialogue on complexity, economic policy. It's a really great pleasure to be here today.

Today, I would like to speak about how complexity economics can help answer salient questions in economic policymaking. In order to illustrate how complexity economics can do so, I would like to zoom into one specific example that I studied in my own research. One of the biggest questions in financial policymaking today is how to resolve the “too big to fail” problem, which arises because regulatory authorities believe that an institution’s failure could impose severe, negative externalities upon other actors. Whether an institution is deemed too big to fail does not just depend on its size, but critically also depends on the interconnectedness of this financial institution with the rest of the financial system.

Interconnectedness determines how easily is failure triggers widespread financial confession with potentially harmful consequences for the real economy.

So an open question is whether bail-in resolves the too big to fail problem. In the 2007-2008 financial crisis, governments were forced to choose between the unattractive alternatives of either bailing out systemically important banks, or allowing them to fail in a disorderly manner. And bail-in has really been put forth as an alternative that potentially address the too big to fail problem and contagion risks simultaneously. While its efficiency has been demonstrated for smaller idiosyncratic failures, its ability to maintain stability in case of large systemically important failures and systemic crisis remains untested.

So tools from complexity economics are highly suitable to answer questions like whether the current bail-in designs, for instance the one adopted under the Bank Resolution and Recovery Directive in Europe, resolves too big to fail problems.

Complexity economics studies how the interacting elements, including institutions and behaviors in a system, create overall patterns, for instance, in asset prices. It also studies how did the overall patterns in turn has interacting elements change and adapt. It's recognized that, especially in a crisis, the financial system is not necessarily in equilibrium. In fact, it may be out of equilibrium.

Equilibrium models ask what behaviors, actions, strategies, and expectations would be upheld by or would be consistent with the aggregate pattern of these schools. Meanwhile, out of equilibrium models study how institutions would react to patterns, how they react, for instance, to dislocated asset prices created in a crisis, and how these reactions, in turn, alter aggregate patterns. Complex systems exhibit positive and negative feedback loops that amplify existing financial distress or dampen them. From simple interactions at the level of institutions, emergence phenomena can arise. The aggregate outcome is typically not the sum of the parts. Complex systems, moreover, can undergo phase changes where with small shocks, no big loss, it is secure. But beyond a certain threshold, positive feedback loops can result in nonlinear amplification of loss.

So the financial system really exhibits all the above mentioned features of a complex financial system. And in a crisis in which bank failures and billions are required to deal with them, it makes special sense to model the out of equilibrium dynamics to capture how institutions' reactions to exogenous and endogenous shocks in a crisis can amplify or dampen financial distress, affecting aggregate dynamics and altering reactions in turn. Another benefit of modeling financial dynamics as an out of equilibrium phenomena is that more realistic models of the financial system can be developed that capture key institutional features, such as financial contracts, policy constraints, and market mechanisms. Whereas with an equilibrium model, capturing all these market features, soon makes computing the equilibrium outcome untenable. What is really special in our model is that we seek to understand how the systemic implications of the bail design affects stability is that we can actually literally model the law. We can literally try to understand how the law impacts financial stability. We can model how to specific features of the bail-in design determining how bail-ins are executed, affects stability and therefore affect whether bail-in resolves the too big to fail problem.

Now, having spoken about complex systems and why the financial system is formed, I do think that the term complexity economics to describe the branch of economic modeling that model such system is a somewhat unhappy name. Because in academia, we really seek to represent the world in a simplest possible way without losing track of salient features affecting outcomes. It is in this quest for simplicity that I think the term complexity doesn't sound very appealing. Therefore, I do not really use it in my own research as a term. But I do think that the ideas of complexity economics are very salient.

In fact, I would argue that in the modeling of financial crisis and financial contagion, the ideas of complexity economics are actually very well understood an increasingly preventive capture in financial crisis models. Actually, throughout the finance profession, both in non-mainstream and mainstream journals. In the year since the great financial crisis of 2007-2008, we have really witnessed an increasing number of papers, also in top finance and economic journals that really focused on modeling crisis dynamics as an out of equilibrium phenomena, where aggregate outcomes are formed from the behavior of institutions. So basically, the dynamics model in many finance papers today focus on financial crisis, basically captured the classic dynamics exhibited in complex financial systems.

I've tried to explain to you why I think the financial system is a complex system. I now really want to focus on a particular example where we try to understand how a policy affects the behavior of complex system in any particular effects, whether the financial system is stable. I already explained that the 2007-2008 financial crisis forced governments to choose between the unattractive alternatives of bailing out a bank or liquidating it in a disorderly manner. Bail-in has been proposed as a tool that can both resolve the too big to fail problem and avoid letting taxpayers shoulder losses. In Europe and the United States, bail-in has been implemented - in Europe under the Bank Resolution and Recovery Directive, and in the United States under the Dodd Frank orderly liquidation provision.

I want to briefly explain to you now, what Bail-in is in practice. Imagine that the bank is about to fail, it's about to turn insolvent. Then the resolution authority has powers to call a bank likely to fail. At which point it has the right to write down debt of the bank. That's what you can see on the left plot and converted this debt into equity. So after the bail-in has taken place, the bank is basically better recapitalized. Its solvency is restored. Because it's better recapitalized presumably it also faces less liquidity problems, because better recapitalized banks usually have less difficulty retaining access to market funding.

In the paper that I've written with Charles Goodheart and Doyne Farmer - who's also here on this call - we try to understand what the systemic implications of the bail-in design are, when we explicitly take into account the financial system, which we can argue to be a complex system as a whole. And we study this in the context of the European financial system. In line with earlier papers in the finance literature, namely by Greenwood et al (2015) and Durte and Eisenbach (2021). These are published in the Journal of Finance and the Journal Financial Economics. And both of these papers, I would argue, are actually complex system models that model crisis dynamics as an out of equilibrium phenomena. What their model does and what we will do is to say that we take as a given the assets, liabilities, equity of each financial institution, the adjustment rule applied by institutions when they are hit by other shocks, and the price impact of liquidating assets. So we calibrate this system-wide stress test model can capture the prevailing contagion mechanisms that could endogenously amplify shocks from bail once we set up our model. I cannot explain the details but I want to convey this key point, which is that initial exogenous shocks, for example, and system wide shock from the real economy or idiosyncratic credit failure of a bank, can really lead to the endogenous amplification shocks as many of the earlier speakers have alluded to. Specifically, when a bail-in takes place, creditors may suffer haircuts. And if this is not sufficiently compensated with equity, then these creditors suffer exposure loss in the financial system. If the exposures are suffered by banks that issue bail-in themselves, this may result in downward valuations of bail-in debt. Investors in the banks that suffer downward revaluations of bail-in debt may decide to stop rolling over bail-in debts. If this leads to a liquidity shock and if this cannot be met with a cash buffer, then institutions may be forced to fire sale assets or pull funding to pay liquidity. In general, if institutions see their solvency drop sharply, they may be inclined to de-lever. So the key point is that the various mechanisms of contagion interact. And they can interact in such a way that initial shocks are amplified. And that's a key feature of a complex system that you may see endogenous amplification of shocks and positive feedback.

Now, the key findings of our study are five-fold. Critically, our results suggest that financial stability really hinges on the bail-in design, which consists of a bank specific and a structural part. A well designed bail-in support financial resilience and avoids amplify existing financial distress, whereas an ill designed bail-in does the opposite.

Now, the surprising finding is that in fact, even in a system wide crisis, we showed that a well designed building can work, defying some of the expectations of leading thinkers, such as Ben Bernanke and Charles Goodheart, who initially thought that would not be possible. But on the downside, our analysis suggests that the current bail-in design might be in the region of instability. In the paper, we provide arguments for why, even though sort of policymakers can fix this, the political economy incentives make this unlikely. So essentially, our findings indicates that the too big to fail problem remains unresolved at present. So this is an example of a study where we really model the law we modeled, how the bill in design is implemented in Europe, and use sort of the tools of complex systems. I would argue, actually that by now a very mainstream tool in the modeling of financial crisis, to address a really big problem, namely, does bail-in resolve the too big to fail problem?

Now, what we show is that an early bail-in, strong recapitalization, fair conversion rates, exclusion of short term debt from bail-in and sufficient loss absorption requirements and limited discretion in the bail-in design, promotes financial stability, whereas a poor bail-in design basically does the opposite - undermines financial stability. I don't have time to explain the details, but I do want to focus on the key intuition of the finding of this paper. Imagine that we're again in the 2007-2008 financial crisis. In the running up to that crisis, we saw a big build up of leverage as Doyne also referred. What happened when the sub prime mortgage market started to implode is that we witness a big leverage cycle where institutions were liquidating assets, where there were runs on possibly or nearly insolvent institutions. And this led to basically the global financial crisis and the ensuing recession.

Now, what does a well design bail-in do? It basically breaks the destabilizing cycles and thereby prevents destabilizing cycles of asset liquidations and runs on possibly or nearly a sovereign institution. And it does so by rapidly bringing down the leverage of the financial system, without imposing significant externalities on the rest of the system. In the paper, I provide much, more detail on why exactly that's the case. Whereas an ill designed bail-in only partially breaks the de-leveraging cycle. So the destabilizing cycles of asset liquidations, runs on possibly or nearly insolvent institutions continue, possibly leading to a next cycle of bail-ins and further de-leveraging. The key qualitative findings of our paper are twofold. First, we show that the difference between a well-designed and an ill-designed bail in is really big. It represents 20.3% of the asset value of the European banking sector. And we all know that if there is a big loss to the financial system, this typically leads to credit contractions and thereby recession. So the choice of building design really has welfare implications.

Now, the second big finding is that whether the increase in systemic risk brought about by a poor design choice, really depends on how well the bail-in mechanism is designed. So the same poor design choice when the rest of the bail-in design is well designed, has a much smaller impact on deteriorating financial stability than when the same poor design choice is used relative to a poor design theory. And this kind of comes back to another feature of complex systems, which is that when there's a certain amount of shocks, there may not be big impacts. But if the shocks exceed a certain severity, the impact may be worse. And the same was for policy design, sort of how bad certain policy design choices really depends on the context. This is the plot that basically shows how much the bail in design matters on the left side for idiosyncratic bank failure, and on the right side as a function of the system wide shock.

Another key thing you can see in this plot is that you have strong nonlinearity. For a system-wide shock up to size one. I can later explain what that exactly means. There's almost no system wide effect, but if the shock size exceeds a certain amount, you see a very sharp shootout of losses in the financial system. And here it just shows that the same poor design choice is less bad when the overall design is good. And it's worse when the overall design is bad.

I want to conclude my remarks by using Ben Bernanke's words, and he asked, "Have we ended bailouts? We cannot guarantee that a future administration, fearful of the economic consequence of a building financial crisis, will not authorize a financial bail-out. But the best way to reduce the also that happening is to have in place a set of procedures to deal with failing financial firms that those responsible for preserving financial stability expect to be affected. The too big to fail problem will be alleviated only if the bail-in is a credible alternative to bail-out." And in this paper, we showed using the financial system, representation as a complex financial system, that the credibility of bail in critically depends on the bail-in design. Thank you very much.

Discussant talk by Long Chen (Luohan Academy)

Katherine Collins

Thank you so much. I'm delighted that our last three speakers have highlighted some interrelated issues related to structure of systems, regulation of systems, intervention, and systems and at each of these layers the tools that we're talking about today, have been helpful in some important ways.

So now team, to bridge us to our open discussion, I'm delighted to introduce our final discussion for the day. We are honored to welcome the President of Luohan Academy, Professor Long Chen to be our summary commentator for today. All of you are well acquainted with Professor Chen already, so I will turn over without further ado for his closing comments before our question and answer discussion.

Long Chen

Thank you, Katherine. It's my great pleasure to have this opportunity to comment and reflect on some of my thoughts on complexity. In a sense, Luohan Academy was born out of the desire to try to understand complex problems. So Alibaba has long called for social scientists, economists, psychiatrist, historians try to join us to conduct research. After Alibaba started to try to build a dynamic based platform for the ecosystem, it finds that many problems that are difficult to solve.

For example, how do we build a mechanism that can support all the agents that are growing to enjoy dynamic growth? What is the most effective way to connect the consumers and suppliers and to have positive feedback to each other? What is the role of information in this regard? What is the relative role of planning versus the natural emergence? Starting from that point Luohan Academy was largely born out of this desire to help the society better understand and cope with the reality.

Now, from a complexity point of view, I believe the digital revolution has a lot of implications for business. I'm going to talk about 5 points I think that are important. They include (1) the changing definition and boundaries of a firm, (2) timely and trustworthy measurement of agents and their status, (3) timely connectivity and communication between the agents, (4) changing organization and management, and finally, (5) changing definition of risk and risk management. The last point is the focus of the of the speakers in this session, which I will dwell on at the end.

So let me talk about the first point, redefining a firm. Now, traditionally, we've been thinking that a firm is like an independent institution that aims to achieve its own goals, such as profit maximization. But more and more, we find that we can better define firms using concept of niche, which emphasize the interactive nature. Several of the speakers already mentioned this firm is more like a co-evolving network.

The firm cannot just think on its own. It has to respond, receiving signals from its environment, from policies, from economies, from society. It has to study trends and technology, and tries to make the right response. And so more generally, there's a rising trend in the business called ESG environmental society and governance. In nature, that is trying to define the value of a firm from the society's perspective. The firm has to define its value in this way and respond in this way. I think that is really, in a sense, what you called a co-evolving system.

Let me take one example. It's from one famous tech company. We all know that company. If we look at the how it's claiming its pledge to battle climate change, it says that "climate change is the most significant, technological and society transformation in modern human history." "This must be a decade of ambition paired with action." They say they "appreciate the urgency, responsibility, risks, and opportunities ahead." And they "want to become the leading technology provider of sustainable solutions." So in this way, you can see that firms nowadays look at the society's challenges and try to become valuable by solving societies problems. And that is in essence of ESG, in essence of an ecosystem.

Now, the second point I want to talk about is the timely connectivity and communication to generate feedback loop between the consumers and producers. Traditionally, recall firms have been more B2C, business to consumers. But more and more they are driven by the consumers. That is the feedback loop between the consumers and producers. We do not know where’s the equilibrium, but we know that firm can be much more agile, valuable by responding quickly to actually measure what the consumers want. Measurement is theory. Measurement is action. So we can do that to have the response. We are seeing a lot of successful businesses models sharing common features of having that reaction. In this process, the consumers become your fans, become your designers, and they can even become your salespeople. They talk to each other. They help you to sell your products. Another example is the Metaverse that is trending these days, but I think besides games themselves, I see that a very important spirit of the Metaverse is that they're often not traditional games in which you actually linearly play it. Actually in the modern Metaverse, everybody becomes a builder and participant.

So more and more, we are blurring the boundaries of the firm. Now we interact with each other and we have the consumers becomes the builders, designers, and a part of the firm. Now, the first point I want to say is, from a complexity point of view, business being changed in the digital age can be seeing in the supply chains of firms becoming more agile and smart enabled by digital technology.

Now this is not new. If we look at United States history, the rise of the modern business, it was due to two things. One is the cable, which brought us information. And the second was the train which gave us logistic power. Then we have the rise of the futures exchange in the 19th century, which is analogous to today's "manufacturing according to sales". Now we first we have the "sales because of information". Now we start to have the very agile supply chain very quickly. So that gave rise to the retail brands in the 19th and 20th century. Now on the one hand, they connected to the consumers. On the other hand, they tried to rebuild the supply chains to make it respond quickly to the consumers' needs. And that is no different from the what we observe these days, the rise of the modern day digital retailer. And this we see a lot of the cases across the world. In China, Xiaomi is a leading a smartphone manufacturer. It sells smartphone relatively cheaply, but most of them on its own e-commerce platform directly to consumers. At the production level, they actually try to invest or cooperate with the suppliers to have higher quality goods. So you can see that this kind of positive feedback loops or adaptive systems happening a lot thanks to the digital technology.

Another example is what Alibaba calls its "Xiniu" smart manufacturing system. Essentially, it digitizes the whole garment industry from design to production within two to three weeks. Traditionally, if you want to prepare the garments for Christmas, you have to start to prepare in spring. You have to guess for the consumers what's the trend this year, and thus what the consumers want after half a year. Then inventory is a huge cost and risk for the garment industry, but nowadays you can actually do this within several weeks or a month. So that's the power of information.

A huge problem of this complexity work is the symmetric information. We often didn't know the agents and we cannot react to them. Now we can do a lot more. A huge part of this is the information revolution, which plays a huge role in reducing the challenge of this complexity world.

The fourth point I want to bring up in business is the changing of the future of the work. We call this hybrid work. After Covid, you can see that as a lot of more remote at home.

But traditionally we have to stay in the office, because it's very hard to measure everybody's work in a timely, precise, transparent, and trustworthy fashion. But nowadays we are seeing this more and more. So in that way, this technology can liberate a lot of those knowledge workers, including many of us academics. It is liberating the workforce and that is a huge part of the future of work. We can work independently with, collaborate independently beyond the traditional boundaries of time and location. For example, Microsoft Teams says that they're seeing a huge opportunity, like Windows before. Teams wants to be the operating system, the platform for this collaboration. Thanks to this kind of digital technology, we are changing how we work and collaborate in the future.

Finally, the point the several brilliant speakers talked this subject is the changing risk management. I'm going to talk about a couple of cases. One is the case of Covid, which several of you brought up earlier. Now, is Covid a systematic risk, or is it not? Is it externality or is it endogenous? Is it something we can actually mitigate? We have to just think about it being very connected and we just have to really control as a static thing. If you think about it, if we can measure it, we can do bottom-up measurement science. If we have the technology and can find and identify the cases, we can isolate them and then we can do a lot to stop the disease from spreading. So what is the smart risk? It's actually very endogenous. You see it feeds back. It's like the butterfly effect. We affect each other from local level. So if you can identify the risk, the atoms then you can do a lot more in dynamic way. In this way, we are defining redefining or at least minimizing somehow the systematic risk.

And so that's the last point I'm talking about. The previous speakers had talked about the interconnected, complex way of dealing with network risks like financial risks. And I have no problem with that, but I'm going to try to talk about other side of that actually, with the measurement and with the digital technology, we can do it in other ways. There's something called real time financial risk management. This is no different from how the suppliers respond to the consumers. No different from how if we can identify the individual Covid cases, we can become more smart.

I will give a couple of cases. Here is one project I'm engaged in with my colleagues and BIS. As you can see, with data from SME loans from MYBank, we study the performance of such a system. In finance, we know this concept called value at risk. Essentially, we're assuming some kind of distribution and then we calculate our risk exposure. Then we ask for capital to cover the risk. That's how it traditionally goes and is one legitimate way of dealing with risk. But we have other ways. For example, how about you can quickly get the risk exposure? Quickly? You can change your risk exposure, the amount of the loans you're lending, the people you are lending to. You can quickly adjust your exposure. You can quickly change your distribution. You can have a dynamic, real time financial management. I think that's one way to do it.

Another way is that I'm thinking about is the algorithm. Now, the algorithm can be interconnected, because a lot of people can do have similar algorithms and we've seen that in the financial market. But another way to do it is to have certain mechanism design to have decentralized decision making. That's a little bit like the logic of cloud computing. It's centralized by design, but it decentralized by use. But in that way, the risk is decentralized. So that can also be applied in financial risk management. Now, and that is some data here. You can see that for the MYBank, because it deals with SMEs with very little credit profile. But we can see it's actually pretty low risk, which is reflected by delinquency rate as being quite low. It's much lower than many of the customers of the big banks. And even during the Covid crisis period, it rapidly declined, because it adjusts its risk exposure very quickly.

Now, let me summarize what we have learned from complexity from modern business in the digital area. I fully agree with the speakers before. We have to look and think about the world in a complexity way. We have learned that agents differ and their interaction matters a lot. That is great. But what I'm emphasizing here is that digital technology, or the information revolution can change this a lot. We have a lot of agents that are different, but we can have much quicker and better measurement of what they want and what their status is. So that is changing a lot of the modern business. It’s also changing the definition and the boundaries of the firm. It's changing the relation between producers and consumers and the ability of the value chain. It is changing how we, as knowledge workers, work and how we coordinate. It is changing risk management. Let me finish in this way. I think in the complexity and messy vitality of the business world, the way we perceive and deal with the world matters. So is the power of the information revolution.

Katherine Collins

Thank you Professor Chen. What a wonderful and vivid way to bring to life a lot of the concepts that we've been talking about today.

Session II: Open Discussion

Katherine Collins

Friends, we are going to go back to a view of the broader audience here again with thanks for everyone for joining. We have a few minutes for discussion and conversation. Now please raise your hand if you would like to make a comment or log into the chat. As we get started here, we do have a comment from Eric Maskin. So Eric, why don't you take it away?

Eric Maskin

Thank you. I would like to make a suggestion to all the complexity economists out there, a friendly suggestion, but a critical one at the same time, I'm not a complexity economist myself, but I would like to see complexity economics succeed. It's now been around for 30 or 35 years or so. From what I can tell, it has only minimally been registered by the conventional economics community. And we might ask, why is that the case? Why is complexity economics not more part of the mainstream? I'd like to suggest that the answer to that might be that it's not enough to show where conventional economics gets it wrong. You have to put something in its place, and you have to show that the thing that you're putting in its place performs better.

I'd like to make an analogy with behavioral economics has been a great success. It also attacks some of the foundations of economics, but what Kahneman and Tversky did is to make behavioral economics such a success within economics was to first carefully document the places where conventional economics was getting predictions wrong. And then to suggest an alternative theory, prospect theory, which got things right. Now, prospect theory itself has been improved on since Kahneman and Tversky, but at least there's a theory which conventional economists can understand and compare with the old model.

I would like to see something like that happen with complexity economics. As I said, I'm friendly toward the subject. I was on the science board of the Santa Fe Institute for a number of years. I think the subject is fascinating, but it's not going to change economics unless you were able to show in detail that conventional economics is inferior and I hope you can do that.

Katherine Collins

Thank you Eric for your comment. And I'll speak on behalf of some of our speakers that the goal is not necessarily to show superiority, but to show additionality to these tools. Let me pause and see if any of our speakers would like to respond to Eric's point before we go to the next comment. And thank you, Eric.

Doyne Farmer

I can if you want. I think the goal is to show superiority. So why not? We want better models. We don't have very good models, of the, things like business cycles right now. And I do think I strongly agree with Eric, the devil is in the details, and we need to show that we're doing a better job of predicting things. We are doing a better job of evaluating policies and understanding what policy outcomes will perform better in terms of the goals of society. And I think that is in motion of. Course, it's tricky to be aware of it as a mainstream economist. Because if nobody lets us publish in top journals than how can economists can be aware of it unless they read our papers and go out looking for things. I think we are starting to accumulate a body of work that does what Eric says, but we need to get a fair hearing.

Katherine Collins

Awesome. Doyne, thanks for that. And for tossing my modest diplomacy to the side, we'll be superior. Always good to have high aspirations.

Dr. Alissa Kleinnijenhuis

I would actually argue, as I tried to do in my introductory remarks, that especially in the modeling of financial contagion, financial crisis, many of the ideas of complexity economics are actually very well understood throughout the profession. I also think that in many more of the mainstream papers, these ideas are captured in the models.

So I think I'm a little different than Doyne that I wouldn't want to say it’s us vs. them. I actually think it is much more integrated already and many of the ideas are being incorporated in mainstream thinking. So I actually think it has made a lot of progress over the years.

Katherine Collins

It's a good point, listen. And I like your point that you made that sometimes the nomenclature gets in our way as opposed to staying focus on the substance of the ideas. Terrific. I do see a hand up from Chen Ping from Peking University. Would you like to comment or ask your question?

Ping Chen

I will make some response to Eric Maskin’s question. Actually, we do have revolutionary breakthrough in complexity. However, mainstream economics had a blind eye for that. I show you one thing. All economics is based on this curve, unlimited growth, right? If you look at Solow growth theory and Romer’s endogenous growth theory. However, now we have climate warming. It means we have a resource limits, right? Then your growth will go down if you reach your resource capacity. And that's a fundamental arguments in Adam

Smith's book called division of labor, which is limited by the market extent. The market extent is resource capacity, right? Once you have the old industry meet the resource capacity, you will fall down. The capital will decline, then new sectors will come out. So once these restraints are introduced, the whole equilibrium economic foundation will collapse.

Secondly, Brian Arthur made a good argument, say increasing return to scale, right? Is not compatible with general equilibrium in economics, both micro and micro. However, we know, increasing return to scale is not a static like Silicon Valley. You see, a lot of companies right now moving from Silicon Valley to Austin, Why is that? Because we have to deal with dynamic return to scale. Once you have dynamic return to scale, then you have a rise and fall of an industry and the rise and fall of great powers. That's we see. In this financial crisis, we solve the business cycle problem.

Actually, this is a Copernicus problem: how to choose a reference. We find out the real business cycle people use the so called HP filter. Solve the problem because global trend has more impact to local business. So the global trend is not even so you can have a non-linear trend, described by so called HP filter. Then you have a cycle around the trend. So called expectation is not static at a micro level. It's on the macro level. So once you separate the time series into long term trend and medium cycle and short term deviations, then immediately find out the financial management to answer Andrew Sheng's question. It is mainly to dealing with the changing the trend and the medium cycle. So that's a Copernicus problem in economics and we solved in 1996, but completely ignored by the mainstream.

Secondly, we need to solve the capitalist problem. What I mean by capitalist problem, if you, if you talk about complexity, in general, you have numerous stories can tell like a computational simulation by Santa Fe group. However, if you find a base function, say it's not straight line, it's not a circle. But it's ellipse. Right? You can dramatically simplify the analysis of empirical data. Then we find out the macro business cycle can be de-imposed, not into shocks, like Bernanke did. So econometrics has a fundamental trouble. They attribute all the market movements to external shock, not like waves. That's a Schumpeter idea. However, the wave is not like a harmonic cycle. So if we use the quantum optics, like Gabo cycles, and the, logistic wavelets. You can decompose the macro and financial index into real data. And we made the discovery in 2005, 3 years before financial crisis.

Katherine Collins

Professor, do you have a closing comment? Thank you. It's very helpful. Any final observation?

Ping Chen

The Brownian motion model is wrong, is explosive. The better model is a population model of births and deaths. We can have high moments, advanced warning, one called ahead of the financial crisis. And we do the historical analysis. And we can diagnosis the real cost of the financial crisis is not too big to fail. Like, I see, it's from a derivative markets. And right now, the derivative market is a 10 times world GDP and 50 times of the US GDP. That's a time bubble. That's a trouble made by Bernanke.

Katherine Collins

So I let's pause there. We're going to note a very important point that you've just made. As usual, this is the point in the discussion where we're all feeling the collected wisdom is gigantic, and our time is very small. So thank you everyone for your patience. We have a final comment, I believe, from Neng Wang who I believe you're at Columbia, please.

Neng Wang

Thank you Katherine. Enjoy the session. If I may, I just like to follow up on Eric's comment. I have to say, I'm in agreement with Eric. I'm very open minded. I'm very accepted to complexity and complexity economics. I think one thing maybe just because of the terminology, it's not clear for various examples that professor Ping Chen just mentioned. I consider them mainstream economics. And some of these are details, I think. For example, for HP filter, there's a paper by Jim Hamilton, that critiques the relevance of HP Filter. But these are details. These are not about the foundations of the standard economic framework. To me, economics means you start with individuals optimizing something. It's going to be some sort of equilibrium concepts. We can quibble about what individuals are optimizing. Maybe they are a rational only subject to certain boundaries called bounded rationality, or maybe their behavior bias, we have prospect theory. We can quibble about these details, but nonetheless, it seems to me hard to get outside of some sort of optimization objective function, some sort of equilibrium condition, or instead of compatibility condition. So these to me are not overbearing assumptions that we put on the table.

Now the details are absolutely essential. Now to me, for example, not just to use Professor Ping Chen's another example, which is this demographic model, population dynamics, birth and death. I use that every day in my own research. So I don't view specific parametric assumptions such as Brownian motion to be critical. Sometimes we need jumps, sure we need fancy statistical model, but they come out of some sort of, by definition, a model starts with exogenous assumptions and with mathematical reasoning. And in the end you get conclusions. Right? So if you don't like conclusions, one of the two things have to be questioned. One, maybe the assumptions are really crappy. So we can quibble with that. Maybe individuals are not fully rational. I don't want to repeat what I just said. Or your reasoning is wrong. So we have to go back and say it takes a paradigm to overturn another paradigm. I'm very much hoping for complexity economics, which I think needs a more precise definition to me. I when I was a grad student, I started in science. I was super intrigued by chaos theory. I came from a physics and chemistry background before I was got interested in international relations and economics. I embraced the whole invisible hand, and I was very intrigued by economic literature. So to me it was very much eye opening and the fact that so much scientific methodologies and this goes back to Paul Samuelson's foundations. He was the one who introduced the LeChatelier Principle to economics. There's a lot of very natural, amazing insights we brought from so many disciplines in science, such as physics. I remembered I was taking Vince Crawford's PhD class, and he was teaching me consumer theory. And I walked in and I told him, look, it looks to me, it's basically thermodynamics reinvented in economics. And he told me to reach to read the Samuelson's Nobel lecture. So that was very eye-opening to me.

Let me summarize. One, I'm extremely excited by this. That's why I spent 2-3 hours here today to listen to the amazing presentations. I enjoyed Farmer and Levin and John Geanakoplos's discussion. So it was a great day for me. But having said, I think there's two things to me that are essential. One, we need a more precise. Maybe this is partly my ignorance, a more precise definition and description of what complexity economics means. How does that really different from the standard economic paradigm? Second, I would say various detailed critiques I don't see them to be all that critical, because after all, the economic profession has evolved, I think, Alissa made this point very well, which is the network economics and so on are actually being embrace and being used all the time, as long as we start with some sort of optimization, some sort of notion of equilibrium. And then we can start from micro to macro. But let me stop here. Thank you very much.

Katherine Collins

We have one more inbound comment. We can take the final inbound comment and then Brian turn it over to you to weave us all together for closing. Okay? Jin Zhang, you had a comment earlier and just sent me a message. Do you want to briefly state your question/comment and then Professor Arthur will wrap us up?

Jin Zhang

I have a question for Brain Arthur. As we know, rationality still has no accurate definition, not only in complexity economics, but in mainstream economics and heterodox economics. It just seems that in complexity economics, agents automatically reacted to other agents, behaviors and environments. In reality, agents don't own unlimited learning abilities and past events on their own behavior modes.

So how will they survive in markets? Will many kinds of such agents waded out gradually from markets since they cannot perform well? Will complex economics take this into consideration? Or does it just look at the macro performance of an economic system uh? Hopefully, I clarify my question. Thank you.

Katherine Collins

Great. Thank you. We've got a lot of inputs here in the last few minutes, and a lot of inputs from the fantastic speakers during the day today. Let me make sure to comfort everyone that this is a long and ongoing arc of discovery and exploration. So today is not our only time to address these questions, but it is our last final moments of the meeting here today. So I'll turn back to Brian to weave together some of these comments and to take us forward to do further research.

Brian Arthur

Thank you very much. I must say I enjoyed the individual speakers, and particularly the discussants as well. Very quick comment, on the last question that was asked. Do we need rationality in complexity? Economics doesn't assume anything in terms of rationality. Rather, I think as one or two of the speakers and particularly Doyne Farmer, we are not rationality was weld into economics with equilibrium and so on. When economics became highly mathematicized. From about 1870 on, we wanted to have simple algebraic systems that were solvable, give unique solutions, show patterns that could persist over time. The cost was that we made a lot of specific assumptions and those who become the bedrock of what we're supposed to compare ourselves against. Rationality was brought in artificially into economics.

And I think if behavioral economics showed anything, it shows that for supposed rationality, we depart from that a great deal in an actual economy. For very good reasons, since we're not in a narrow equilibrium situation that persists. We're discovering frameworks, matter, et cetera. So I think that we're shifting into wider and better of view of how human beings react. And as Doyne Farmer said, complexity economics is looking for real behavior, and we can find that within behavioral economics, so that fits pretty well. I like Eric Maskin’s comments that if this is an alternative to standard, neoclassical theory, equilibrium theory. And if that's the case, why hasn't it overturned that by now? With all due respect there, I'd like to differ, again, go back from analogy in mathematics.

In the early 1900s, especially in dynamics, mathematicians began to understand that there were non-linear, mathematics, as well as linear systems in mathematics. And non-linear mathematics never replaced linear mathematics. Both are needed. As I see it, complexity economics is a non-equilibrium, non-well defined problem type of economics. There's no reason it should replace equilibrium or well-defined optimization. The two live side by side than just different assumptions and relevant to different cases.

It's not when one will replace the other. We will finish up, I'm sure, with both. And you see, it's happened again and again over history of science. We still have Newtonian physics, but also relativity theory, quantum physics, et cetera. So basically think this is my final take on the day, owing to many years of thinking about this. Complexity economics is not an alternative to anything, is simply looking at economics under what we consider to be more realistic assumptions. We don't assume equilibrium must emerge, if it's to be in equilibrium. We don't assume rationality. So much of the world is not well defined. The rationality seems to be well defined and so on. I think we will still in the best possible situation in 10 or 15 years time, I think we will have standard classical economics, being taught, practiced as it should be. And we will have different forms of economics, behavioral economics and complexity economics as a close cousin to that, to handle non-equilibrium, non-well defined situations. I am happy with both. Thank you.

Katherine Collins

Perfect. Thank you. You bridged us into the future. So we will conclude for today, I want to say, thank you to everyone who joined us for this frontier dialogue, particular things to all of our many speakers and to the team that organized all of the logistics as well as the ongoing work of the Luohan Academy. So thank you everyone for joining today more to come. And we look forward to our ongoing partnerships on all of these vital topics. Thank you again.

Brian Arthur

Thanks to the moderator and to the team at Luohan Academy, absolutely brilliant.

Acknowledgement

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Luohan Academy *was founded in Hangzhou on June 26th, 2018. It is an open research institute initiated by the Alibaba Group and launched by world-renowned social scientists, which consist of the academy's academic committee, including seven Nobel Prize laureates in economics. A primary mission of Luohan Academy is to work with the best minds across the world to tackle first-order questions to help the world better embrace digital technology. Together we hope to build the best digital research community— a mission more relevant now than ever in today's turbulent and fractured world.*

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