Financial Complexity & Nonlinear Dynamics

Complexity Labs & Fasanara Capital

August 26st 2018

TABLE OF CONTENTS:

Part 1:

Complexity Finance Overview

By Joss Colchester

Section 1 Overview

In a recent interview George Soros captured much of the predicament that finance as a science finds itself in today when he said "The efficient markets hypothesis has failed and it is recognized that it has failed and therefore economist need to find a new understanding of financial markets.... this is what science is, it is a trial and error. Unfortunately, we don't have a properly developed alternative and that is what we are looking for." He goes on to say that the approach to finance that we developed under the efficient markets paradigm is not applicable to the real world and that he, in fact, made his money betting against the efficient markets hypothesis.

Since the financial crisis, much of economic and financial theory has been called into question. We are increasingly recognizing the limitations of the many kinds of financial models that are dependent upon assumptions of linearity and equilibrium; that agents are rational and independent and that the future will resemble the past.

We come to increasingly recognize that linear development is but one kind of change, nonlinearity is another and of equal importance, if we are to build a more comprehensive understanding of financial systems. When systems involve synergies and feedback then they become nonlinear. You can get cascading effects that take the system out of equilibrium and into phase transitions and that these periods of what seems to be chaos, in fact, have their own kind of dynamics. By understanding the science of nonlinear dynamics we stand a much better chance of seeing and dealing with these periods of exponential and fundamental transformation.

This is indeed an exciting time for economics and finance as after almost two centuries of studying equilibrium solutions economists are beginning to study the emergence of non-equilibria and the general evolution of patterns in the economy. That is, we are starting to study the economy out of equilibrium and increasingly doing this through a computer-based algorithmic approach.

This new complexity approach is certainly a paradigm shift, one of its creators W. Brian Arthur describes the essence of this change in perception when he notes "really it is a shift from looking at the world in reductionist terms, from the top down and imagine everything holding everything else in equilibrium where not much is changing at all, to looking at the world as alive everything is affecting everything."

A key tool in this new approach is agent-based modeling (ABM) that gives us an inherently dynamic vision of markets, as patterns are continually being created and recreated through endless computations across complex networks of interaction; just as we see in the real world. When seen in this way financial markets show themselves not as mechanical, deterministic systems always moving towards stability and equilibrium but instead more like an ecosystem continuously evolving and creating new structures and patterns.

The complexity approach brings into focus connectivity and networks. After the 2008 financial crisis, many economists have come to the view that the very networked architecture of the financial system plays a central role in shaping the dynamics of the system - even more so now that it has become globally interconnected and interdependent. That to properly understand the vulnerabilities and opportunities we have to look at the networks of connections. Here again, complexity science provides us with a new set of models and computer tools for understanding financial network structure and dynamics. The science and mathematics of networks is now almost fifty years old and advancements are being made every year; these insights from network theory can be of critical value in providing the theoretical underpinnings to finance as a more mature science.

This changing paradigm of complexity is already proving critical to rethinking financial theory. The science of finance is very young and is changing very fast, but by integrating complexity theory we believe that it may well be key to actually studying finance as a science in a much more realistic way than we have done in the past. The importance of rethinking our approach to finance can't be understated, as professor Andrew Lo notes "you all know the saying 'seeing is believing' I would argue that other times things need to be believed to be seen, our narrative changes our behavior which changes reality, that's what I want to leave you with, the fact that we need new narratives in finance both from the perspective of financial advisers but also from a societal perspective, finance is a means to an end not an end unto itself."

1. What are Financial System?

Dealing with complexity requires shifting our focus so as to look at not just the parts to a system but also the overall macro system as a whole. Ideally, this means formulating some kind of overall systemic model of the financial organization we are dealing with. Even if this model may appear very basic it helps to structure our reasoning and place our more focused analytical understanding within a broader conceptual framework.

Finance serves the function of accounting for and exchanging economic value. Financial systems allow funds to be stored and moved between economic actors; they enable individuals and organizations to share and exchange ownership with the associated risks and returns. A key distinction in financial systems can be made between systems designed to enable immediate economic exchange or systems designed to enable the longer-term exchange of ownership through investment; this can be thought of as a distinction between liquid capital and investment capital.

Financial systems enable the exchange of products and services via liquid capital where currencies function as a shared medium of exchange enabling people to fluidly exchange underlying economic resources. Investment capital is concerned with the allocation of assets and liabilities over space and time, with associated risks and returns.

To facilitate this recording and exchanging of economic value a financial system converts economic claims to ownership and liabilities into an information based form of a financial asset or liability. As such we can say a financial system is an information form of the real economy; it is an information system for the recording and exchanging of value.

Finance quantifies underlying value within the economy and creates an information representation of that in the form of what we call a financial asset. Financial assets derive their value from a contractual claim on an underlying economic asset.

The point of this is that information can be more easily stored, processed and exchanged than real economic assets. This linking, recording and exchanging of economic value creates a network of interlinked assets and liabilities, a financial system.

Systems

A system is a set of elements and relations between these elements through which they form an interconnected whole. We can then represent an element(node) in the system as a financial asset or financial entity. A financial asset is a claim to some economic resource - when the value is negative it can be termed a liability. A financial entity is an individual or organization with an accounting record of assets and liabilities represented as a balance sheet. A node in the system can be represented by a single absolute value of the size of their assets. Connections represent the exchange or linkages between assets and liabilities between different organizations.

To serve its function a financial system has to be able to record and move assets from one entity to another; from those who have savings to those who need it for investment; from those who are buying to those who are selling a good or service through a currency; from one generation to another through inheritance; from individuals to public administration through taxes; from low interest nations to locations of high returns through stocks, bonds and loans; for spreading risk through insurance, for joint investment via special purpose vehicles. This relationship between those that have capital(the investors/buyers) and those that need it(debtors/sellers) forms the core of what financial systems are and do.

Nodes in the network make decisions about how to allocate their capital so as to obtain the economic resources they desire through exchange or investment. Nodes exchange resources or invest in other nodes to generate a return on their investment or obtain the things they desire. Financial assets are used as the medium of exchange. They serve as a standardized medium of known value for which goods and ownership can be exchanged as an alternative to bartering.

The type of transaction - and type of financial security used to enable it - can be seen to exist on a spectrum of liquidity, which defines how widely accepted and rapidly a financial asset can be converted. Economic exchange is done through liquid capital, such as fiat currencies. Investment is done through capital markets in the form of various capital market instruments, such as bonds, stock, commodities, derivatives. These are all claims to ownership or claims to a portion of a revenue stream. A derivative instrument is a contract that derives its value from one or more underlying entities. Financial intermediaries - such as banks, insurance companies, hedge funds and various forms of market makers etc - perform the function of aggregating resources, spreading investments and enabling exchanges.

Risk Returns

Financial entities make exchanges to obtain the things they desire. All exchanges involve a dynamic between risk and returns. Risk defines the potential of a financial loss and returns defines a gain e.g. when we exchange liquid capital for some good it may or may not deliver the functionality we hoped for, when we invest in a company it may or may not deliver returns, these are forms of risk.

Through financial instruments like loans, bonds, shares etc. financial entities connect their risks and returns with others within contractual agreements. Participants in the market aim to price assets based on their underlying value, their risk level and their expected rate of return.
Thus the core of a financial system is the relationship between creditor and debtor and the risk-return ratio of that connection, which defines the contractual agreements as to prices, dividends, liabilities etc.

Much of economics can be understood in terms of investment, risk and returns; buying a house or bicycle, starting a company, a government choosing to build a new bridge in the hope that it will stimulate the economy. Combining assets makes it possible to spread risk and returns and thus engage in larger investments without any one party needing to take on the full risk or provide the full capital investment cost.

As the cost of the transaction goes down resources can be more easily moved around in the system and assets and liabilities shared. A financial system is a type of information system, thus the form of the financial system is heavily contingent upon the underlying information technology used to enable it. The financial system's capacity to share assets and liabilities is relative to the level of the underlying information technology's efficiency at recording, organizing and exchanging financial information. The complexity of the financial system is fully contingent upon the information technology used to operate the network. Coupled with this social factors such as legal frameworks are key to the form of the financial system.

Complexity

All systems can be defined as either simple linear systems or complex nonlinear systems. The increase in complexity is a function of the number of different component parts in the system and the degree of interconnectivity and interdependence between those elements.

A simpler system is one that has few parts with those parts being relatively undifferentiated and independent. A complex system is one that has many diverse components that are highly interconnected and interdependent.

An increase in complexity changes systems in fundamental ways and the same can be said of financial systems. At a low level of complexity with few parts, limited connectivity and interdependence simpler systems can be described as just a set of parts; because the parts are not interdependent they do not form synergies and thus the whole is simply equal to the set of parts.

As the system becomes more interconnected and interdependent it starts to take on a networks structure and the conditions for systems level processes and phenomena emerge. Whereas we can analyze simpler systems as being closed this is not the case for complex systems because they are open systems it is required that we understand the system in relation to its environment.

Subjectivity is a key aspect of complexity. Simpler systems due to their finite amount of components and limited interactions can be fully knowable and thus there can be one correct way of knowing the system, one right answer. Complex systems can not be fully known and thus any valuable insight must be recognized to be subjective and a product of a multiplicity of perspectives.

Nonlinear Dynamics

As systems go from simpler to more complex they go from being linear to nonlinear. With low degrees of interconnectivity and interdependence in simpler systems, an effect can create a cause without the cause returning to its source, this is called linear causality. As we increase the interconnectivity there are more channels for an effect to return to its cause and this creates a feedback loop between elements within the system. This feedback creates interdependence, and it means that the system can change very fast as actions become coupled; what one actor does can feedback to induce another to do more of the same action, creating the possibility for compounded exponential change.

As the system becomes more complex, i.e. larger with greater connectivity with more channels for effects to propagate through, it becomes more difficult to trace through the implications and effects of a given event and how it will feedback to its source.

Financial systems are dynamic, meaning they change over time. These dynamics can be understood and modeled in terms of feedback loops. The long-term dynamics of a complex system are a function of positive and negative feedback loops. Negative feedback is a balancing loop where the agent is connected to the costs and benefits of their actions. When the cost and benefits to the agents in the system are connected - through a feedback loop - to the whole then the system is stable because there are no externalities.

When the agent's actions are not connected to the consequences, there is the option for externalities, which can be both positive or negative. A positive externality is when the actions of the agent add value to the whole and thus over time it evolves to a higher level of organization. Positive synergies between both parties involved in the exchange can create value for the overall organization, many examples of trade are positive-sum games. Likewise, investments can be also positive-sum interactions, wealthy nations may have a large amount of capital with low growth, while emerging economies may have high growth potential but lack the capital to realize it, the exchange of capital investment can form a synergistic relationship creating value for the whole global economy and financial system.

Inversely, negative externalities mean the agents actions deplete from the whole leading to a critical state and collapse. The asymmetry between private gains and the risk to the whole creates externalities. Systems collapse when they become critically fragile due to externalities depleting the resources in the system. For example, when traders purchase an asset knowing the underlying resource is not valuable but believing that the market price will go up, this is a negative externality that over time leads to a critical state as the system fills up with overpriced assets, eventually leading to collapse e.g. a housing bubble.

These externalities can take many forms but they work ultimately to create a mismatch between the level of risk or value of the underlying asset and the level that is perceived by the market. The result of this is a false evaluation which enables over leverage, overexposure and ultimately criticality as smaller changes in sentiment can have larger effects due to the lack of fundamentals. The inherently subjective nature to the financial system and the possibility to exploit that towards the creation of credit where there is no real asset or underlying value creates instability. All of this can be understood in terms of system dynamics, feedback loops, and externalities.

Evolution

Financial systems operate at all levels from personal finance, to corporate finance, to national, to the global financial system. Complex systems have a scale-free property with structure found at different levels. All complex systems involved emergence and the formation of qualitatively different levels, from the micro to the macro. Agent's actions on the micro-level create the overall structures and patterns that then feedback to enable and constrain them.

Financial markets form complex adaptive systems evolving through an interaction between the overall system and the agents on the micro-level. Actors adopt certain strategies, make investments, those strategies that prove successful become more prevalent in the system while others die out, this changes the state of the system which then feeds back to change the success of the strategies adopted, as agents need to constantly adapt and the whole system changes over time.

2. Financial Agent-Based Modeling

Financial theory and economics in general as they have evolved over the past century have adopted the modeling framework of physics and standard mathematics, which is known to be a reductionist framework. Much of current financial theory is based on linear assumptions and top-down equation-based models. Dynamic stochastic general equilibrium models are a paragon of this approach - an equation based macro rule with a limited number of variables that are designed to describe how the whole system works based upon rational expectations of the agents in the system. This approach involves a degree of model expectation; meaning the agents are expected to act as if they understand the model so that the agents fit into the overall model. The general approach is that of aggregating over representative agents to achieve a general equilibrium that can be captured in a single global rule.

Just as Newtonian physics still works as an approximation for most physical motion, for much of science, economic and finance the equilibrium top-down approach works as a rough approximation.
However just as we know that Newtonian physics is a shortcut description of a more complex underlying physical reality of general relativity, so too these general equilibrium models are a shortcut for a more complex underlying economic and financial reality. Just as we have to switch from Newtonian physics to general relativity or quantum physics to talk about certain phenomena in our universe, we also have to shift the paradigm within finance if we are to approach important economic phenomena, moving from top-down general rules and equilibrium to bottom-up local rules and nonequilibrium processes of change.

Emergence

What these general equation based models do not allow for is the reality of how people act and interact locally to create emergent bottom-up patterns based upon local rules; which is to a certain extent how markets work. People find themselves with some set of rules, some kind of local information, and then make their decisions, the interaction of these decisions lead to the overall outcomes in the market. Previously this vision of the world was not possible for our scientific and mathematical models to deal with because it involves massive amounts of free parameters and information. Prior to the advent of computer simulations, we could only write global rules and hope that the empirical data fitted into it, but today new models from complexity theory dealing with self-organization and emergence coupled with computer simulation are changing this.

Dealing with heterogeneous agents making local decisions creates many parameters; it is a high-dimensional problem and this is why large amounts of data and computer models are needed. With computers, we can define bottom-up models, where we start by asking what rules the agents are acting under and then simulate that leading to interaction and emergence. Solutions are no longer well defined and closed, they are more like patterns. We are trying to simulate the rules, actions, and interactions of agents looking at how overall patterns are created and change over time.

Simple Rules

One of the key premises of complex systems theory is that global coordination and complex behavior can emerge out of very simple rules governing the interaction between agents on the local level without the need for centralized coordination. At the heart of this is the question of how agents synchronize their state or

cooperate to create local patterns of organization. We see many examples of self-organization within complex adaptive systems that are composed of elements following simple rules. For example, swarms of fireflies who may start out flashing their light in a random fashion with respect to each other come, through their interaction, to coordinate their behavior into an emergent pattern of the whole swarm flashing in synchrony.
This type of self-organization can be modeled using agent-based models (ABM) where agents with simple rules are programmed into a computer, the program is left to run and out of the interaction between these simple agents we see emerging surprisingly dynamic patterns that are able to stay evolving over prolonged periods of time to produce novel behavior.

This agent-based modeling approach helps to capture important aspects to financial markets that are left out of equation-based models; most importantly this includes interconnectivity. As systems become more complex we get more horizontal peer interactions which allow for the formation of patterns based upon local interaction only. The fact that actors are interacting with others locally and those specific interactions and the context they create becomes important to the overall workings of the system. Likewise, this approach can allow for a diversity of motives and rules under which the members make decisions and act.

Attractors

By incorporating local interactions and feedback we can begin to see emergent patterns such as attractors. An attractor is a particular set of states towards which any new component within the system will be drawn as it becomes a default. Cities are good examples of this. By having such a high density of people, they reduce transaction costs, increase economic coordination and leverage economies of scale as they become an attractor for anyone in the locality of the city looking for work, trade or business opportunities. We might cite Hong Kong as an example. Having offered itself as a center for free trade during the colonial era, it managed to reach a critical mass to become an attractor for trade and finance within East Asia. But without global regulation and coordination, we will typically get a number of different local attractors forming. For example, Hong Kong is just one attractor within the global financial system. We also have New York, London, Tokyo, Shanghai, etc. Each of these is a different attractor that has emerged from their local context and now has to compete within this global environment. These attractors make the system's topology heterogeneous.

Multi-Level Systems

By allowing for the importance of local interactions agent-based models allow for self-organization and this gives rise to new levels of organization; what are called integrative levels. It is out of this self-organization that we get the emergence of institutions from the micro-level of a small local market to large business organizations, industries, economies and ultimately our whole global market economy, which is a complex adaptive self-organizing system that has evolved over thousands of years.

By looking at the economy and financial markets as a self-organizing system, we can begin to recognize these emergent patterns that are not identifiable when we use standard linear models where we simply aggregate up from the micro-level. With self-organization, we can get non-equilibrium and the emergence of attractors on different levels, with these attractors having their own emergent internal dynamics, meaning they can’t just be abstracted away or derived from simple aggregations of lower level phenomena, and they are very important to the behavior of the system.

Non-equilibrium

Whereas equation based models are always looking for equilibrium points with which to model the market, agent-based models do not do this, thus they allow for non-equilibrium outcomes and continuously novel dynamic behavior in the system. Agent-based models do not require that the system comes back to some form of overall equilibrium and relaxing this constraint can enable a much more realistic vision of markets.

As Brian Arthur states in his paper Out-of-Equilibrium Economics and Agent-Based Modeling "Standard neoclassical economics asks what agents' actions, strategies, or expectations are in equilibrium with (consistent with) the outcome or pattern these behaviors aggregatively create. Agent-based computational economics enables us to ask a wider question: how agents' actions, strategies, or expectations might react to—might endogenously change with—the patterns they create. In other words, it enables us to examine how the economy behaves out of equilibrium when it is not at a steady state. This out-of-equilibrium approach is not a minor adjunct to standard economic theory; it is economics done in a more general way."

In 1988 Brian Arthur and John Holland at the Santa Fe Institute built an agent-based model of the US stock market. They built a computer model with agents as investors who were trying to form a hypothesis about how the market works; allowing them to start with a random hypothesis and adapt and learn over time if they did not make money they would replace their model with ones that improve over time. These agents were not rational or uniform and they could learn. After running the computer simulated model they found the market looked similar to the standard equilibrium model, but over time they came to see out of equilibrium solutions. When they ran the simulation long enough they started to see little bubbles and crashes and periods of random high volatility that were followed by periods of volatility that was low. They saw all the same Autocorrelations and cross-correlations that one would see in real markets.

After almost two centuries of studying equilibria economists are beginning to study the emergence of equilibria and the general evolution of patterns in the economy. That is, we are starting to study the economy out of equilibrium through a computer-based algorithmic approach.

ABMs give us an inherently dynamic vision of markets, as patterns are continually being created and recreated through endless computations across complex networks of interaction, just as we see in the real world. When seen in this way the economy shows itself not as a mechanical, deterministic system always moving towards stability and equilibrium but instead as continuously evolving and creating new structures and patterns.

3. Behavioural Finance Overview

Financial systems are composed of agents and the exchange of financial instruments within institutions and markets. Thus to understand this system we need to first understand something about the logic of the agents in the system; how agents make decisions about the allocation and exchange of financial assets is clearly important.

Agents have motivations that drive them to value things. In order for agents to pursue their valued ends, act and affect their environment towards achieving those outcomes they need some logic under which to do this. That is to say, they need to take in and process information according to rules so as to generate a response that will lead to their ultimate desired end. If we want to understand how agents behave within a financial context we thus need to define, to some extent, how this is done.

There are two fundamentally different paradigms with respect to understanding how agents make choices and evaluate financial resources. Our actions may derive from individual deliberative reasoning, and this would be called a rational action, or they may derive from some other non-deliberative source, such as instinct and emotion, heuristic or social cues etc.

The assumption of rationality - and market efficiency - is central to modern portfolio theory (the CAPM), and to the Black–Scholes theory for option valuation. Rational means designed or conducted according to reason. Reasoning is a process whereby data is amassed, processed according to some logic in order to produce a conclusion that is both logically consistent and in accordance with objective data.

Thus a rational decision is one where an agent amasses all relevant information, processes it according to a consistent and objective logic and then acts in accordance with the outcome of that process. In so doing the agent acts independently, they act on their own internal logic in an autonomous fashion.

Thus for a decision to be rational, there are a number of requirements; firstly that the agent has all the relevant information and that any information that is not fully known can have a probability distribution assigned to it. Secondly, the agent must act according to a consistent and objective logic set, which means that the choices made will not change unless there is some alteration to the objective factors determining the decision.
Agents have to have a fixed set of preferences and these preferences have to be complete - the person can always say which of two alternatives they consider preferable or that neither is preferred to the other. An actor is acting rationally when they take account of available information, probabilities of events, and potential costs and benefits in determining preferences, and act consistently in choosing the self-determined best choice of action.

Although the term rationality simply means according to reason, the requirements for achieving this are only met in some circumstances or some of the time. Rationality requires that we have intelligent calculating agents operating in relatively simple environments. In such circumstances, it is reasonable to say that people often act rationally in pursuing the things they value. However, just as often we will be dealing with contexts wherein agents with limited intelligence and limited propensity for reasoning will find themselves in relatively complex environments. In such circumstances, agents do not use reason to determine their actions but use a variety of alternative means, that are contingent upon the social, physical or cultural context within which the decisions are being made. That is to say, that the rationality of an agent is bounded, when it reaches a limit it switches to alternative means for making decisions. This limit is both contingent on the particular subject, i.e. their propensity to use reason, and the environment, i.e. how complex the environment is.

While traditional economic and financial theory posits an objectivist rational understanding of agents decision making, complexity theory sees the environment within which agents make choices as often being fundamentally too complex for them to make rational choices and is thus based upon more of a subjectivist model to human behavior which is the idea of bounded rationality.

Bounded rationality is the idea that agents do not have complete information and/or cannot rationally process all the information available to them. Agents find themselves in a system that they do not fully understand and have incomplete knowledge. Because they a part of complex systems that they can not fully know they use all sorts of shortcuts to try and find some basis for action; they create narratives, they copy others, they use simple rules that have worked for them in the past etc.

Much of the time people operate in environments where there is incomplete information, radical uncertainty may exist, where they do not wish to expend the time and energy to reason through their actions, we don't want to take the responsibility for our actions, there are time limitations, social power dynamics or a series of other limiting factors involved. In such circumstances we defer our decisions to heuristics - which are shortcuts - we use social and cultural norms, we copy what others do, we allow random events to determine our decisions.

Behavioral finance deals with people as they are, i.e. with many psychological biases that means their actions and behaviors deviate from what would be expected if they were basing their decisions on rational thought processes alone. Some of these include anchoring, meaning the person places an arbitrary value as an anchor point and then bases future expectations around that. Another is mental accounting, referring to the process whereby people divide up their money mentally into different accounts based on subjective criteria, such as the source of the money or the proposed usage of it, this can prompt biases and systematic departures from rational, value-maximizing behavior.

A fully rational agent has a fully comprehensive view of the system or environment within which they are operating. However, this is not the case for most investors whose patterns of activity follow a vision that is more narrow and a function of their psychology, e.g. what often dominates people's' behavior is immediate losses and gains when what really matters is overall wealth. This is the so-called disposition effect, which relates to the tendency of investors to sell shares whose price has increased while keeping assets that have dropped in value. Given rational expectations, the price at which you purchase a stock should not determine when or whether you sell it.

Uncertainty

Complexity theory sees uncertainty as something inherent to nonlinear complex systems and environments, not something that can be modeled using probability and statistical methods. Much of mainstream finance assumes uncertainty can always be modeled mathematically, and that everyone should arrive at the same assessment of an uncertain event probability, at least given the same information. The Austrian School notes every individual always perceives a unique information set, and that each individual values every item of information in a unique manner. Even if participants had exactly the same information, their assessment of its importance would be subjective. One person's behavior may be quite different from another's, even when presented with identical choices.

Connections

The efficient markets hypothesis is that people bring large amounts of information into the market and cannot be systematically incorrect - that prices reflect all available information. It views actors as rational and independent and it is possible to use statistical averages to abstract away the underlining diversity and particularities to arrive at a single average that can then be used to represent the whole sample. This is often done in financial models where a number of heterogeneous assets - like mortgages - are bundled together and given a single value based upon the average. This only works well if the collection of variables is random, independent and identically distributed (IID) if each random variable has the same probability distribution as the others and all are mutually independent.

However, if you view agents as not necessarily rational and as being interconnected than the assumptions behind this no longer hold. An actor in a market is often not disconnected nor acting in an isolated fashion but instead communicating and interacting with others creating interdependencies and feedback loops. Self-fulfilling speculative attacks by investors expecting other investors to follow suit given doubts about a nation's currency peg is an example of a feedback loop that creates macro-level disequilibrium in the market defying statistical averages.

Value Theory

Finance is an abstraction of the real economy. The foundations of finance is the abstraction of value, i.e. it is built on an accounting system that is designed as an information record of value within the real economy. Whereas real economic assets have value in use, finance is based upon an assessment of the value of something, thus there is always a subjective factor involved in finance. As soon as we come to exchange an asset it also comes to have a subjective value which is the value that the particular individual places upon it based upon their subjective evaluation of it, which is a product of their particular desire for it and many psychological and contextual factors that contribute to that assessment. This being noted many of the traditional models - efficient market hypothesis - in finance are based upon the idea that financial assets derive their value from market fundamentals. Fundamental analysis is a method of valuing securities that attempts to discover their true value by examining related economic and financial factors; looking for the intrinsic or "true" value of the asset. This is an objectivist view of value theory, that the value of something derives from objective factors.

The subjective theory of value is a theory which advances the idea that the value of a good is determined by the importance an acting individual places on a good for the achievement of his or her desired ends, what is called utility. The theory of extrinsic value posits that value cannot be measured or observed directly but the value is simply given to things based on people subjective perception of them.

Reflexivity

As noted by George Soros, financial markets involve a feedback loop between the subjective models of agents and the objective structures of the market. The subjective models that actors create to understand the market creates the actions they take which then affect the state of the market which then feeds back to shape their understanding and acting. There is a constant feedback between agents and structure, agents acting, affecting the overall structure, with that then feeding back to change their behavior, with a continuous feedback loop between the subjective and objective.

Models and theories are not real. There is a real world and models do not exist there. They simply help us to interpret and give structure to it, sometimes even predict it. But this is not to say that models do not affect the world – quite the contrary, within the social sciences, they have a very significant effect. We create these models. People adopt them and go around seeing the world through them and acting on them. In so doing, the models change the world. Thus, in creating models we are responsible for creating the future state of the system.

This is one insight from Andrew Lo's adaptive market hypothesis that integrates an aspect of the efficient market hypothesis and behavioral finance's understanding - that both have aspects to contribute but much is dependent upon the kind of market environment that is being operated within. In simpler environments that are knowable and limited in dynamic change and unpredictability, an objective analysis may well reflect outcomes in the market. However, as the environment becomes more complex, more dynamic, uncertain and unknowable and the actions of agents more interconnected, than more subjective factors come into account for which a more complex model incorporating psychology and contextual factors must be used.

4. Financial Networks

Over the past decades, our financial system has evolved into a global network of connections between institutions, markets, assets and liabilities, leading many to the insight that this system may well be best modeled using the science of network theory. Network science is becoming a topic of major interest in financial research, particularly due to its implications for financial crises. Some current applications of network modeling in finance include looking at the spreading of financial contagion and systemic risk, the formation of interbank markets or stock correlation networks, among many others.

Network theory, also called graph theory, is one of the very few major modeling frameworks within complexity theory. It is an abstract formal language which deals with the idea of connectivity. This world of connectivity is very different from the one we are used to. It is all about access, where you are in the network, what is the overall structure of that network and what is flowing through it. With networks, it is the structure of the connections within the system that determines the outcomes and not so much the component parts.

A financial network is a system of financial entities that are linked through a set of connections in some way. A node in the network can be any organization with a balance sheet or any asset or liability. Connections between them can be exchanges of various forms, such as that of ownership, e.g. between shareholders and a company or credit and debt between borrower and lender. A financial network thus forms an interlinked system of interdependence between a group of financial entities, their assets and liabilities.

Connectivity

Network theory is a modeling framework that can help us to understand financial systems by looking at the structure of the connections between nodes. The first thing we really need to know about a financial network is how connected it is. Complexity theory has in many ways taught us that connectivity is a fundamental parameter to a system. At a low level of connectivity, events do not travel far and there are not enough connections for events to return to their source. The more interconnected a network the greater the capacity for feedback loops, nonlinearity, and cascading effects.

Going from a low level of connectivity to a high one is a paradigm shift in that it is a systemic change that affects how the whole system operates. A key parameter here is that of transaction cost. Generally, as transaction costs go down exchanges go up, connectivity goes up, interdependence goes up. As interdependence is the fundamental source of nonlinearity the consequence is that the system starts to behave in a nonlinear fashion. The transaction cost within a financial system can take many forms, such as with telecommunication technology, i.e. how easy is it to send information around or it could be regulatory, how easily can capital be moved into or out of a jurisdiction. For example, we have seen how much the global financial system has changed over the past decades and a lot of this is due to a reduction in transaction cost increasing interconnectivity and interdependence - the advancement of communication and information technology and the deregulation of capital markets.
One way of quantifying this concept of the overall connectivity to a network is with reference to its density. The density of a network is defined as a ratio of the number of connections to the number of possible connections, and this will also correlate to the average degree of connectivity to the nodes in the network.

Node Significance

How important a node is within a financial network is a function of both how much of the network's resources are flowing through it and how critical that node is to the system. A node's real significance within a network - what is called its centrality - is not a trivial feature to analyze.

As an example of centrality analysis, we might think about government bailouts during a financial crisis. As the government is interested in maintaining the functionality of the entire network, it needs to ask a number of questions about its connections including: how many links does this bank node have and what volume are those links? Does the node play some critical role within the financial network that no other institution could perform? How closely connected is it to all the other nodes and how important are the other nodes that it is directly connected to? By answering all these questions, we would be able to get some understanding of its importance in maintaining the entire network.

The way in which a network is connected plays a large part in how networks are analyzed and interpreted, this overall structure to a financial network we would call its topology. The topology of the network defines how things flow through it. Information and resources flow very differently in a centralized star structured network as opposed to a distributed network, likewise spreading will happen very differently on a network that is homogeneous versus heterogeneous in terms of its clustering.

Due to some common set of properties shared by a subset of the system, we often get subsystems forming within networks. These subsystems are called clusters and often have a significant effect on the makeup of the network. For example, we might think here about the clustering in different commodity markets or different geographic areas, such as that of Anglo-America or the Chinese market, that create discontinuity and disparities between them resulting in resistance to something flowing evenly across the whole network.

Degree Distribution

The degree distribution to a network is a key factor in its overall structure and dynamics. Degree distribution answers the question how evenly distributed are the connections in the system, do some people or institutions have a lot of connectivity while others have little, thus creating a very unequal system, or do all have roughly the same degree of connectivity creating a relatively equal system. As in many cases, connectivity equates to the flow of resources and opportunities this metric can tell us much about the level of equality within the system and how centralized or distributed it is - analyzing degree distribution may tell us whether some institutions in the financial system dominate over all others or if power and influence are more evenly distributed in the system.

Degree distribution helps to capture a critical aspect to a network of any kind, how centralized or distributed it is. The degree of centralization to the overall network is a major determinant of many factors, such as its robustness and criticality, how resources flow across the network and how one might go about intervening in the network.

With a relatively equal distribution of connections across the nodes, we get a distributed system, e.g. everyone has more or less the same amount of connections. One example of this in a financial network might be peer-to-peer lending which works to match many small lenders with many small borrowers. Without any form of centralized hubs, distributed networks are typically user-generated. However, distributed systems are often not what we see when we look around us and typically not the case for financial systems; often we see networks that are more concentrated creating centralized hubs.

Scale-Free Networks

Highly centralized networks represent a radically unequal level of connectivity to the nodes. Many nodes have very few connections while some have very many. These centralized networks are also called scale-free networks as their degree distribution follows a power law, meaning, unlike a distributed or random network - that have a normal distribution with most nodes tending towards the average degree - in scale-free networks, there are very many nodes with very few connections, very few with very many. Thus, the vast majority link into just one or a few centralized mega hubs.

This power law relation is a more exact description of the Pareto principle, which has been identified in many areas, from the distribution of land ownership to that of wealth; where the richest 20% of the world's population control approximately 80% of the world's income. Or for example, in a financial context, power laws are also seen within stock market pricing and the interbank network, where the fat tail indicates that there exist few banks interacting with many others, giving us banks that are too big to fail.

Highly centralized systems are often the product of preferential attachment. A preferential attachment process is any of a class of processes in which some quantity, typically some form of wealth or credit, is distributed among a number of individuals or objects according to how much they already have so that those who are already wealthy receive more than those who are not. For example, these major hubs in scale-free networks can leverage significant economies of scale to reduce the marginal cost of interaction, working to make them a default attractor for the formation of new connections e.g. large markets that have high liquidity reducing exchange costs.

Diffusion

The process under which a network was created and matured will play a large role in how something will spread across it and ultimately how resilient it is to failure. There are a few key parameters that will greatly affect this process of spreading. Firstly, how contagious is the phenomenon that is spreading? An important consideration here is whether this is being driven by some positive feedback loop, as is typically the case within financial markets where loss of confidence begets more loss of confidence, or inversely, increase in confidence creates even more confidence. Secondly, how resistant are the nodes in the network to this phenomenon? So for a financial institution facing a mass of defaults, this resistance might represent how much capital they are holding. Thirdly, we need to consider the overall structure of the network; is it centralized or decentralized? Centralized networks are more susceptible to certain kinds of attack. This is one of the great benefits of distributed ledger technology. It reduces the current cybersecurity vulnerability of having large amounts of financial data within centralized repositories. Lastly, we need to also take into account whether this failure is being spread strategically or at random, as different network topologies exhibit different vulnerability characteristics depending on how random the failure is.

Resilience

Resilience and robustness have become a hot topic since the financial crisis and many researchers have since tried to apply network models to financial systems in order to make an assessment of their resilience to shocks and spreading. On a very general level connectivity can both add and reduce to the system's robustness. It works both ways; greater connectivity can provide channels for spreading risk and supporting each other but it also works as channels for failures and shocks to spread.

Part 2:

Applying Complexity Theory to Market Analysis

By Francesco Filia

Section 2 Overview

Financial markets are best analyzed as Complex Adaptive Systems, borrowing from the inter-disciplinary studies offered to us by Complexity Science, where the Positive Feedback Loops between extraordinary monetary policymaking and a growingly passive investment community undermined System Resilience and brought to the brink of Critical Transformation

This note posits that **Systemic Risk in financial markets is better analyzed through the prism of Complexity Science**, using the analytical tools available to non-linear socio-ecological systems, where a shift in positive loops comes in anticipation of a dramatic transformation. **Chaos theory** and **Catastrophe Theory** can then help shed light on the current set-up in markets. Years of monumental **Quantitative Easing / Negative Interest Rates** monetary policy affected the behavioral patterns of investors and changed the structure itself of the market, in what accounts as **self-amplifying positive feedbacks**. The structure of the market moved into a **low-diversity trap**, where concentration risks of various nature intersect and compound: approx. 90% of daily equity flows in the US is today passive or quasi-passive, approx. 90% of investment strategies is doing the same thing in being either trend-linked or volatility-linked, a massive concentration in managers sees the first 3 asset managers globally controlling a mind-blowing USD 15 trillions (at more than 20 times the entire market cap of several G20 countries), approx. 80% of index performance in 2018 is due to 3 stocks only, a handful of tech stocks – so-called 'market darlings' - are disseminated across the vast majority of passive and active investment instruments. The **morphing structure of the market**, under the unequivocal push of QE/ZIRP new-age ideologism, is the driver of a simultaneous **overvaluation for Bonds and Equities (Twin Bubbles) which has no match in modern financial history**, so measured against most valuation metrics ever deemed reputable; a condition which further compounds potential systemic damages. The market has lost its key function of price-discovery, its ability to learn and evolve, its inherent buffers and redundancy mechanisms: in a word, the market lost its 'resilience'. It is, therefore, prone to the dynamics of criticality, as described by Complexity Science in copious details. This is the under-explored, unintended consequence of extreme experimental monetary policymaking. A far-from-equilibrium status for markets is reached, a so-called unstable equilibrium, where System Resilience weakens and **Market Fragility approaches Critical Tipping Points.** A small disturbance is then able to provoke a large adjustment, pushing into another basin of attraction altogether, where a whole new equilibrium is found. In market parlance, more prosaically, a **market crash is incubating - and has been so for a while**. While it is impossible to determine the precise threshold for such critical transitioning within a stochastic world, it is very possible to say that we are already in such phase transition zone, where markets got inherently fragile, poised at criticality for small disturbances, and where it is increasingly probable to see severe regime shifts. **Fragile markets now sit on the edge of chaos. This is the magic zone, theorized by complexity scientists, where rare events become typical.**

5. From Efficient Hypothesis Theory to Behavioral Finance to Complexity Theory

Here below follows a brief and simplified excursus over the main analytical frameworks used for looking at global securities' markets over time.

Efficient Hypothesis Theory

The Efficient Market Hypothesis (EMH) is a cornerstone of modern financial theory. It states that all people are rationale, markets are efficient, share prices reflect all information available at all times. Investors are rationale adults, effecting decisions based on meticulous calculations and careful assessment of probability.

The theory emerged as prominent in the 60's, although it dates back to 1900, and has been a dominant view across market participants for decades, representing an evolution to classical political economy, after the discoveries occurred during the Industrial Revolution. More recently, the hypothesis was used by Eugene Fama to argue that stocks always trade at their fair value, making it impossible for investors to either purchase undervalued stocks or sell stocks for inflated prices, thus making consistent alpha generation (read, outperformance) in the market impossible.

The hypothesis has a hard time justifying multiple financial crises in the last several decades, and the typical boom/bust cycles the economy and financial markets went through with uncanny regularity.

The idea that investors are all rationale is easily exposed; too often is it possible to spot irrational behaviour on the side of market participants, emotional reactions of economic agents, in response to social or cultural factors. The EMH is visibly ill-suited to explain what led into the big market crises described in the history books.

Behavioral Finance

Behavioural finance is the study of these emotional and cognitive factors affective economic agents, both individuals and institutions, when they take investment decisions, and how those decisions vary from those implied by classical theory. Behavioral economics is better suited to explain how investors would react to perverse incentives and bring the system to a sudden collapse in 2007, to a point of implosion believed my many to me imaginable. Including US Central Bank Governor Alan Greenspan: "It became very apparent to me that we misunderstand how systematic fear is. The fear that led to panic selling and the euphoria that inflated the housing bubble were not factored into the Federal Reserve's computer models. I myself believed irrational behavior could not be projected or analyzed. I was wrong."

Economic models of rational behaviour operating within the framework of 'rationale expectations' are then replaced by cognitive models of decision-making under risk and uncertainty. The work of Amos Tversk, Herbert Simon, Daniel Kahneman, Robert Shiller, Richard Thaler expands upon this fascinating field of research, and won its proponents several Nobel prizes.

From it, the concept of 'bounded rationality' originates, the idea that rationality of economic agents is limited by their cognitive limitations, the information available and the time at disposal, therefore seeking a satisfactory solution rather than an optimal one: "rationality as optimisation".

Quantitative behavioral finance uses mathematical and statistical methodology to understand behavioral biases.

Behavioural finance finds that systemic errors originate from the irrationality of market participants, in contrast to what expected by Efficient Market Hyphothesis. Systemic errors give rise to market inefficiencies, dislocations, bubbles and busts, systemic risks, major market ruptures.

From behavioural finance we learn of the relevance of certain quirks in the human brain, that are capable of affecting investment decisions in the most predictable and recurrent ways. Among others, we learn how several mental biases can cloud investors' judgment and create under- or over-reactions to available information.

- Recency Bias: tendency to think that what is been happening lately will keep happening can cause investors to stay in stocks or other instruments because they have been performing well, despite warning signs like historical or relative high valuation.

- Hot hand fallacy: tendency that a person who experiences a successful outcome with a random event has a greater probability of success in further attempts.

- The gambler's fallacy, also known as the Monte Carlo fallacy or the fallacy of the maturity of chances, is the mistaken belief that, if something happens more frequently than normal during a given period, it will happen less frequently in the future.

- Confirmation bias is the tendency to search for, interpret, favor, and recall information in a way that confirms one's preexisting beliefs or hypotheses.

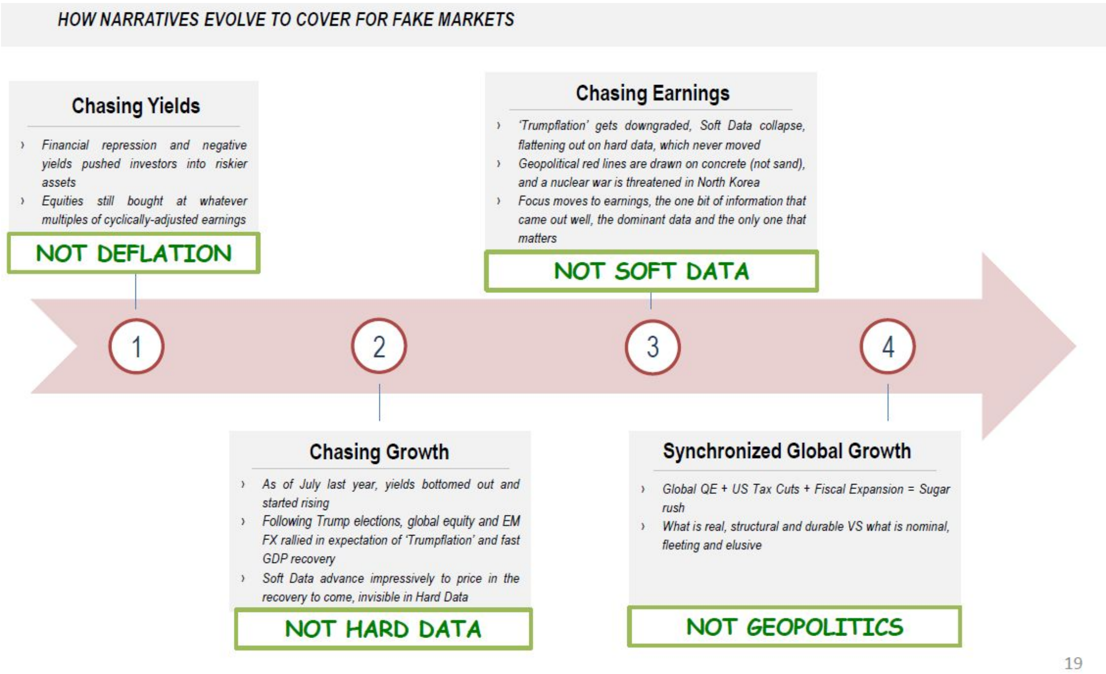
- Cognitive bias go great lengths in highlighting how financial markets can fell prey to systemic risks and sudden crashes, as irrational investment behaviour creates pricing inefficiencies and divergence from fair valuation and market equilibrium.

Narrative Machines

Helped by the mental preferences and irrational regularities of the human brain, market participants can then find themselves following not the hard data of available information, but rather elusive economic narratives, and financial fairy tales. Nobel laureate Robert Shiller calls it 'narrative economics'. In his words, 'the human brain has always been highly tuned towards narratives, whether factual or not, to justify ongoing actions, even such basic actions as spending and investing. Stories motivate and connect activities to deeply felt values and needs. Narratives "go viral" and spread far, even worldwide, with economic impact. The 1920-21 Depression, the Great Depression of the 1930s, the so-called "Great Recession" of 2007-9 and the contentious political economic situation of today, are considered as the results of the popular narratives of their respective times.'

Economist Arthur Pigou also warned against the perils of extrapolating too readily from current events into the future: 'Prosperity ends in a crisis. The error of optimism dies in the crisis, but in dying it gives birth to an error of pessimism. This new error is born not an infant, but a giant. This new error would make business 'unduly depressed' and a recovery seem unfathomable. But all crises do end, and time do heal all wounds. Optimism will regain its former power, growth will resume, and prosperity will return, even as it sets the stage for future crises.'

Today's market provides yet another epidemiology of narratives capable of providing justification for economic fluctuations, as the slide attached shows.



Chasing Narratives

Something is still missing: entry Complexity Markets

The analysis of past systemic crises showed the flaws in the Efficient Market Hypothesis, which were only partially filled in with what we learnt in studies of Behavioral Finance. A move to a Complex Markets Hypothesis can help shed light on the life cycle of a market system, as it naturally degrades and systemic risk compounds. A more realistic representation of reality should include key concepts from complexity theory, such as, for example:

- The whole matters more than the single parts, what makes sense and is rationale at the individual level can become a systemic risk at the aggregate level if all do the same at the same time,

- Markets are 'complex dynamic adaptive systems', they adapt to local conditions as emerging properties arise, and the system evolves. In the words of Complexity Labs, they are 'open and self-organizing, where overall functionality and desirable outcomes are an emergent phenomenon of local interactions between members'. As such, they typically exhibit non-linear dynamics, and the dynamics of criticality. A chief lesson from complex theory is that there is not one single trigger, no cause and effect relationship. Human brain tends to look for one, forgetting the system as a whole. In analogy, Mike Tyson lost not to Buster Douglas, but when he was ready to go. Subprime mortgages in 2007 were an issue, but the system was ready to transition beforehand; subprime was just the trigger jumpstarting the autolytic reaction function and chain effect. When the system is tight in all directions of potential expansion, hitting capacity constraints in synchronicity, it becomes brittle, it is acting weirdly, ready to snap.

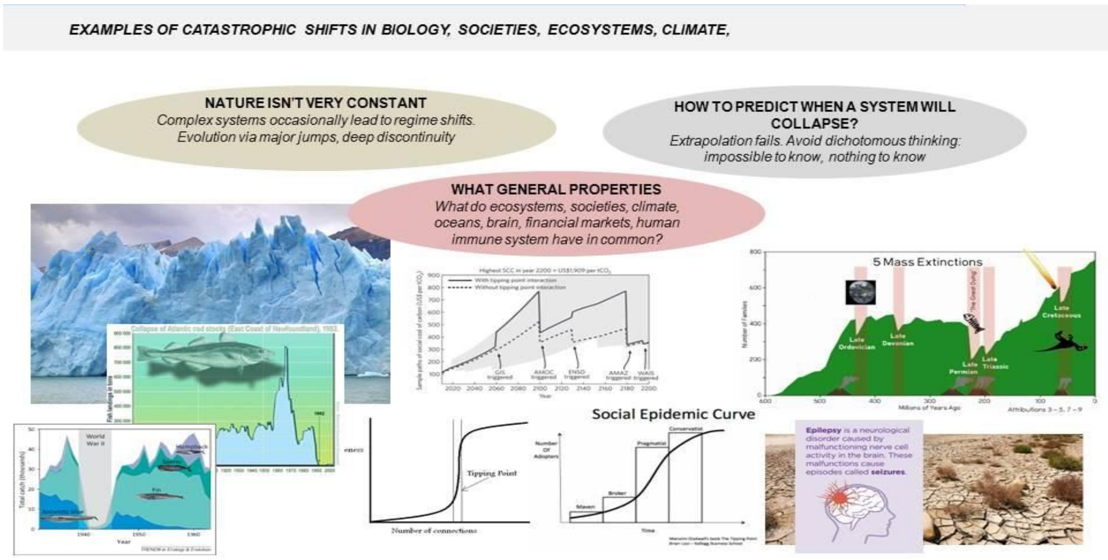
- The need for using and enriching agent-based modelling, in an ever-evolving effort to represent the various interactions of a complex network across a large number of nodes. Agent based unsupervised machine learning algorithms can be used to monitor the complex dynamic behavior of market participants, clustering them according to both pre-identified and emerging risk factors, analyzing crowding effects as they evolve.

A framework of analysis which encompasses the key elements of Complexity Markets should then be considered, one where the importance of non-linear effects, convexity, interactions between economic agents emerge as key functionalities. The nature of positive and negative feedback loops get to center stage, together with knock on effects, time steps, beyond a classic cause-effect relationship: non linear dynamics, points of no return, implosion of a system under its own weight. We will expand upon Complexity Markets in the following pages.

6. A rapid excursus across Chaos Theory, Catastrophe Theory, Edge of Chaos

What it means to be on the 'Edge Of Chaos'

There is a magic space between order and chaos, a phase transition zone where a system reaches criticality, and can suddenly and abruptly morph into a whole new contrasting system. It is a place where its resilience may get weakened to the point where disorder and randomness prevail, and lead into a totally different environment, for an entirely new equilibrium. If the system degrades at the edge of chaos, it can then drift away from an ordered predictable regime into a chaotic unpredictable regime. It is the space, hypothesized to exist by scientists, where snowflakes suddenly accrete to form avalanches at some critical tipping point, where fluid crystallize, where desertification rapidly oversets a green valley, where a volcano breaks into eruption, a forest burns itself out, a pandemic breaks loose.



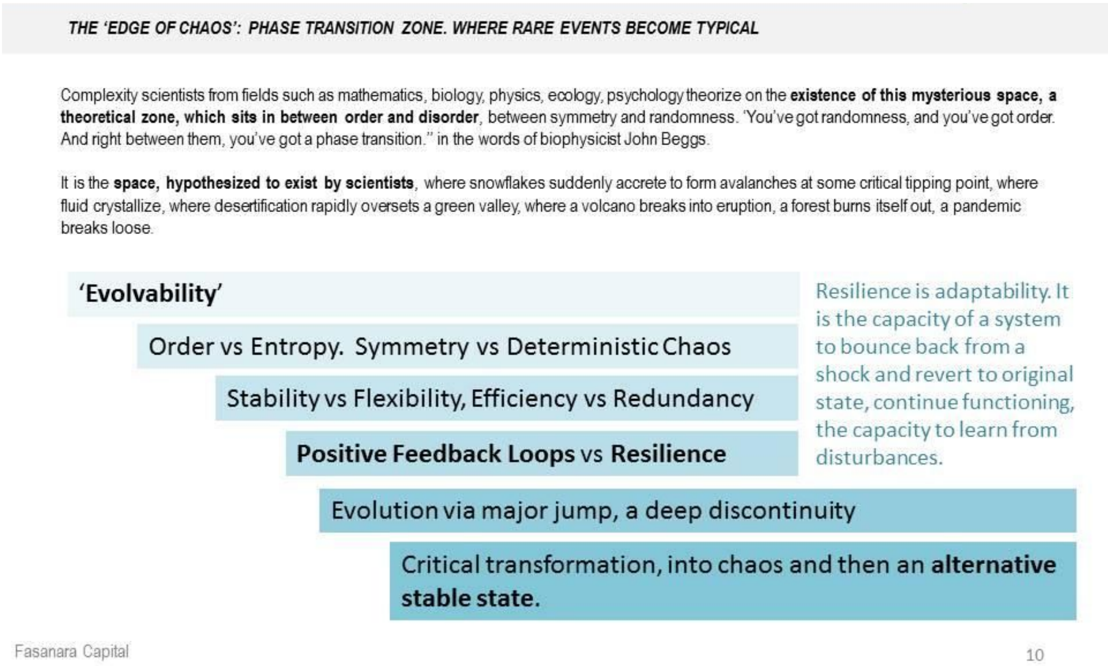
Transitions are Common in Ecosystems

In an intrinsically interdisciplinary endeavor, complexity scientists from fields such as mathematics, biology, physics, ecology, psychology theorize of the existence of this mysterious space, a theoretical zone, which sits in between order and disorder, between symmetry and randomness. '**You've got randomness, and you've got order. And right between them, you've got the phase transition**," in the words of biophysicist John Beggs of Indiana University.

His **analogy of a pile of sand** is illustrative. 'Sand grains are dropped one-by-one from a single point. For a long time, nothing much happens: a conical pile slowly accumulates. Eventually, however, it becomes so steep that the addition of just one more grain can trigger a miniature avalanche, though not in a predictable way. Avalanches can be small or large, and sometimes they don't happen at all. Just before the pile enters its avalanche-prone state, said Beggs, it's poised at criticality. From a biological perspective, the trick is to harness the capacity for small perturbations to produce large effects without entirely entering that avalanche-prone state, in which perturbations would soon become overwhelming. Researchers studying such behaviors sometimes refer to this as the 'edge of chaos.'

Sand Pile Model

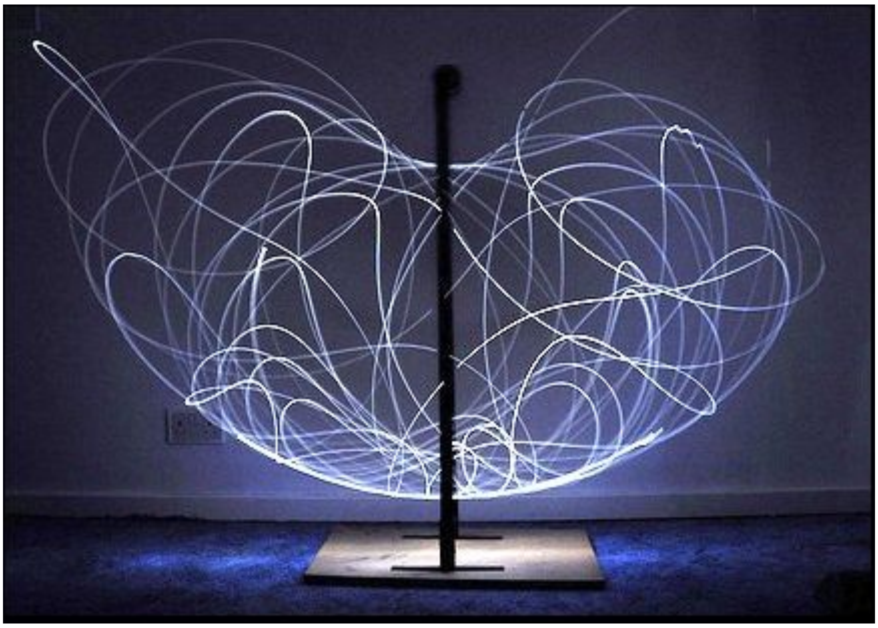
There is nothing intrinsically negative about stationing at the edge of chaos. Edge of chaos is not to be seen as necessarily a negative zone to be in. If anything, the interaction between chaos and order builds resilience. The criticality of the balance between order and deterministic chaos is an optimal evolutionary solution for systems that need to balance order and stability with flexibility and adaptability, in harmony. Complexity theorists talk of '**evolvability**', as the capacity of a system for adaptive evolution. Evolution happens at the edge of chaos, the boundary between ordered and entropic regimes. However, such evolution is sometimes a major jump, a deep discontinuity, when the delicate balance between stability and flexibility is suddenly lost. **It happens when feedback loops change in ways in which resilience drops, making it dangerous to be there at the edge, poising for critical transformation, into chaos and then an alternative stable state**.



The Theoretical Zone Between Order and Disorder

Also, not all transitions are negative. Some systems tend to order, not disorder. What matters though is the identification and the awareness of criticality, as a state where large swings can follow swiftly, by the very nature of the state. It is an essential element of resilience management.

The sensitivity of a complex system to parameters is well known. **Chaos theory** focuses on the 'deterministic chaotic behavior' of dynamical systems that are highly sensitive to initial conditions: 'chaos is when the present determines the future, but the approximate present does not approximately determine the future', in the words of the theory pioneer Edward Lorenz. The **butterfly effect** describes how a small change in one state of a deterministic nonlinear system can result in large differences in a later state, or as is famously rephrased how 'a butterfly flapping its wings in Brazil can cause a hurricane in Texas'.



A double rod pendulum is the classic example of chaotic behavior, one of the simplest complex systems with chaotic solutions. Try it yourself here: labs chaotic pendulum simulation

Sensitivity to original conditions is a key characteristic of complex deterministic systems, but a system may change dramatically without a change to initial conditions, but rather as the result of moving beyond **critical tipping points, or points of no return**. Within systems theory and complexity science, around the boundaries of chaos theory, the field focusing on dramatic transformations into disorder is **catastrophe theory**, which attempts at isolating global properties for systems drifting into disorder beyond certain critical thresholds. Tipping point analysis is more relevant to our analysis of financial markets today.

French mathematician *René Thom* is the father of catastrophe theory; growing beyond certain critical thresholds in a nonlinear system can cause equilibria to appear or disappear, or morph, leading to large and sudden changes of the behaviour of the system. It may lead to abrupt ruptures, such as the unpredictable timing and magnitude of a landslide. The subject is so fascinating that even captured the attention of Salvador Dalí, who would dedicate its last painting to one of the catastrophe-types categorized by Thom, *The Swallow's Tail*.

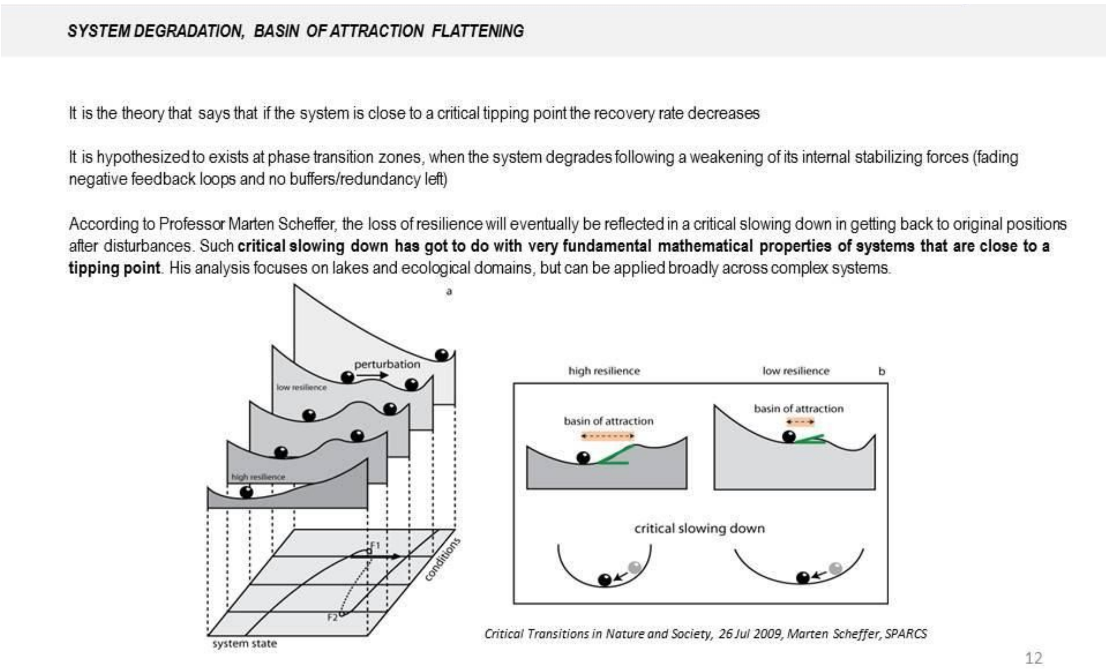
The Swallow's Tail Catastrophe

$$V = x^5 + ax^3 + bx^2 + cx$$

The question then becomes one of identification of such **critical tipping points**, or 'bifurcation events'. **What is the level beyond which a small change can provoke a large swing, a big transformation? What is the last grain of sand on the pile that the system can take in before transformation? How to predict when a system collapses?**

The relevance of a tipping point is clear to the human mind when associated to a simple element. Too many people on the side on a boat, at some tipping point the boat flips. Or the pushing of a chair out of balance, at some tipping point the chair flips. However, we struggle with the concept when it comes to complex systems, ecosystems, societies, climate change, forests and fisheries, human immune system and brain, and financial markets.

Mathematical biologist Marten Scheffer of Wageningen University studies social-ecological tipping point dynamics. **He argues that there may be several critical switching points, not just one, on one key variable. The resilience of the system may degrade to some tipping point where a small perturbation can push it into another state. The loss of resilience makes it snap, eventually, at a point.** There are jumps, discontinuities beyond certain tipping points for key variables, where the system snatches to a totally different equilibrium / attractor, into an alternative stable state. The loss of resilience will eventually be reflected in a critical slowing down in getting back to original positions after disturbances. Such critical slowing down has got to do with very fundamental mathematical properties of systems that are close to a tipping point. His analysis focuses on lakes and ecological domains, but can be applied broadly across complex systems.



Critical Slowing Down

Critical Transitions Follow Changes In Feedback Loops

How does the system degrade? How is resilience lost? How does it happen? One such way is with a change in feedbacks. It happens when self-correcting negative feedback loops weaken, and self-amplifying positive feedback loops arise.

Feedback loops are essential forces in the build-up of any ecosystem. They are mutual causal interactions between the elements of the system. The natural world is full of it. **Negative feedback loops are the internal stabilizing forces of a system, as they bring the system back into balance early on after small perturbations**.

As negative feedback loops get impaired or lose relevance within a system, the system degrades, and the basin of attraction becomes smaller, flatter, less concave, to the point where new small disturbances can push the equilibrium out of the basin. Resilience falls and the system nears a critical transition zone. The system stands at an unstable equilibrium, from where it can flip at any time on closing up to the tipping point.

In the words of Brian Walker of the Stockholm Resilience Centre, 'if you never burn a forest the species in there who are capable of putting up with fire eventually go out-competed; the only way to make a forest resilient to fire is to burn it. The only way to make children resilient to the environment is to expose them to it ('sheltered kids do not make for capable adults' Lythcott-Haims). Resilience is maintained by probing the boundaries of the basin, otherwise the basin becomes smaller and smaller. That's how the body maintains a body temperature of 38 degrees (at 41 you die). We had 10 million years to develop the feedbacks we needed to adapt. Our earlier versions extinguished/ got extinct.'

Resilience in a system is the ability to absorb shocks and to retain the same structure functions and feedback as before. It implies persistence, adaptability, transformability of the system. It requires a wide basin of attraction, a good balance between order and disorder. Essential to resilience is the presence of negative feedback loops.

Dr. Walker argues that one should manage feedbacks to reach resilience. You lose your feedback, you lose resilience. The essence of resilience is then to understand the feedbacks in the system that keep it self-organized, stable, robust.

SYSTEM FRAGILITY: DISEASE IS THE CURE

"The more efficient a market is, the less resilient it becomes.
When a system is tight in all directions, it loses the ability to learn, it becomes brittle."
Roland Kupers, Resilience Action Initiative

"The disease is due to a deficiency of force.
The disease is the body's attempt to cure itself.
The disease is the cure.
It's a healing process."
Dr Isaac Jennings, founder of philosophy of natural hygiene

"If you never burn a forest the species in there who are capable of putting up with fire eventually go out-competed; the only way to make a forest resilient to fire is to burn it.
The only way to make children resilient to the environment is to expose them to it ['sheltered kids do not make for capable adults' Lythcott-Haims].
Resilience is maintained by probing the boundaries of the basin, otherwise the basin becomes smaller and smaller.
That's how the body maintains a body temperature of 38 degrees (at 41 you die). We had 10 million years to develop the feedbacks we needed to adapt. Our earlier versions extinguished / got extinct."
Brian Walker, Stockholm Resilience Centre

11

What Can Be Learned From Nature

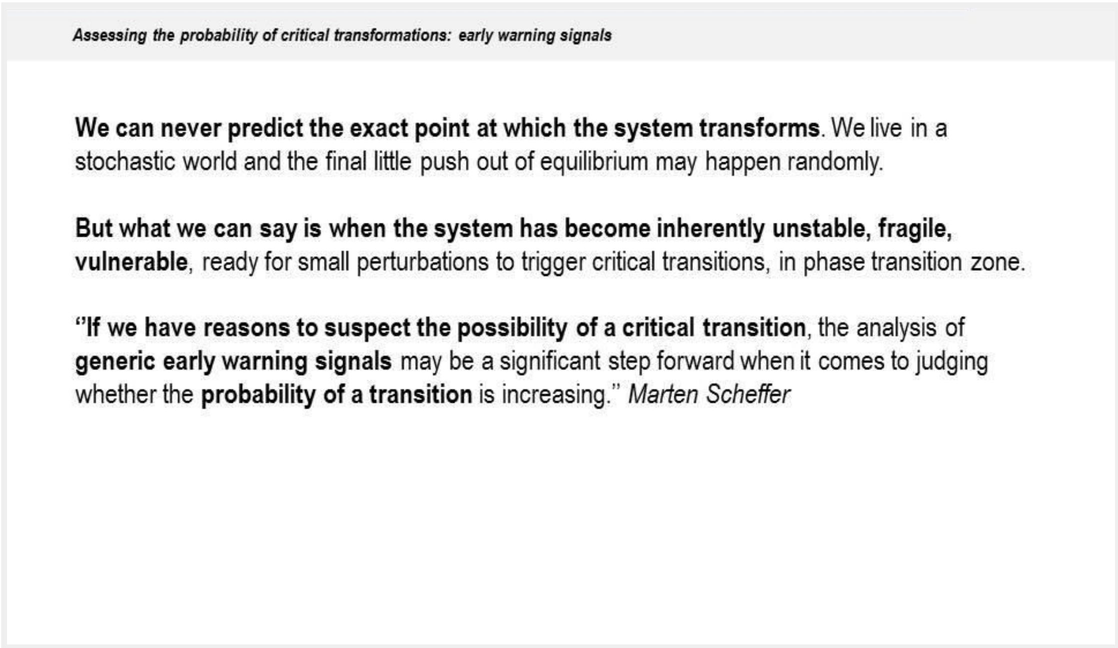
On the contrary, **positive feedback loops are amplifiers**, or amplifying loops, as they exacerbate a particular set of conditions of a system. As such, **they can ultimately be harmful, and lead to an unstable balance, towards a critical tipping point**.

At the edge of chaos, a shift in feedback loops provokes a proximity to one or more critical tipping points. This is the zone where rare events become typical.

Assessing the probability of Critical Transformations: Early Warning Signals

We can never predict the exact point at which the system transforms. We live in a stochastic world and the final little push out of equilibrium may happen randomly. **But what we can say is when the system has**

become inherently unstable, fragile, vulnerable, ready for small perturbations to trigger critical transitions, in phase transition zone. If we have reasons to suspect the possibility of a critical transition, the analysis of generic early warning signals may be a significant step forward when it comes to judging whether the probability of a transition is increasing.



How Probable is a Major Gap Risk

Edge of Chaos, Positive Feedback Loops and Financial Markets

In conclusion of the introductory theoretical section, it can be argued that **the dynamics of positive feedback loops acting on an unstable equilibrium at the edge of chaos are one likely precursor of a regime shift. Sooner or later, at some critical tipping point in close reach.**

And this is where we move the attention to today's financial markets…

7. Financial Markets as 'Complex Adaptive Systems'

The analytical tools of 'complexity theory' can be used to understand phenomena as diverse as biological ecosystems, climate change, forests, lakes, brain and … financial markets. Features typical of complex systems include the broad inter-connectedness of global markets - only increased with globalization, the vast network of factors at play, the flipping correlation between assets over time, the non-linear relationship between the various elements in the system. The endogenous crises, broad discontinuities and sudden ruptures experienced by financial markets over history also do resemble far-from-equilibrium phenomena in complex systems.

'Complex means non-linear, as there is more in them than purely direct relationships of cause and effect, showcasing deterministic chaos. Adaptive means evolving, dynamical. In ecosystems species evolve, in financial systems people will change their behavior. Systems mean very broad, operating over a range of scales', in the words of Dr Walker.

Financial markets share the three characteristics of complex dynamical systems, as defined by the Stockholm Resilience Centre: (i) **highly unpredictable**, due to their non-linear relationships / interactions, it is hard to say what the state of the system might be some time in the future. (ii) **contagio effect**, things can spread very quickly and (iii) **modularity**, although the whole system is well connected parts of the system are more connected within than between, which may help its **resilience**, or the ability for the system to return to equilibrium after turbulence.

In a military parlance later adopted by the business world, **financial markets are typical VUCA, an acronym which stands for Volatility, Uncertainty, Complexity, Ambiguity: they are interconnected, interdependent, non-linear and a structurally volatile complex system.** In markets is visible the non-linear interactions between the elements in the complex system, as they co-evolve over time to adapt to local events.

Positive Feedback Loops in Finance

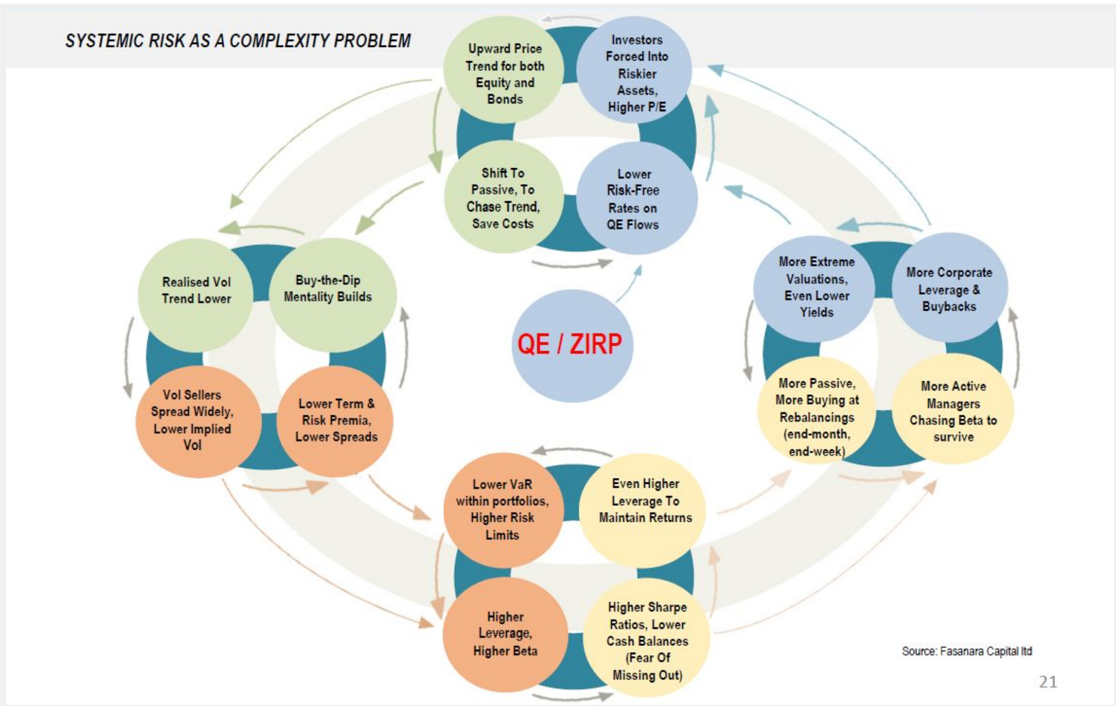
As we learn in complexity theory, resilience is lost when positive feedback loops arise and are held constant for long enough, while at the edge of chaos. Then, it becomes more probable to be nearing critical thresholds for transformation. **The biggest change in markets over the last few years has been exactly that: the formation of positive feedback loops between QE/NIRP policies and the private investment community**. Private flows followed public flows, exacerbating valuations, leverage, debt levels, concentration of positions, correlation amongst strategies, life-dependence on low levels of volatility. Economic narratives built at the margin helped the shift (chasing yields, chasing growth, chasing reflation, chasing earning, chasing global synchronized growth, chasing 4th Industrial Revolution), but flows were the real key driver. **The structure of the market itself morphed, and is now dominated by passive or quasi-passive investors**, that incorporated the 'trend factor' or the 'volatility factor' within their constructs.

Multiple years of monumental **Quantitative Easing ('QE') / Negative Interest Rates Policy ('NIRP')** affected the behavioral patterns of investors and **changed the structure itself of the market**, in what accounts as **self-amplifying positive feedbacks**. Fake markets, where artificial money flows killed data dependency, affected market functioning and changed the structure itself of the market (May 2017). The positive feedback loop between fake markets and investors created system instability, and divergence from equilibrium (July 2017). That is the under-explored, unintended consequence of extreme monetary policymaking. A jammed-up, stuffed-turkey market system, where it is easy to detect heavy concentration risks, all the while as its size (i.e. valuations across both equities and bonds) got ginormous.

Here below we display the Tree of Feedback Loops, a visualization attempt to expose the various and interacting feedback loops at work across the market system. This is just an example of interactions across the market system of the numerous players involved, and the nodes across which the initial wave of extreme monetary policy propagates across the network.

This is the story of how public flows (in the form of QE/NIRP) are amplified/leveraged by private and passive flows – to become much bigger than you ever thought.

Bonds are manipulated - everybody knows it as a fact of life, being them a direct target of QE. Yet when it comes to equities, narratives prevent from recognizing manipulation, as dust in the eyes of market watchers and practitioners. The king is naked, but a magic spell makes viewers blind and deaf to reality. Number crunching (in the form of historically grounded valuation metrics) is replaced by easy economic narratives, elusive and over-fitting.



The Tree Of Positive Feedback Loops

The aspect of today's markets that should worry the most, is the one-sided risk of the investor community, long-only, fully invested, short volatility, short convexity. Years of monumental monetary printing rescued markets at every minor turn and ingrained a buy-the-dip mentality in the investment community which is now reflected in the structure of the market itself. The shift from active managers to passive managed ETFs in past years (for over $4trn now) is only the tip of the iceberg, and encapsulates the boundary between risk-conscious and risk-insensitive investing, resulting in the clash between under-weighted longs (active managers) and over-performing longs (passive vehicles). Beyond ETFs, other quasi-passive players prosper as they mechanically go long with leverage, follow the trend or sell vol: **the end result is that today it's all one single giant position, and normal 'market risk' itself became 'systemic risk'.**

The structure of markets resembles that of a pressure cooker, owing to the synchronicity of three elements: **massive concentration of passive or quasi-passive players (90% of US daily equity flows), massive concentration in few fund players (top 3 Asset Management shops account for almost $15trn in AUM), massive concentration/correlation of investment strategies (90% are either volatility-linked or trend-linked).**

Positive Feedback Loops create divergence from general equilibrium, and Systemic Risks

Positive feedback loops, in finance like in biology, chemistry, cybernetics, breed system instability, as they orchestrate a **further divergence from equilibrium**. An **unstable equilibrium** is defined as one where a small disturbance is sufficient to trigger a large adjustment.

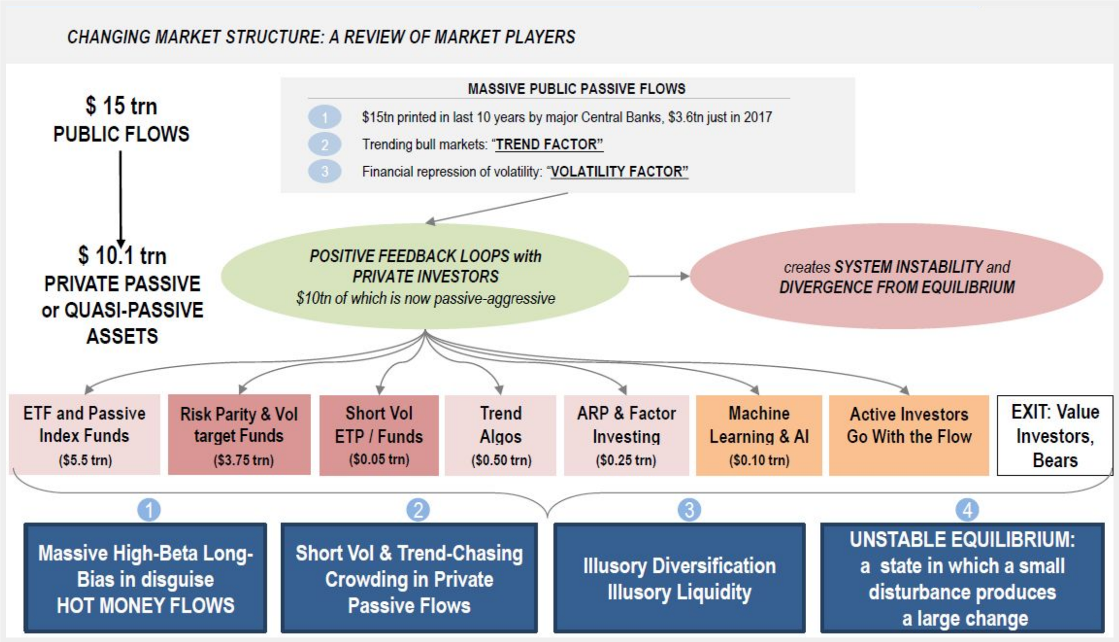
QE and NIRP have two predominant effects on markets: (i) relentless up-trend in stocks and bonds (the 'Trend Factor'), dominated by the buy-the-dip mentality, which encapsulates the 'moral hazard' of investors knowing Central Banks are prompt to come to their rescue (otherwise known as 'Bernanke/Yellen/Kuroda/Draghi put'), and (ii) the **relentless down-trend in volatility** (**the 'Volatility Factor').**

Two Factors Explain All: Trend and Volatility

The most fashionable investment strategies these days are directly impacted by either one or both of these drivers. Such strategies **make the bulk of the overall market, after leverage or turnover is taken into account**: we will refer to them in the following as **'passive' or 'quasi-passive'**. The trend impacts the long-only community, crowning it as a sure winner, making the case for low-cost passive investing. The low volatility permeates everything else, making the case for full-investment and leverage.

The vast majority of investors these days are not independent from the QE environment they operate within: ETFs and index funds, Risk Parity funds and Target Volatility vehicles, Low Volatility / Short Volatility vehicles, trend-chasing algos, Machine Learning-inspired funds, behavioral Alternative Risk Premia funds. They are the poster children of the QE world. **We estimate combined assets under management of in excess of $8trn across the spectrum. They form a broad category of 'passive' or 'quasi-passive' investors,**

as are being mechanically driven by two main factors: trend and volatility.



Positive Feedback Loops

Source: [Fasanara Presentations](#) | Market Fragility - How to Position for Twin Bubbles Bust, 16th October 2017. Updated with new data on 6th January 2018.

Extraordinary monetary policies have feedback loops with the asset management industry as a whole, reinforcing the effects on markets of such policies in a vicious – or virtuous - cycle. QE and NIRP help a large number of investment strategies to flourish, validating their success and supporting their asset gathering in the process, and are in return helped in boosting bond and stock markets by their flows joining the already monumental public flows.

Private flows so reach singularity with public flows, and the whole market economy morphs into a one big common bet on ever-rising prices, in shallow volatility. Here is the story of how $15trn of money printing by major Central Banks in the last ten years, of which $3.7trn in 2017 alone, is joined by total assets of $8trn managed into buying the same safe and risk assets across, with leverage, indiscriminately.

How Market Risk became Systemic Risk

Let's give a cursory look at the main players involved (a recent presentation we did is recorded here). As markets trend higher, no matter what happens (ever against the shocked disbeliefs of Brexit, Trump, an Italian failed referendum and nuclear threats in North Korea), investors understand the outperformance that comes from pricing risks out of their portfolios entirely and going long-only and fully-invested. Whoever under-weighs positions in an attempt to be prudent ends up underperforming its benchmarks and is then penalized with redemptions. Passive investors who are long-only and fully invested are the winners, as they are designed to be bold and insensitive to risks. As Central Banks policies reduce the level of interest rates to zero or whereabouts, fees become ever more relevant, making the case for passive investing most compelling. The **rise of ETF and passive index funds** is then inevitable.

According to JP Morgan, in the last 10 years, $2trn left active managers in equities and $2trn entered passive managers (pag.39 here). We may be excused for thinking they are the same $ 2trn of underlying investors progressively pricing risk provisions out of books, *de facto*, while chasing outperformance and lower fees.

To be sure, ETFs are a great financial innovation, helping reducing costs in an expensive industry and giving entry to markets previously un-accessible to most investors. Yet, what matters here is their impact on systemic risks, via positive feedback loops. In circular reference, beyond Central Banks flows, markets are helped rise by such classes of valuations-insensitive passive investors, which are then rewarded with further inflows, with which they can then buy more. The more expensive valuations get, the more they disconnect from fundamentals, the more divergence from equilibrium occurs, the larger fat-tail risks become.

In ever-rising markets, 'buy-and-hold' strategies may only possibly be outsmarted by 'buy-the-dip' strategies. Whatever the outcome of risk events, be ready to buy the dip quickly and blindly. As more investors design themselves up to do so, the dips are shallower over time, leading to an S&P500 that never lost 3% in 2017, an historical milestone. **Machine learning** is another beautiful market innovation, but what is there to learn from the time series of the last several years, if not that buy-the-dip works, irrespective of what caused the dip. Big Data is yet another great concept, shaping the future of us all. Yet, most data ever generated in humankind dates back three years only, in and by itself a striking limitation. The quality of the deduction cannot exceed the quality of the time series upon which the data science was applied. If the time series is untrustworthy, as is heavily influenced by monumental public flows ($300bn per months), what trust can we put on any model output originating from it? What pattern recognition can we really be hopeful of getting, in the first place? May some of it just be a commercial disguise for going long, selling volatility and leveraging up in various shapes or forms? What is hype and what is real? A short and compromised data series makes it hard, if not possible, to really know. Once public flows abate and price discovery is let free again, then and only then will we be in a position to know the difference.

Low volatility does what trending markets alone cannot. A state of low volatility presents the appearance of stuporous, innocuous, narcotized markets, thus enticing new swathes of unfitting investors in, mostly retail-type 'weak hands'. Weak hands are investors who are brought to like investments by certain characteristics which are uncommon to the specific investment itself, such as featuring a low volatility. It is in this form that we see bond-like investors looking at the stock market for yield pick-up purposes, magnetized by levels of realized volatility similar to what fixed income used to provide with during the Great Moderation. It is in this form that Tech companies out of the US have started filling the coffers of not just Growth ETF, where they should rightfully reside, but also Momentum ETF, and even, incredibly, Low-Volatility ETF.

Low volatility is also a dominant input for **Risk Parity funds** and **Target Volatility vehicles**. The lower the volatility, the higher the leverage allowed in such players, mechanically. All of which are long-only players, joining public flows, again helping the market rise to record levels in the process, in circular reference. Rewarded by new inflows, the buying spree gathers momentum, in a virtuous circle. Valuations are no real inputs in the process, volatility is what matters the most. Volatility is not risk, except for them it is.

It goes further than that. It is not only the level of volatility that count, but its direction too. As volatility implodes, relentlessly, into historical lows never seen before in history, a plethora of investment strategies is launched to capitalize on just that, directly: **Short Volatility vehicles**. They are the best performing strategy of the last decade, by and large. The problem here is that, due to construction, as volatility got to single-digit territory, relatively small spikes are now enough to trigger wipe-out events on several of these instruments. Our analysis shows that if equity volatility doubles up from current levels (while still being half of what it was as recently as in August 2015), certain Short Vol ETFs may stand to lose up to 75% or more. Moreover, short positions on long-vol ETFs can lose up to 250% of capital. For some, 'termination events' are built into contracts for sudden losses of this magnitude, meaning that the notes would be prematurely withdrawn. It is one thing to expect a spike in volatility to cause losses, it is quite another to know that a minor move is all it takes to trigger a default event.

On such spikes in volatility, Morgan Stanley Quant Derivatives Strategy desk warns further that market makers may be forced to rebalance their exposure non-linearly on a spike in volatility. **A drop in the S&P 500 of 5% in one day may trigger approximately $ 400mn of Vega notional of rebalancing** (pag.48 here). We estimate that **half a trillion dollars of additional selling on S&P stocks may occur following a correction of between 5% and 10%.** That is a lot of selling, pre-set in markets, waiting to strike. Unless you expect the market to not have another 5% sell-off, ever again.

It's All One Big Position

What do ETFs, Risk Parity and Target Vol vehicles, Low Vol / Short Vol vehicles, trend-chasing algos, Machine Learning, behavioral Alternative Risk Premia, factor investing have in common? Except, of course, being the 'winners take all' of QE-driven markets. They all share one or more of the following risk factors: **long-only, fully invested when not leveraged-up, short volatility, short correlation, short gamma**. **Thanks to QE and NIRP, the whole market is becoming one single big position.**

The 'Trend Factor' and the 'Volatility Factor' are over-whelming, making it inevitable for a high-beta, long-bias, short-vol proxy to disseminate across. Almost inescapably so, given the time series the asset management industry has to deal with, and derive its signals from.

Several classes of investors may move to sell in lock-steps if and when markets turn. The boost to asset prices and the zero-volatility environment created the conditions for systemic risks in the form of an over-compensation to the downside. Record-low volatility breeds market fragility, it precedes system instability.

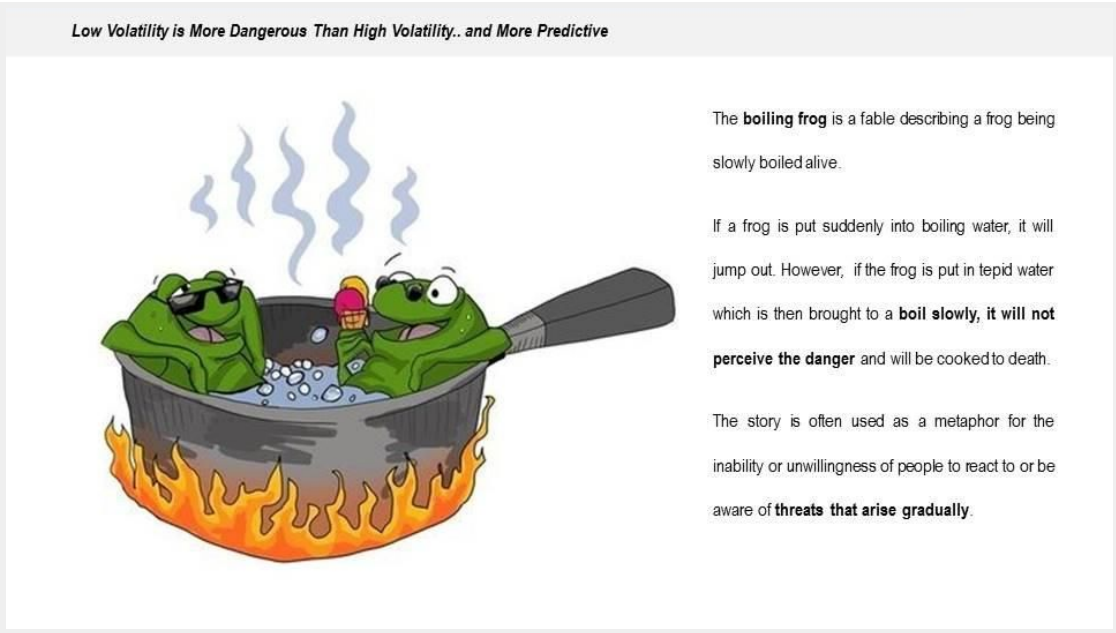
Flows Matter, Both Ways!

We will know soon if the fragility of markets is that bad. The undoing of loose monetary policies (NIRP, ZIRP) will create a liquidity withdrawal of over $1 trillion in 2018 alone (pag.61-62 here). **The reaction of the passive and quasi-passive communities will determine the speed of the adjustment in the pricing for both safe and risk assets, and how quickly risk provisions will re-enter portfolios.** Such liquidity withdrawal will represent the first real crash-test for markets in 10 years.

As public spending on Wall Street abates, the risk is evident of seeing the whole market turning with it. The shocks of Trump and Brexit did not manage to derail markets for long, as public flows were overwhelming. Flows is what mattered, above all elusive, over-fitting economic narratives justifying price action at the margin. **Flows may matter again now as they fade**.

Boiling Frogs

In many ways, positive feedback loops are synonyms to market complacency and help asset volatility go lower. The loss in resilience for the system is then a similar concept to what hypothesized by economist Hyman Minsky: 'stability is destabilizing'. In his "Financial Instability Hypothesis" in 1977, he analyzed the behavioral changes induced by a reduction of volatility, postulating that economic agents observing a low risk are induced to increase risk taking, which may in turn lead to a crisis: "the more stable things become and the longer things are stable, the more unstable they will be when the crisis hits."



Low Volatility and Boiling Frogs

8. Positive Feedback Loops and Financial Instability: The Blind Spot of Policymakers

A Dangerous Market Structure is More Worrying than Expensive Asset Valuations and Record Debt Levels

Macro-prudential regulations follow financial crises, rarely do they precede one. Even when evidence is abundant of **systemic risks building up,** as is today, regulators and policymakers have a marked tendency to turn an institutional blind eye, hoping for imbalances to fizzle out on their own – at least beyond the duration of their mandates. It does not work differently in economics than it does for politics, where short-termism drives the agenda, oftentimes at the expenses of either the next government, the broader population or the next generation.

It does not work differently in the business world either, where corporate actions are selected based on the immediate gratification of shareholders, which means pleasing them at the next round of earnings, often at the expenses of long-term planning and at times exposing the company itself to disruption threats from up-and-comers.

Long-term vision does not pay; it barely shows up in the incentive schemes laid out for most professions.

Economics is no exception. Orthodoxy and stillness preserve the status quo, and the advantages hard earned by the few who rose from the ranks of the establishment beforehand.

Yet, when it comes to Central Banking, and more in general policy making, financial stability should top the priority list. It honorably shows up in the utility function, together with price stability and employment, but is not pursued nearly as actively as them. Central planning and interventionism is no anathema when it comes to target the decimals of unemployment or consumer prices, yet is residual when it comes to master systemic risks, relegated to the camp of ex-post macro-prudential regulation. This is all the more surprising as we know all too well how badly a deep unsettlement of financial markets can reverberate across the real economy, possibly leading into recessions, unemployment, un-anchoring of inflation expectations and durable disruption to consumer patterns. There is no shortage of reminders for that in the history books, looking at the fallout of deep dives in markets in 1929, 2000 and 2007, amongst others.

Intriguingly, the other way round is accepted and even theorized. Manipulating bond and stock prices, directly or indirectly, is mainstream policy theory today. From Ben Bernanke's 'portfolio balance channel theory', to the relentless pursuit of the 'wealth effect' via financial repression under Janet Yellen and Haruhiko Kuroda, to Mario Draghi tackling the fragmentation of credit markets across the EU via direct asset purchases, the practice has become commonplace. To some, like us, the 'wealth effect' may be proving to be more of an 'inequality effect' than much, leading to populism and constantly threatening regime change, but that is beyond the scope of this note today.

What we want to focus on instead is the direct impact that monetary interventionism like Quantitative Easing ('QE') and Negative or Zero Interest Rate Policies ('NIRP' or 'ZIRP') have on the structure of the market itself, how they help create a one-sided investment community, oftentimes long-only, fully invested when not levered up, relying on record-highs for bonds and stocks to perpetuate themselves endlessly - despite a striking disconnect from fundamentals, life-dependent on the lowest levels of volatility ever seen in history. The market structure morphed under the eyes of policymakers over the last few years, to become a pressure cooker at risk of blowing-up, with a small but steadily growing probability as times goes by and the bubble inflates. **The positive feedback loops between monetary flooding and the private investment community are culpable for transforming an ever present market risk into a systemic risk, and for masking as peaceful what is instead an unstable equilibrium and market fragility.**

Systemic Risk is Not Just About Banks: Look at Funds

The **role of trending markets** is known when it comes to systemic risks: a not sufficient but necessary condition. Most trends do not necessarily lead to systemic risks, but hardly systemic risks ever build up without a prolonged period of uptrend beforehand. Prolonged uptrends in any asset class hold the potential to instill the perception that such asset class will grow forever, irrespective of the fundamentals, and may thus lead to excessive risk taking, excess leverage, the formation of a bubble and, ultimately, systemic risks. The mind goes to the asset class of real estate, its undeterred uptrend into 2006/2007, its perception of perpetuity ("we have never had a decline in house prices on a nationwide basis" Ben Bernanke), the credit bubble built on banks hazardous activities on subprime mortgages as a result, and the systemic risks which emanated, with damages spanning well beyond the borders of real estate.

The **role of volatility** is also well-researched, especially low volatility. Hayman Minsky, in his "Financial Instability Hypothesis" in 1977, analyses the behavioral changes induced by a reduction of volatility, postulating that economic agents observing a low risk are induced to increase risk taking, which may in turn lead to a crisis: "stability is destabilizing". In a recent study, Jon Danielsson, Director of the Systemic Risk Centre at the LSE, finds unambiguous support for the 'low volatility channel', insofar as **prolonged periods of low volatility have a strong predictive power over the incidence of a banking crisis, owing to excess lending and excess leverage**. The economic impact is the highest if the economy stays in the low volatility environment for **five years**: a 1% decrease in volatility below its trend translates in a 1.01% increase in the probability of a crisis. He also finds that, counter-intuitively, **high volatility has little predictive power**: very interesting, when the whole finance world at large is based on retrospective VAR metrics, and equivocates high volatility for high risk.

Both a persistent trend and prolonged low-volatility can lead banks to take excessive risks. But what about their impact on the asset management industry?

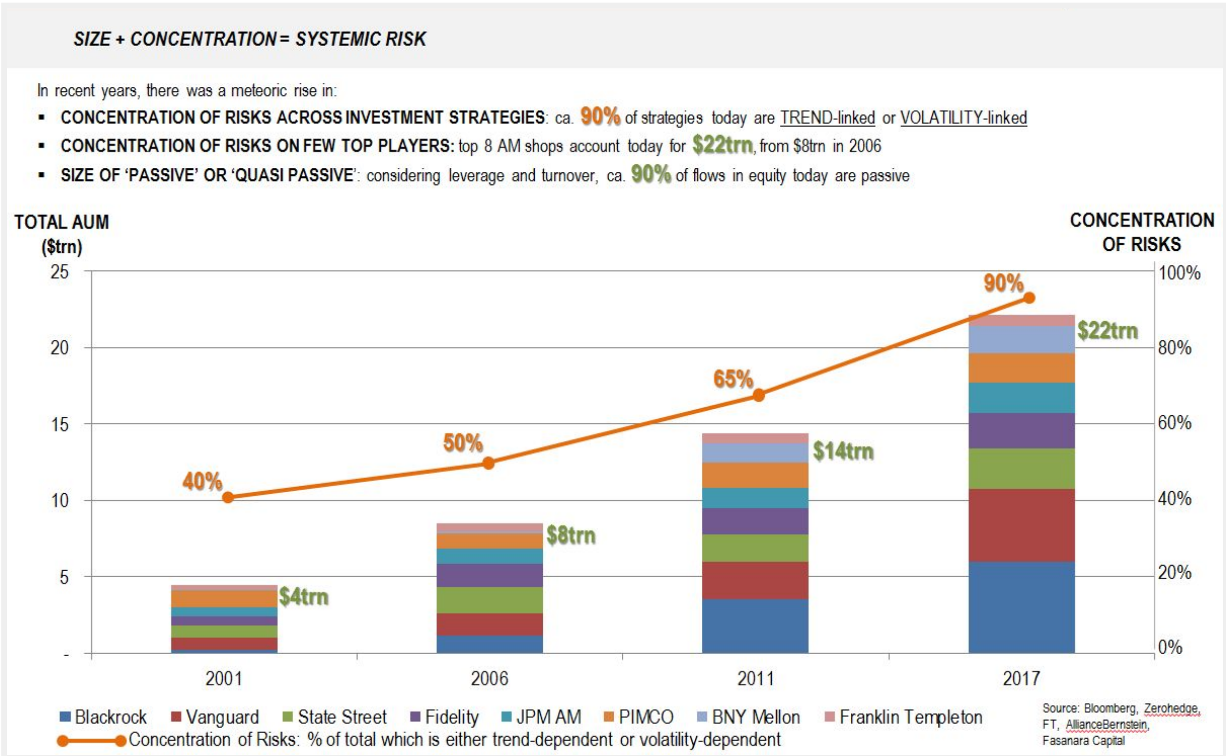
Thinking at the hard economic impact of the Great Depression (1929-1932) and the Great Recession (2007-2009), and the eminent role played by banks in both, it comes as little surprise that the banking sector captures all the attention. However, what remains to be looked into, and **perhaps more worrying in today's environment, is the role of prolonged periods of uptrend and low-vol on the asset management industry**.

In 2014, the Financial Stability Board (FSB), an international body that makes recommendations to G20 nations on financial risks, published a consultation paper asking whether fund managers might need to be designated as "**global systemically important financial institution**" or G-SIFI, a step that would involve greater regulation and oversight. It did not result in much, as the industry lobbied in protest, emphasizing the difference between the levered balance sheet of a bank and the business of funds.

The reason for asking the question is evident: (i) **sheer size**, as the AM industry ballooned in the last few years, to now represent over [15trnXX] for just the top 5 US players!, (ii) funds have partially **substituted banks** in certain market-making activities, as banks dialed back their participation in response to tighter regulation and (iii) , funds can indeed do damage: think of **LTCM** in 1998, the fatal bailout of two Real Estate funds by **Bear Stearns** in 2007, the **money market funds 'breaking the buck'** in 2008 amongst others.

But it is not just sheer size that matters for asset managers. What may worry more is the **positive feedback loops** discussed above and the resulting **concentration of bets in one single global pot**, life-dependent on infinite momentum/trend and ever-falling volatility. **Positive feedback loops are the link for the sheer size of the AM industry to become systemically relevant. Today more than ever, they morph market risks in systemic risks.**

Volatility will not forever be low, the trend will not forever go: how bad a damage when it stops? As macro prudential policy is not the art of "whether or not it will happen" but of "what happens if", it is hard not to see this as a blind spot for policymakers nowadays.



Systemic Risk: Funds, Not Just Banks

The addiction that could not be let go

In conclusion, we believe that markets are being brought into an **unstable equilibrium, at risk of snapping violently**. The stability of markets resembles the one of a **pendulum held in vertical position**: a small disturbance is able to create large swings. The swing can be so violent as to send tremors across the real economy, thus jeopardizing the hard earned progress on recovery in growth rates and unemployment of recent years. If positive feedback loops are ignored and bubbles are left unchecked, that may one day most unambiguously qualify as a policy mistake: the addiction to monetary steroids and price control that could not be let go, on time. A bust that was entirely predictable, if only macropru conditions had been a real target, and short termism had not prevailed.

9. Financial Markets are on the 'Edge Of Chaos'

When analyzed through the prism of complexity theory, **today's markets exhibit the signatures characteristic of criticality, lack of resilience, flipping feedback loops and likely proximity to critical tipping points**. In other terms, markets are unstable, while stationing on the edge of chaos.

Such signatures characteristics include:

(i) **Extreme valuations.** Asset markets have reached bubble valuations, which are disconnected to fundamentals by a magnitude never seen before in modern financial history, when judged against **most valuation metrics ever used**: Shiller CAPE, the 'Buffett Indicator' market cap on GDP, the median debt on total assets, the corporate debt to GDP, the price on sales, the price to book, enterprise value on sales, enterprise value on EBITDA, financial assets on disposable income (we discussed it recently in this podcast). The disconnect itself is such that the speed of adjustment for valuations may catch investors by violent surprise, when the time comes.

(ii) **Extreme valuations for bonds and equities simultaneously, now unable to hedge one another**. This is a striking difference to previous big equity market crashes (2008, 2000, 1987, 1929 amongst others). Viewed as different modules within a complex system (modularity of the system), back then the rally in bonds helped healing losses on equities, in a sort of negative feedback loop, offering a form of resilience to investors, mostly exposed through balanced portfolios. From here, **if equities gap down, it will be a rare moment in history when bonds cannot help, and flight to quality** (a self-stabilizing force within the system) **is impaired.**

(iii) **Patterns of correlation between major asset classes**. Bonds and equities have been negatively correlated in the last few decades. From here on, they are likely to be positively correlated. A change in correlations in major asset classes is worth watching in a complex system held at the edge of chaos.

(iv) **Inability for valuations on Bonds to progress much from here**, mathematically, due to **zero-bound on interest rates**. This shows a lack of capacity for the recent trend to advance. Rephrased in the context of complexity theory, the basin of attraction is not as steep as before.

(v) A **long list of anomalies in valuations globally** may point to a limited scope left for the perpetuation of the linear trend. The list includes certain European BBB-rated bonds trading at negative yields, loans being covenant-lite for 70% of the total across Europe and the US, a suppressed volatility in the face of a VUCA world, 2yr Greek bonds, EU Junk Bonds and Russia USD bonds all trading at yields below US Treasuries of comparable maturities, US equity valuations at all-time highs when compared to trend growth (please refer to 'A Long List Of Anomalies', pages 23-52, of our Investor Presentation).

(vi) **Extreme indebtedness** and closeness to BIS' debt saturation / Rogoff's debt tolerance limits / Minsky Moment for several subsets within the system, despite the record-low interest rates available to service such debt (China, Turkey, Italy, Japan). The falling productivity of new credit lending (decreasing marginal effectiveness of lending) is visibly at play. Rephrased in the context of complexity theory, the basin of attraction is not as steep as before.

(vii) **Extreme leverage to buy financial assets**. Amongst others, NYSE leverage is at all-time highs. After a long trip up the basin of attraction.

(viii) **Extreme monetary policymaking** brought the cost of capital close to zero, depriving the system from resilience through preservation of so-called 'zombie companies' and other mis-allocation of resources.

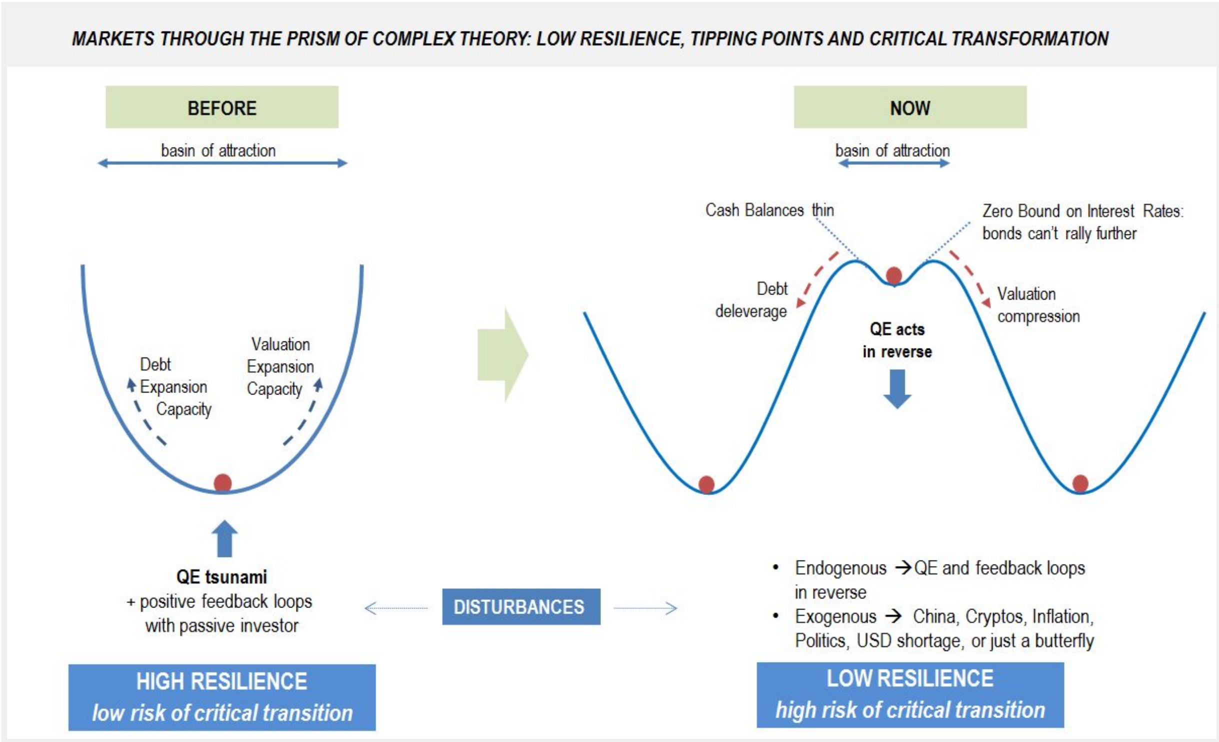
(ix) **Extreme monetary policymaking created correlation across most investment strategies and concentration of positions**. Financial markets are no longer a marketplace where buyers and sellers meet for exchange, but rather a platform where buyers line-up for allocation. Value investors and other active players incorporating risk provisions within portfolio underperformed passive / fully invested players, and got out-selected in the evolution of the last decade of market action. With them, the system is losing self-stabilising forces, unwilling to buy without merit and therefore preventing price action from becoming senseless. In complexity theory terms, negative feedback loops flipped into **positive feedback loops** in recent times, creating a singularity between public and private flows in hovering up assets, price-insensitively, through one-sided regular flows. Examples of positive feedback loops in today's financial markets are discussed in our previous notes here, here, here, here. The change in feedback loops is the biggest change of recent times, in our opinion, in relation to systemic risk, and caused the likely nearing of critical thresholds for large transformation.

(x) **Changing structure of markets.** The rise of passive strategies / ETFs relates to the price-insensitivity of today's markets. The correlation amongst investment strategies created crowding around two main style factors: 'trend factor' and 'volatility factor'. The effects of a loss of momentum or a spike in volatility would then quickly disseminate across the industry. No diversification means no resilience.

(xi) **Cash balances running thin.** Most institutional investors are all-in, invested between 90% and 100%. Limited scope for further valuation expansion. Rephrased in the context of complexity theory, the basin of attraction is not as steep as before.

(xii) **Quantitative Easing has passed its peak**, which was in mid-2017, and is now going in reverse. It is believed to be an active tool in the hands of Central Banks, although capacity constraints are known (capital key in Europe, negative rates on Bunds etc.), unintended consequences (zombie companies let to live and saturate the system blocking the rise of newcomers), political instability and populism (critical income inequality). **A tipping point may be already in. Surely, they just rolled over from peak. Although it is not widely perceived, year 2017 marked the peak in Quantitative Easing, at $3.7trn of asset purchases, for a monthly average of approx. $300bn. Such money printing will fast descend over the course of 2018, to go below $20bn** per month by December 2018**. As this liquidity tide goes off, we expect markets to face their first real crash test in 10 years. Only then will we know what is real and what is not in today's markets, only then will we be able to assess how sustainable is the global synchronized GDP growth spurred by global synchronized monetary printing.

(xiii) **Volatility: both a tipping point and a domino effect are in reach**. It can't go negative; most of the move is past us. Meanwhile, lower Value-at-Risk metrics pulled swathes of risk-averse investors in, like fisheries in the net, at the mercy of the next turbulence in markets. Vast amounts of capital are either directly or indirectly linked to volatility. A rise in volatility would push through de-leverage and de-risking for VAR-based investors. In addition, as predicted in mid-2017, certain strategies were indeed wiped-out for minor moves higher in volatility ('the XIV ETP will run into early termination when VIX crosses 20').



Markets On The Edge Of Chaos

Source: Fasanara Capital ltd

The list can be longer, but it does not need to be any longer to draw conclusions on the sustainability of the current setting. If **unsustainable and unstable**, a transformation may loom ahead. How severe a transformation depends on how big an anomaly was built beforehand. From the look of things, the anomaly is bigger than at any point in history, thus making the potential shift potentially large and disruptive.

On the edge of chaos, it does not take much to flip, no need for a major catalyst. The flapping of a butterfly's wings may do. As we heard in a recent show: 'remember: it was not Holyfield or Lewis to knock

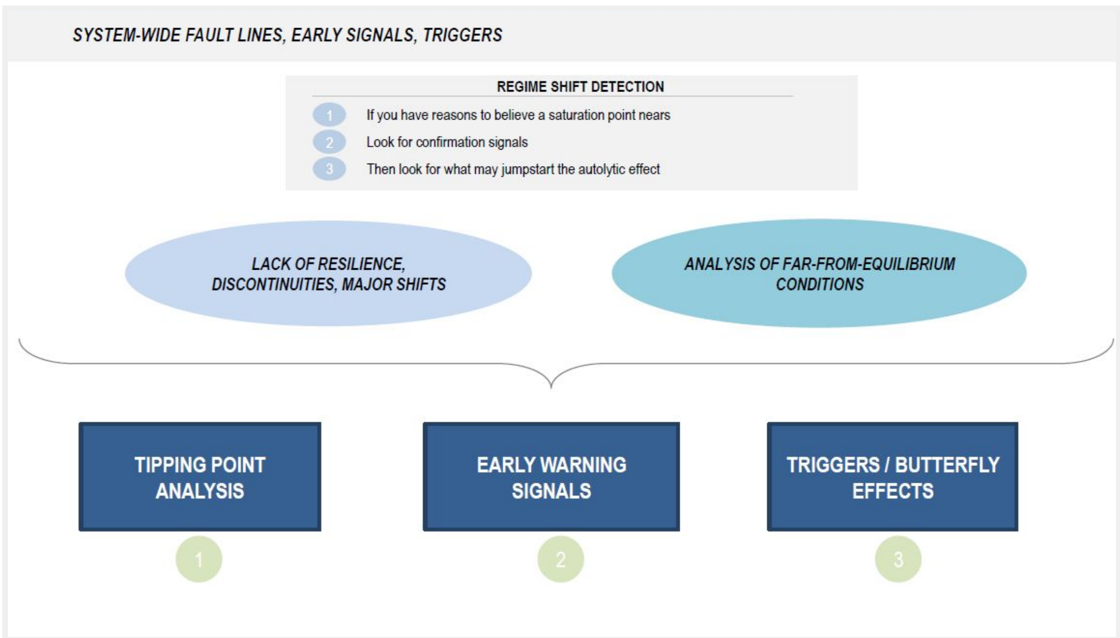
Tyson out in 1990, but Buster Douglas. A mostly unknown, to remain unknown, second-tier boxer. It doesn't take much to take you down when your time is up.'

If this analysis is correct, and **tipping points are near**, markets are in an uncomfortable spot, where not much escape is available via new lending, not much escape via higher valuations, not much escape with new QE, not much escape with more leverage, not much escape with more cash to deploy. **No escape, no further rise does not necessarily imply a crash. However, treading water on the edge of chaos is dangerous, as any small perturbations can trigger a critical transformation. An exogenous or endogenous trigger can easily push the equilibrium out of its small basin of attraction. A new equilibrium may be waiting to assert itself, nearby, through chaos**.

At the edge of chaos, a shift in feedback loops provokes a proximity to one or more critical tipping points. This is the magic zone where rare events become typical.

10. Framework of analysis for 'Complex Markets': how to embed the Dynamics of Criticality

Here we propose a framework of analysis for '**Complex Markets**', looking at systemic risk in financial markets as a complexity problem: slide 14). Our analysis points to high alert for systemic risk, and the increasing probability of an impending market crash.



Tipping Points, Crash Hallmarks, Butterflies

The framework consists of three modules.

i. **TIPPING POINT ANALYSIS**: it shows that enough is enough, points to abundance of systemic risks, unstable equilibrium and market fragility. Fault lines in the system, tightness in capacity constraints and their synchronicity. Our thoughts are expanded in this video slideshow.

ii. **EARLY WARNING SIGNALS ANALYSIS**: if you have reasons to believe that a cliff is approaching, you then look for confirmation signals, or **crash hallmarks**. Many are in sight today! Frequency of VAR shocks/pressure points, 'critical slowing down', 'flickering', autocorrelation, skewness of fluctuations are all general properties of systems in phase transition zone (be it a natural ecosystem, a fishery, or a financial market). **The analysis of Early Warning Signals** (slide 30) **confirms the increasing likelihood of severe market ruptures**.

iii. **BUTTERFLIES ANALYSIS**: If so, you should look for triggers. Normally a fragile system can run into disorder for small changes in initial conditions, the so-called butterfly effects. Here though, more than butterflies, you see ''elephants'', as risk are all too evident and tangible: slides 61-66.

The framework lies on a key rule in complex theory: not one single trigger, no linear cause and effect relationships only. Human brain tends to look for one single cause, forgetting the system as a whole. Analogically, Tyson lost not to Buster Douglas, but when he was ready to go; likewise, subprime mortgages in 2007 were there, but the system was ready to transition beforehand, that was just the trigger jumpstarting the autolytic reaction function and chain effect. When the system is tight in all directions of potential expansion, hitting capacity constraints in synchronicity, it becomes brittle, it is acting weirdly, ready to snap.

Tipping Point Analysis ('TPA')

What are the Tipping Points for Critical Transformation in Finance? We know that the system is fragile, on the Edge of Chaos, when it became brittle, with little buffers, little redundancy mechanism left, in non-equilibrium or unstable equilibrium. It typically happens when the system is tight in all directions of potential expansion. In market parlance, a severe shift occurs when the bubble cannot expand any further with ease, and decelerates its expansion, as it runs progressively out of fuel.

The reason why the market is prone to an historical downfall is to be found in the synchronicity of capacity constraints across the several dimensions of market expansion:

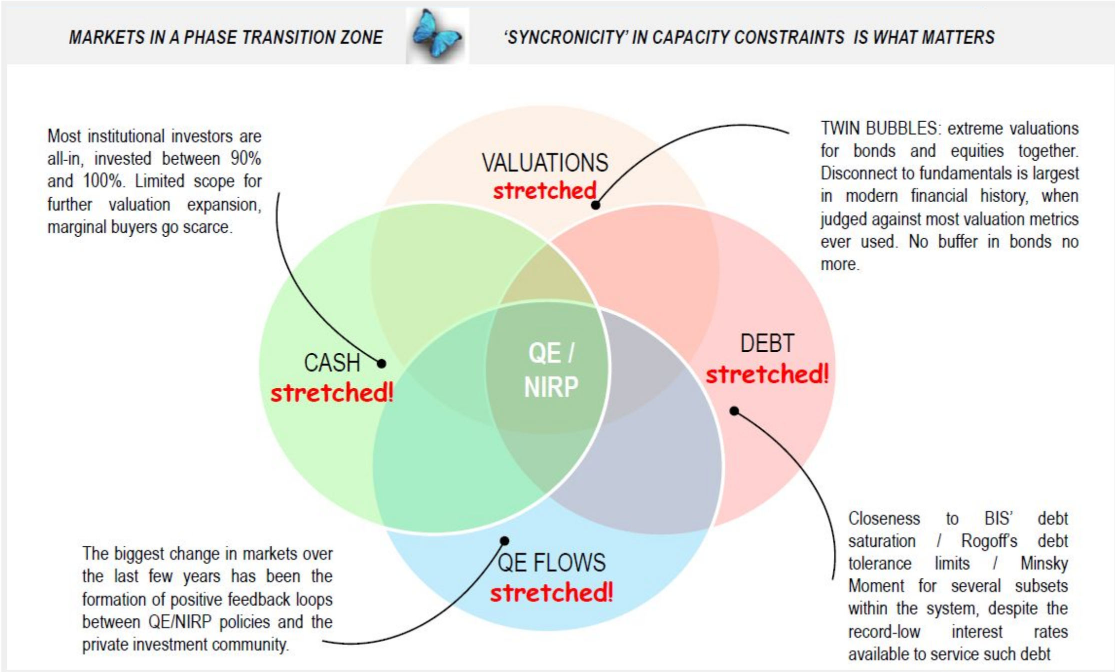
- **Size of 'passive' or 'quasi passive'**: considering leverage and turnover, ca. 90% of daily flows in equity today are passive, the **largest amount of passive** as % of daily trading - don't ask for mercy when the tide turns. Market structure is inflammable, as passive and quasi-passive have dynamically adapted to the local environment of QE-sedated price dynamics across major equity markets and

NIRP-impaired price discovery across major bond markets (S&P/Nasdaq and EU/Japan government bonds in particular).

- **Crowding on few stocks:** approx. 80% of index performance in 2018 is due to 3 stocks only. Additionally, a handful of tech stocks – so-called 'market darlings' - are disseminated across the vast majority of passive and active investment instruments.
- **Correlation of risks across investment strategies:** approx. 90% of investment strategies is doing the same thing in being either TREND-linked or VOLATILITY-linked
- **Concentration of size on few top players**: top 8 AM shops account today for $22trn, from $8trn in 2006. A massive concentration in managers sees the first 3 asset managers globally controlling a mind-blowing USD 15 trillions (at more than 20 times the entire market cap of several G20 countries)
- The **biggest long position** in the history of equity, bond and credit markets
- The **largest amount of financial leverage** to buy assets as % of GDP. The largest indebtedness in public debt for some of the largest G10 countries in decades as % of GDP. The **smallest saving rates** for US households in decades. The **worst debt metrics** for Corporates in a decade.
- The **biggest short-vol position** in the history of markets, directly and indirectly, across equity, bonds, credit
- The **most evanescent liquidity**: several studies have identified the market fragility as market makers and passive players left the market during recent periods of stress, with the result of bid-offers blowing out and liquidity drying all up at the same time.
- The largest amount of central bank interventionism as % of GDP
- Now soon the **largest Quantitative Tightening** in history

All at the same time. The synchronicity, more than any one factor taken in isolation, is the recipe for severe gap risks, as Complexity Theory teaches.

Years of monumental **Quantitative Easing / Negative Interest Rates** monetary policy affected the behavioral patterns of investors and changed the structure itself of the market, in what accounts as **self-amplifying positive feedbacks**. The **structure of the market** moved into a **low-diversity trap**, where concentration risks of various nature intersect and compound: The **morphing structure of the market**, under the unequivocal push of QE/ZIRP new-age ideologism, is the driver of a **simultaneous overvaluation for Bonds and Equities (Twin Bubbles) which has no match in modern financial history**, so measured against most valuation metrics ever deemed reputable; a condition which further compounds potential systemic damages. The market has lost its key function of price-discovery, its ability to learn and evolve, its inherent buffers and redundancy mechanisms: in a word, **the market lost its 'resilience'**. It is, therefore, prone to the dynamics of criticality, as described by Complexity Science in copious details. This is the **under-explored, unintended consequence of extreme experimental monetary policymaking**. A far-from-equilibrium status for markets is reached, a so-called unstable equilibrium, where System Resilience weakens and **Market Fragility approaches Critical Tipping Points**. A small disturbance is then able to provoke a large adjustment, pushing into another basin of attraction altogether, where a whole new equilibrium is found. In market parlance, more prosaically, **a market crash is incubating - and has been so for a while**. While it is impossible to determine the precise threshold for such critical transitioning within a stochastic world, it is very possible to say that we are already in such phase transition zone, where markets got inherently fragile, poised at criticality for small disturbances, and where it is increasingly probable to see severe regime shifts.



Tipping Points Analysis: Market System is Tight in All Directions

Early Warning Signals Analysis ('EWSA')

We can never predict the exact point ..

Assessing the probability of critical transformations: early warning signals

We can never predict the exact point at which the system transforms. We live in a stochastic world and the final little push out of equilibrium may happen randomly.

But what we can say is when the system has become inherently unstable, fragile, vulnerable, ready for small perturbations to trigger critical transitions, in phase transition zone.

"If we have reasons to suspect the possibility of a critical transition, the analysis of **generic early warning signals** may be a significant step forward when it comes to judging whether the **probability of a transition** is increasing." *Marten Scheffer*

How Probable is a Major Gap Risk

The list of crash hallmarks and early warning signals for market fragility is long and getting longer. On accounts of our framework of analysis looking at systemic risks as a complexity problem, we can isolate the following line items:

- **CRITICAL SLOWING DOWN:** The **rate of recovery** rate **after a small perturbation is reduced, and will approach zero when a system moves towards a catastrophic bifurcation point (less slope of basin of attraction).** The difference between now and the fast recoveries of Oct14, Aug15, Jan16, Trump, Brexit may be informative. Calls for further investigation.
- **VARIANCE:** 1) Volatility had already bottomed out 9 months ago; 2) Volatility rising with market in January; 3) Volatility still not reflected in longer expiries and other asset classes. **As a bifurcation approaches (eigenvalue zero), the impact of shocks do not decay, and their accumulating effect increases the variance of the state variable**
- **CORRELATION / AUTOCORRELATION**: 1) Correlation across asset classed increases at times of systemic risk. 2) Increase in autocorrelation, the memory of the system increases , the **state of the system** at any given moment becomes **more and more like its past state**
- **SKEWNESS OF FLUCTUATIONS:** The **asymmetry of fluctuations** may increase. Rates of recovery are lower. As a result, **the system will tend to stay in the vicinity of the unstable point relatively longer** than it would on the opposite side of the stable equilibrium. Vicinity to 200-days MA may qualify.
- **FLICKERING / Bi-Modality: In the vicinity of a catastrophic bifurcation, the system goes back and forth between the basins of attraction of two alternative attractors**. Such behavior is also considered an early warning. **rapid alternations between a cold mode and a warm mode are typical in climate changes over history. In epileptic seizures, smaller transient excursions in the vicinity of an alternative state** precede the upcoming **major shift**. Call them 'EARLY TREMORS'. Violent rallies seen in bear market about to crash, may qualify.
- **POCKETS OF STRESS: XIV was only the first ETF to go , many could follow (issues of 'fake diversification', 'fake liquidity' across several household ETFs),** Turkey, OIS-Llibor spread / DB, default events, HKD, EU Economic Surprise Index, Italian 2yr BTPs, Brasil.
- **SHIFTING FEEDBACK LOOPS from NEGATIVE to POSITIVE: Critical Transitions Follow Shifts In Feedback Loops: they are likely to be the final stressors.** How does the system degrade? How is resilience lost? One such way is with a change in feedbacks. It happens when self-correcting negative feedback loops weaken, and self-amplifying positive feedback loops arise, and the system degrades. Positive loops correlate to an increase in system-level fragility. Now they flipped again to negative: saturation.
- **CLIFF IN NAKED EYE / it started raining:** One **key stressor in clean sight**. To markets, it is **REAL RATES RISING**. Inflation made a comeback, but it is really real rates that are rising. So, bond bubble started deflating, just started. Decade-long technical trend-lines are now broken. We will see below how further it can go, across the credit spectrum (HY, Lev Loans, Subordinated)

CRITICAL TRANSFORMATION HYPHOTHESIS

1	CRITICAL SLOWING DOWN	The **rate of recovery** rate **after a small perturbation is reduced, and will approach zero when a system moves towards a catastrophic bifurcation point (less slope of basin of attraction).** The difference to Oct14, Aug15, Jan16, Trump, Brexit may be informative. Calls for further investigation.
2	VARIANCE	1) Volatility had already bottomed out 9 months ago; 2) Volatility rising with market in January; 3) Volatility still not reflected in longer expiries and other asset classes. **As a bifurcation approaches (eigenvalue zero), the impact of shocks do not decay, and their accumulating effect increases the variance of the state variable**
3	CORRELATION / AUTOCORRELATION	1) Correlation across asset classed increases at times of systemic risk. 2) Increase in autocorrelation, the memory of the system increases , the **state of the system** at any given moment becomes **more and more like its past state**
4	SKEWNESS OF FLUCTUATIONS	The **asymmetry of fluctuations** may increase. Rates of recovery are lower. As a result, **the system will tend to stay in the vicinity of the unstable point relatively longer** than it would on the opposite side of the stable equilibrium. Vicinity to 200 days MA may qualify.
5	FLICKERING / Bi-Modality	**In the vicinity of a catastrophic bifurcation, the system goes back and forth between the basins of attraction of two alternative attractors**. Such behavior is also considered an early warning. **rapid alternations between a cold mode and a warm mode are typical in climate changes over history. In epileptic seizures, smaller transient excursions in the vicinity of an alternative state** precede the upcoming **major shift**. Call them 'EARLY TREMORS'. Violent rallies seen in bear market about to crash, may qualify.
6	POCKETS OF STRESS	**XIV was only the first ETF to go , many could follow (issues of 'fake diversification', 'fake liquidity')** Turkey, OIS-Llibor spread / DB, default events, HKD, EU Economic Surprise Index
7	SHIFTING FEEDBACK LOOPS from NEGATIVE to POSITIVE	**Critical Transitions Follow Shifts In Feedback Loops: they can be the final stressors** How does the system degrade? How is resilience lost? One such way is with a change in feedbacks. It happens when self-correcting negative feedback loops weaken, and self-amplifying positive feedback loops arise, and the system degrades. Positive loops correlate to an increase in system-level fragility. Now they flipped again to negative: saturation.
8	CLIFF IN NAKED EYE / it started raining	One **key stressor in clean sight**. To markets, it is **REAL RATES RISING**. Inflation made a comeback, but it is really real rates that are rising. So, bond bubble started deflating, just started. Decade-long technical trend-lines are now broken. We will see below how further it can go, across the credit spectrum (HY, Lev Loans, Subordinated)

Early Warning Signals

Butterflies Analysis ('BA')

In a **critical state**, markets are **vulnerable to the point that a small disturbance** - a butterfly - can trigger a large adjustment: the **famous butterfly of the chaos theory**, whose wings flapping in Brazil can cause an earthquake in Texas. Here though, there is more than one butterfly in the room. **More than butterfly, triggers look like elephants. And more than a room, financial markets look like a china shop** (given their fragility, overconcentration and lack of buffers). There are then **several elephants in the china shop**, as regulators hide and markets nap over ever-changing overfitting elusive economic narratives.

- **ENDOGENOUS: STRUCTURE OF THE MARKET. Over-concentrated, across strategies and investors.** The autolytic effect already triggered by volatility (chain effect across major market players (Risk Parity funds, Short Vol ETFs, Low Vol ETF, momentum strategies). The rebalancing/deleveraging effect triggered by UP-TREND breaking down. The 200-days moving average is a Maginot Line (same fate).

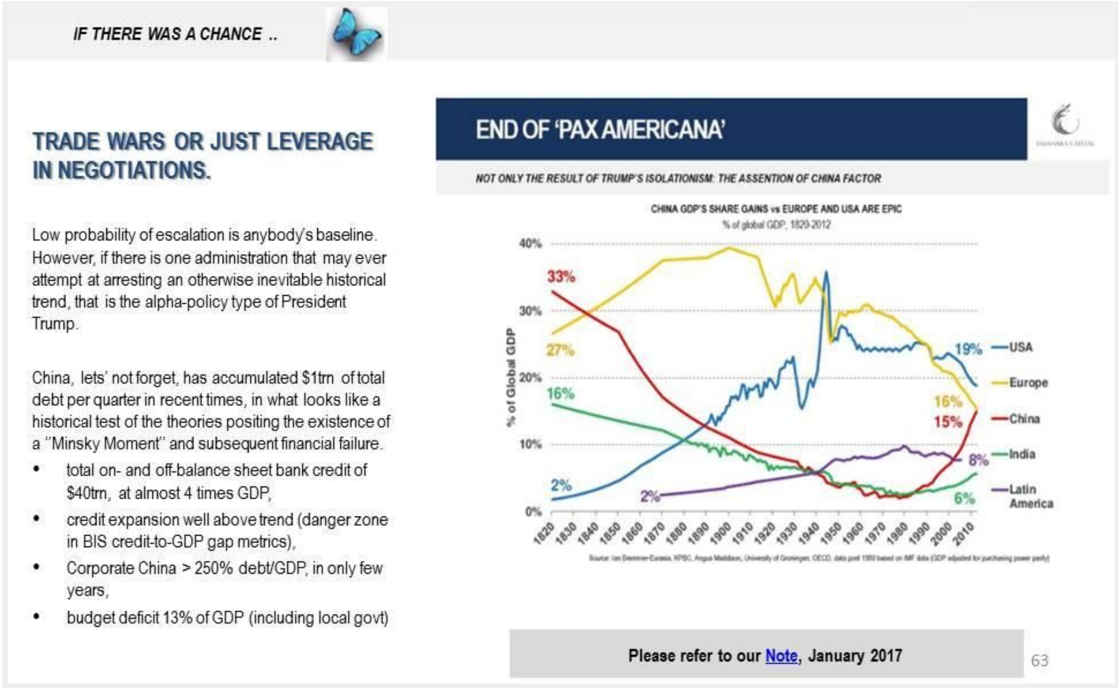
- **EXOGENOUS TRIGGERS: LIQUIDITY TIDE PETERING OUT.** The global liquidity tide from Central Banks is withdrawing. Flows work in reverse, for the first time in 10 years. First real crash test for momentum / volatility.

- **RATES RISING. The cliff is now in sight.** It started raining. Over-indebtedness may may be closing in onto its Minsky point. Inflation or Real rates does not matter !

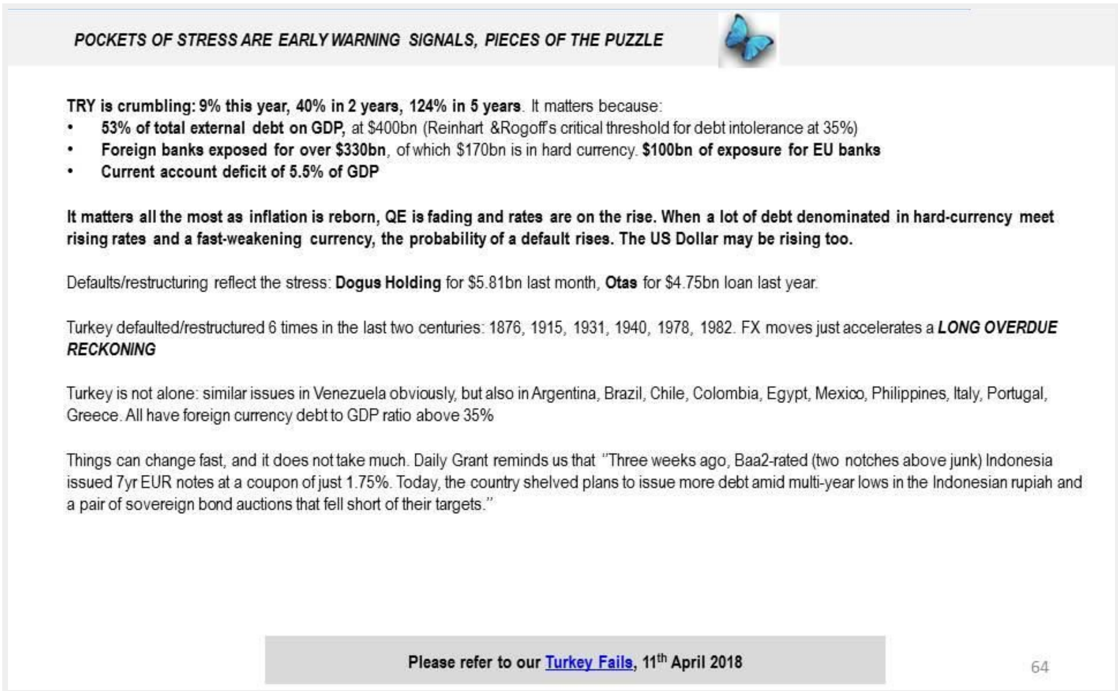
- **(IL)LIQUIDITY EVENT.** The liquidity in markets is deceptive and ephemeral, likely to dissipate as markets move lower. XIV is no isolated case ! Other much larger ETFs exhibit 'fake diversification', 'fake liquidity'.

- **GEOPOLITICS / POLITICS.** From populism in developed countries (Germany, Catalonia, Italy, Brexit, Trump) to confrontations in North Korea / Middle East (end of Pax Americana).

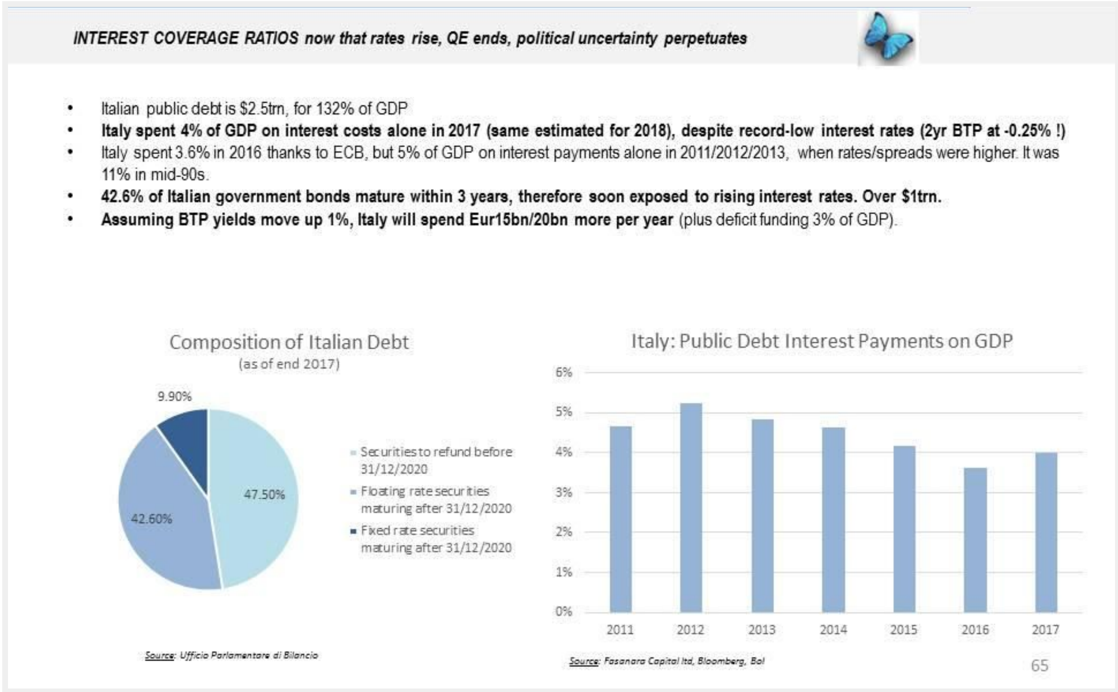
- **HOT SPOTS: TURKEY, ITALY, CHINA.** Smoking in a gas station. What are weaker FX and geopolitical tensions to Turkey, what are rising rates to Italy, what are trade wars to China?



China's Thucydides Trap



Turkey's Foreign Debt



Italy's Public Debt

Elephants in the China Shops

11. Analysis of Market Structure: Towards A Low-Diversity Trap

In supporting the case for a 'Critical Transformation Hypothesis' in global markets, we further analyse the structure of the market, and how it weakened under the force of positive feedback loops between public flows and the private investment community. QE/NIRP created 'Fake Markets', within which passive and quasi-passive investors blossomed, under the cover of deceptive economic narratives. We look at asset managers and ETFs as a meaningful proxy for the broader financial system, as we think they represent the weakest links, the cracks in between tectonic plates in the market crust. **We find that, over recent years, measures of market diversity and resilience fell in lockstep with measures of entropy, all the while as size rose to record levels**. Entropy in the ETF market decayed at an average rate of 4.5% per year in the last ten years, and its trend-line has almost reached 2008 levels. Measured as 'average closeness centrality', concentration in the ETF market increased by a striking 12.1% year-on-year since 2008, and its trend-line too reached levels seen in 2008. Our analysis framework borrows from complexity theory and network modeling, we investigate phase transition from one state of the market to another by applying ideas from earthquakes prediction, information theory and pure mathematics. **Looking at systemic risk as a complexity problem, we attempt a visualization of how the market structure on passive ETFs evolved over time, using agent-based modeling.** This is the visual story of how the market structure weakened relentlessly in the last ten years, **becoming more concentrated, entropic-fragile, and ready to snap. We analyze the structure of the market network during good and bad times**, trying to identify the DNA of a market crash. **The current market exhibits the typical structure visible during flash crashes, yet despite not being in one. We conclude that the market system is full, stationing on paper-thin ice, ready to transition.**

Analysis Of The Market Structure: Weakest Links

As we try to substantiate the view with hard data, we now further analyze the market structure across the two dimensions which may well represent its fault lines:

- Concentration of size on few top players**:** we use as proxy the top 22 asset managers globally
- Size of 'passive' or 'quasi passive': we use as proxy the top 2000 ETFs, as represented by their largest 350 since 2007

We focus on largest ETFs and largest Asset Managers as we believe them to be the cracks in the financial system, the fault lines that lead to market fragility, hence our focus on them as a meaningful proxy for the broader financial market. In so doing, we consider a static and a dynamic picture:

- Static snapshot of the structure of the market
- Dynamic evolution of the structure over time

The analysis that follows is powered by our Fasanara Analytics team, a proud addition to the Fasanara family of late. It is not intended to be a finished product, but rather a work-in-progress, along the way of truth-seeking data mining. Any feedback/critique, please reach out, happy to collaborate and incorporate.

Measures Of How The Market Structure Weakened Over Time

Our analysis framework borrows from complexity theory and network modelling, we investigate phase transition from one state of the market to another by applying ideas from earthquakes prediction, information theory and pure mathematics.

We model the market as a network of agents (the nodes of the figure below) whose strength of interaction (edges, distance) is computed using a non-linear transformation of the pairwise correlations; for details on the network construction please see Onnela et al. "Dynamics of market correlations: Taxonomy and portfolio analysis".

Figure 1 |
The Market As A Network Of Agents
Systemic Risk as a Complexity Problem

Source: Fasanara Analytics, Bloomberg
Data: Minimum spanning tree
Agents are the nodes, the strength of interaction are the edges
Computed using a non-linear transformation of the pairwise correlations

ANALYSIS OF LARGEST ASSET MANAGERS

The chart below is derived from the market structure as represented by nodes and edges. It measures the pairwise correlation across nodes for the largest Asset Managers globally.

In the chart, we observe recurrent spikes in average pairwise correlation, with a frequency of approximately 6 months, caused by variously meaningful price declines in the stock market (although never truly corrections, but rather speed bumps).

During market stress, correlation across asset classes and market players goes higher, reaching one at mayhem. This is no surprise and nothing new. Here instead, what we want to emphasize is the frequency of correlation flickering, which reminds of the early tremors occurring ahead of earthquakes - using insights from geophysics. The ripples may then be used as the Richter scale of a financial seismograph.

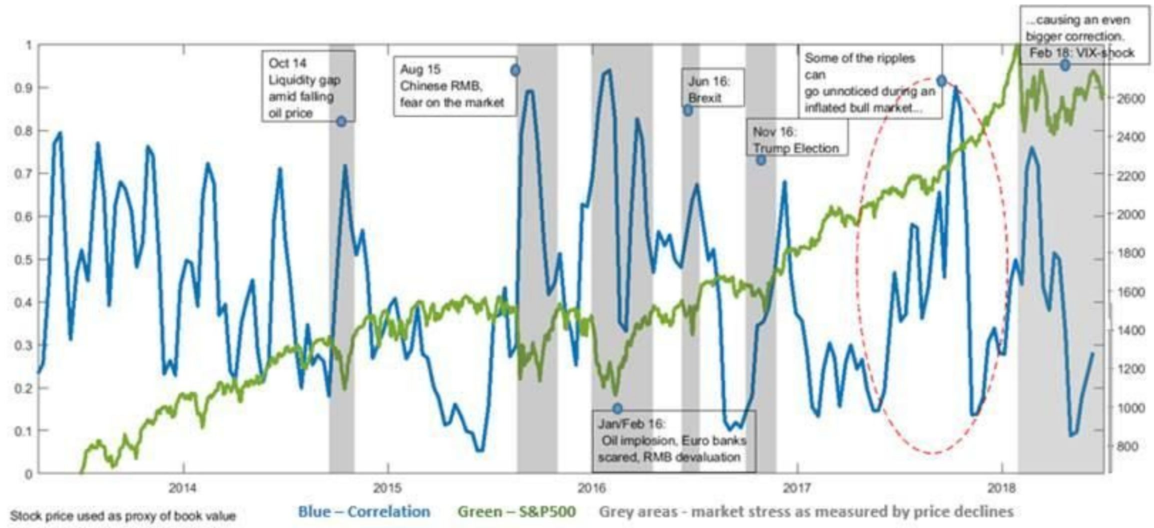
Borrowing from earthquake studies, in analogy, we allude that **each ripple weakens the market structure**, exposing fault lines, and nears the moment when full release of the energy in the system may occur, with severe effects. As ripples keep propagating across markets, the probability of a major reset increases: the instability is building up until eventually the pressure is released when the market structure falls under the weight of any new price correction, at some point along the way. Every new ripple manifesting itself may then represent a tick on the countdown clock towards phase transition.

Like tectonic plates do for the lithosphere, the market system can absorb latent energy, for long periods, in what physicist call a 'metastable state', until such point in time when it gets abruptly and devastatingly released.

Sheer-sized Asset Managers and passive and 'quasi-passive' vehicles (a broad category which includes ETFs, Risk Parity, Risk Premia / factor investing, Low-Vol vehicles, Short-Vol ETPs and option overwriting/variable annuities plans, AI / Quant funds, Trend-Chasing Algos, more on it here) are the cracks in between tectonic plates in the market crust, hence our focus on them as a meaningful proxy for the broader financial market.

As to when energy for markets may get released, this is an evolving idea. We give our take here (at slide 30).

Figure 2 |
Market System Absorbing Latent Energy, One Ripple At A Time: The Case of The Largest Asset Managers
Average Pairwise Correlation Of 22 Largest Asset Managers



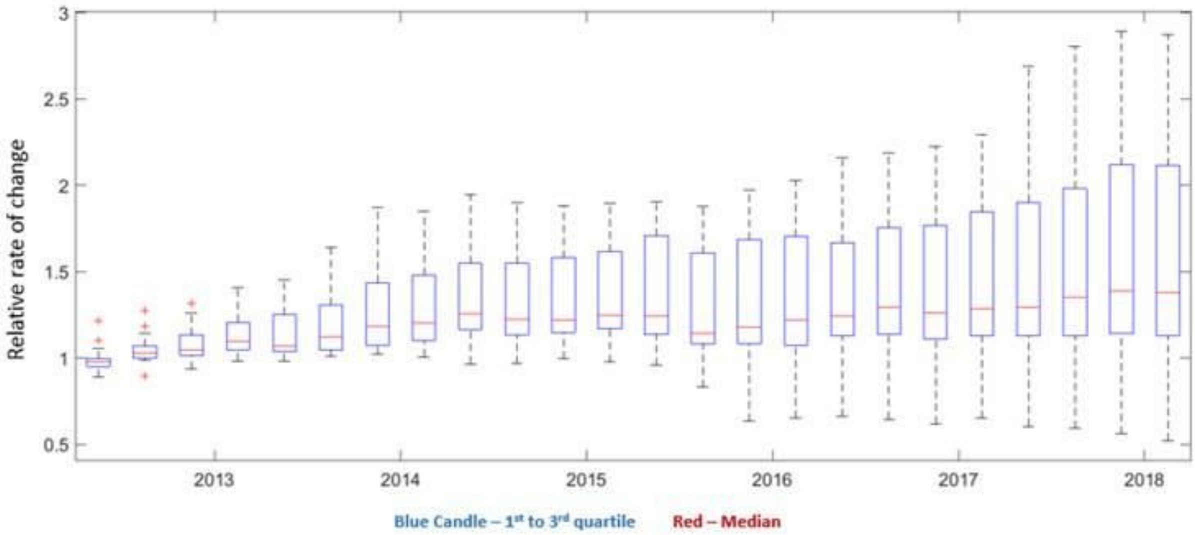
Source: Fasanara Analytics, Bloomberg

In our next chart we focus instead on the **ballooning size of the passive asset manager industry, and its progressive concentration**. We use a boxplot representation of the relative increase in Asset Under Management for the top 22 managers globally, since mid-2012. Two phenomena can be inferred: the mean size of the managers is increasing over time (50% over 5 years, within our sample of listed companies); the variability is increasing over time too. As some of the smaller managers are getting smaller, some big players are getting considerably bigger (between 100% and 400% in 5 years), suggesting a concentration of the passive industry in the hands of few strategic players.

The conclusion is hardly a surprise, if one considers that Blackrock, Vanguard and State Street alone today manage almost USD 15 trillions. Which is 22 times the total stock market capitalization of a G8 country like Italy, to put things in perspective. Praised be.

As numbers go out of whack, such concentration is under-researched, to say the least. Naturally, the 'too-big-to-fail' concept applied to banks in the aftermath of the Great Financial Crisis should be expanded to include asset managers, for some of them to be considered G-SIFI (Global Systemically Important Financial Institutions). But this is not happening - as we discuss in Systemic Risk is Not Just About Banks: Look at Funds. Not long ago, the Financial Stability Oversight Council commissioned a study on the matter, but no steps have since been taken to adapt the regulatory oversight for these institutions.

Figure 3 |
Asset Managers: Ever Bigger, and More Heavily Concentrated
Relative Size Increase Over Time for 22 Top Managers Globally



Source: Fasanara Analytics, Bloomberg

ANALYSIS OF LARGEST ETFs

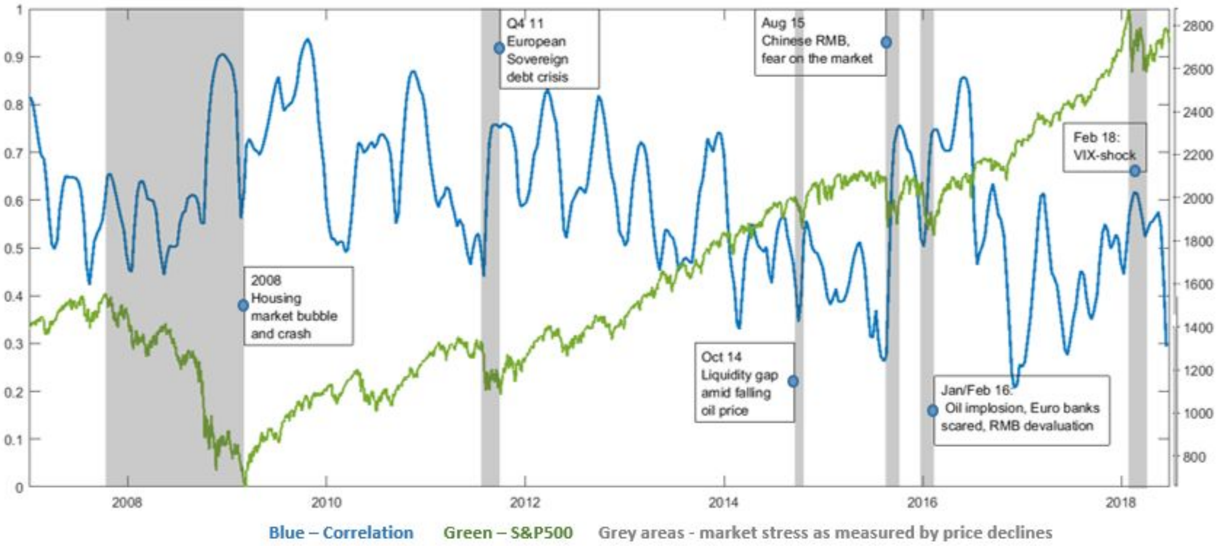
Having touched on the concentration of size on few top AM players, we now discuss the size and dynamics of the 'passive' and 'quasi passive' industry. We do this using the proxy of its largest 350 ETFs globally, as a first initial step in understanding.

Similarly to what shown in the previous model, we observe that the correlation structure among ETFs follows a similar behaviour, suggesting that **instability ripples are propagating through the passive-investment subset of the market too**.

Figure 4 |

Market System Absorbing Latent Energy, One Ripple At A Time: The Case of The Largest ETFs

Average Pairwise Correlation of 350 Largest Asset Managers

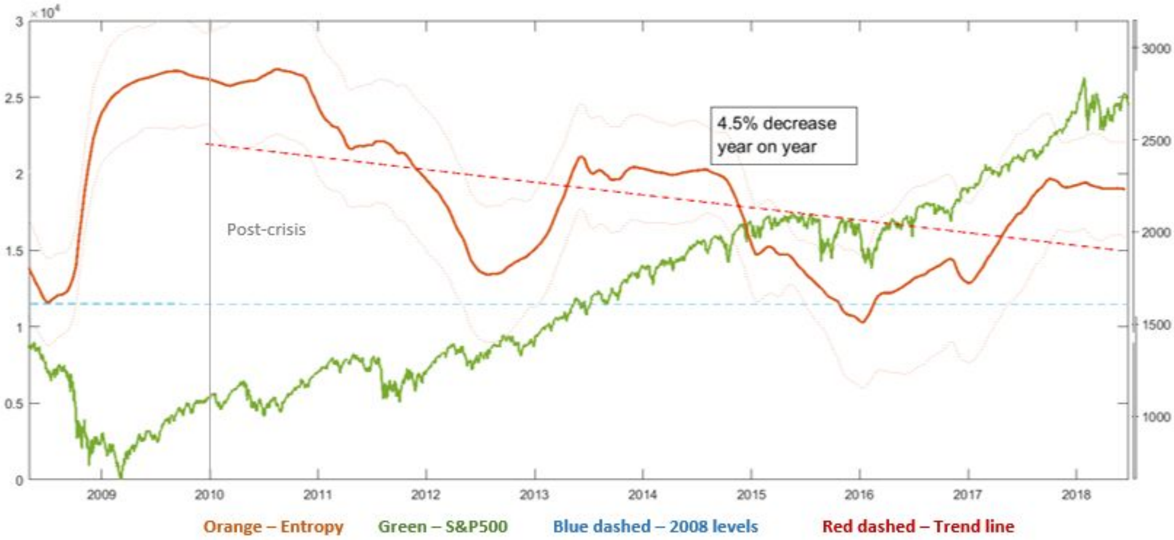


Source: Fasanara Analytics, Bloomberg

Inspired by a number of works on the information entropy as a measure of market risk (among which Pele et al. "Information entropy and measures of market risk"), we study the entropy on our network representation of the subset passive investment industry. The average information content in the system, or average entropy – computed on the edges of the graph, not to be confused with the entropy of prices – represents a local measure of unpredictability of the system, or equivalently, of its average information content. In this specific vein, when a tail-probability event occurs, it carries more "information" than an ordinary day, thereby causing a spike in entropy.

The second law of thermodynamics states that ''**entropy always rises within an isolated system, over time**'' (to be precise: cannot decrease). This is in contrast with empirical evidence in the market, as we analyse below that **average entropy is on a decade-long down-trend**. It may serve as a stark reminder that the market system is currently therefore not an 'isolated system'. Little surprise there, when we think of the exogenous factor of unprecedented/unorthodox Central Banks' manipulation, in the forms of Quantitative Easing and Negative and Zero interest Rate policies. Anti-gravity policies blow bubbles in valuations, drive positive feedback loops with private investors, divergence from equilibrium, spur system instability: latent energy accumulates in the market crust, ripple after ripple.

Figure 5 |
Declining Entropy In The ETFs Market Structure
Information Density Of The Network Of The 350 Largest ETFs

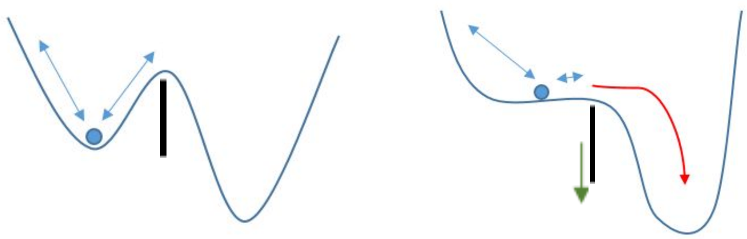


Source: Fasanara Analytics, Bloomberg

We find that information **entropy is decaying at an average rate of 4.5% per year** (orange line in the chart below below) and its trend-line (**dashed red line**) has almost reached 2008 levels (**dashed light blue line**). To be sure, a low-entropy market is not necessarily a market ready to crash, no causality there. Said that, it is historically also true that long periods of low vol and, in this vein, declining entropy have preceded the market crashes of 1929, 1987, 2000, 2007, by tricking investors into a bull trap (Minsky's 'stability is destabilising' factor, which we most often discuss in our papers).

In order to further contextualise such claims we refer to the work of Risso (2008), Zunino et al. (2009) and Billio et al. (2016) among others, where the authors show how the entropy can be used as a measure of stock market efficiency. In particular it has been found that the probability of a market crash increases as the information efficiency of the market, measured by entropy, decreases. As also recently discussed by Howard Marks in a recent note, the flow of capital from active to passive investors helps weakening the process of price discovery in turn driving down the information efficiency of the market; in our study we find more mathematical evidence backing these ideas.

A market robust to instabilities is a dynamic market that can test price swings with confidence; in a low-noise condition, as we observe today, a small correction could cause the equilibrium to break down, inducing a phase transition from a metastable state to a stable equilibrium.

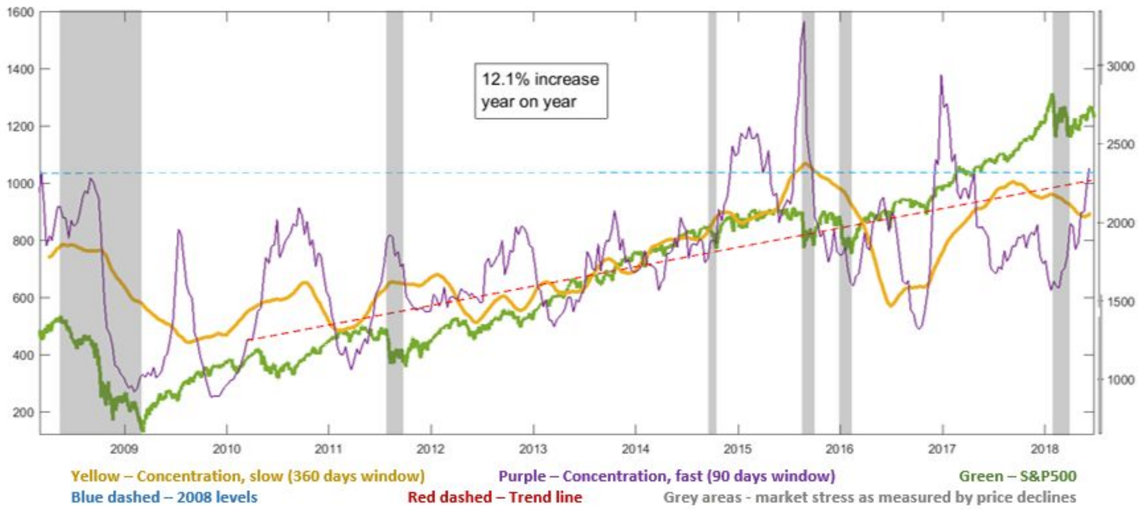


On the left we present a schematic representation of a stable equilibrium point, where entropy might be high and market participants compete in a normal market structure. On the right hand side, on the other hand, we observe a market with declining entropy, thereby inducing investors – the boiling frogs of [slides 24-25]() – to lower their defences (**black thick line** above), and cease to provide negative feedback loops. The context is then broader than just low and declining entropy, and it includes several fundamental factors acting in unison, such as QE, feedback loops, liquidity and easiness to grow debt/leverage, which altogether bring markets towards a low resilience state.

We now throw concentration in the picture of the low-entropy ETFs market. We again use a representation of the market structure on ETFs made of nodes and edges. We here measure concentration using the ''average closeness centrality measure'' (**purple** and **yellow** lines). The closeness of a node is a measure of centrality in a network, calculated as the reciprocal of the sum of the length of the shortest paths between a node and all other nodes in the graph, thus the more central a node is, the closer it is to all other nodes. **So measured, the concentration in the ETF market has been increasing by a striking 12.1% year-on-year since 2008**. Moreover its trend line (**dashed red line**) has reached the levels of concentration seen in 2008 (**dashed light blue line**), while our shorter-term estimation of market concentration (**purple** line) has spiked above such levels already twice: just before the market corrections during Aug '15 and Jan '16 and during the rally at the beginning of 2017, which ended in the VIX explosion.

Generally, **greater market concentration translates in stiffness of the market structure**, which then becomes fragile as a crystal glass, which in turn is less and less able to absorb idiosyncratic shocks. Following through on the analogy, it may allow the next ripple to compound and morph into a full blown quake, propagating across more easily given the concentration.

Figure 6 |
ETFs: Ever Bigger, and More Heavily Concentrated
Average Concentration Of The Network Of 350 Largest ETFs



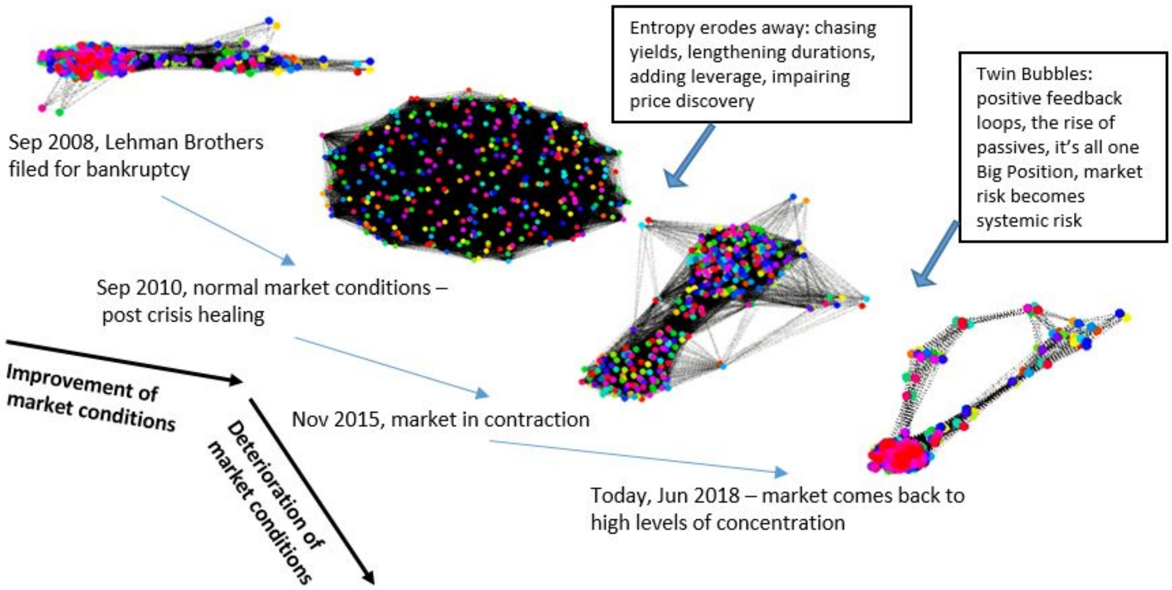
Source: Fasanara Analytics, Bloomberg

Contrary to previous indicators in this paper that had only inference power, we believe that this measure of market concentration may possess some predictive power (with the exception of VIX-driven sell-off, possibly more idiosyncratically centred around the VIX complex). In particular, short-term concentration (narrower estimation windows) seems to peak before price declines, while longer-term concentration (wider estimation windows) may provide a signal that fragility is increasing and a full phase transition approaching.

A Visual History Of The Market Structure In Last Ten Years

To corroborate this take, we provide a **visualisation of the market structure** as modelled by a graph where each node represents an ETF, and the length of the edge represent the strength of interaction (inversely proportional). Please note the density/crowding of the nodes (market concentration) in September 2008, and how it looks after the pressure is released, in the healthier conditions of 2010. **The stiffness of the market increases again after 2015, leading to a current situation of high density and potential danger as the market is no longer able to absorb shocks.**

Figure 7 |
Market Structure Over Time, With Agent-Based Modeling:
Healthy vs Unhealthy Market Structures
Average Concentration Of The Network Of 350 Largest ETFs



Source: Fasanara Analytics, Bloomberg, Method IT

All in all, we observe signals that a phase transition in the passive investment industry might be approaching, as shown by our analysis of the Asset Management and ETFs segments of the industry, which give similar results. When coupled with their size, and the tight ties with financial markets at large, we believe systemic risk are at or close to the cliff, ready to transition.

Similar levels of fragility, as defined and measured in this paper, were visible in the most recent proper crash of 2007/2008.

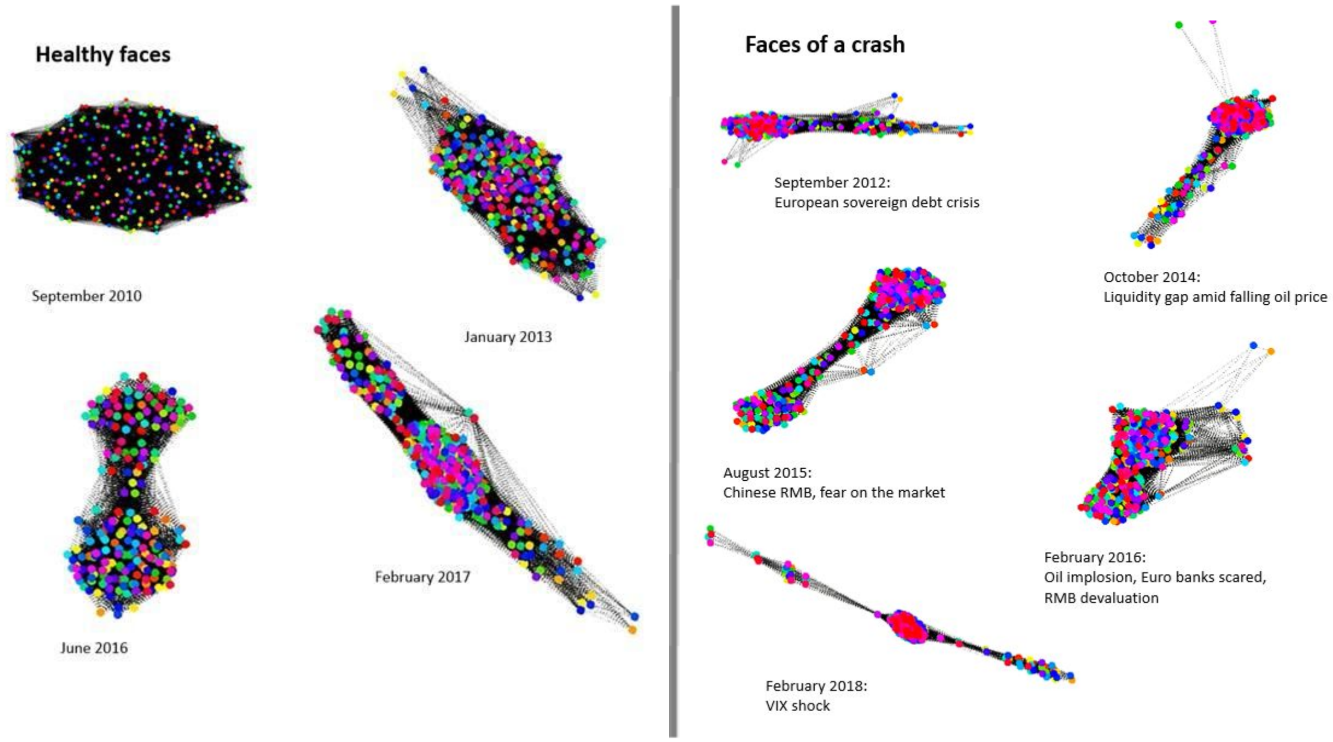
Sequencing The DNA Of A Market Crash

How does a crashing market looks like in terms of market structure?

Here below we pit the healthy faces of the market, in peaceful blue-sky environments, against the ugly faces revealed during periods of stress.

One big annotation: no truly meaningful crash occurred ever since the Lehman-moment. Here we only see timid, tepid, shallow, fleeting market sell-offs. None of them lasted, if anything they got more and more irrelevant over the years as the buy-the-dip mentality compounded. Most importantly, none of them look even remotely like the one we expect in the not-so-distant future for markets. Still, they can be analysed as 'small-scale rehearsals' for the Big One approaching, and certain general properties of their structure can be learned.

Figure 8 |
Structure Of The Market Network During Good and Bad Times
Sequencing The DNA Of A Market Crash



What kind of structure do we have today?

Today (June 2018)

Where do you think it fits better?

Source: Fasanara Analytics, Bloomberg, Method IT

c. Attributes Of Today's Market Structure

Where does the current market structure belong? It may belong to the list on the right, the ugly faces of the market in the midst of a stress period.

With one notable difference: there is no crash today. Today's market structure looks like the market structures visible during flash crashes, without being in one.

It may be yet another signpost, in a long list of early warning signals, that the market system is full, stationing on paper-thin ice, ready to transition.

12. Concluding remarks

The Critical Transformation Hypothesis: Positive Feedback Loops led into Phase Transition Zone

This note is intended to provide a **theoretical conceptual framework** around **financial market system fragility**, where a strong case can be argued that that an unstable equilibrium in financial markets is brought about by **positive feedback loops** between public and private investors, exposing markets to the **risk of a systemic risk escalation**. The analysis of **generic early warning signals for chaos outburst** comes in confirmation of an increasing likelihood of Critical Transitioning.

Needless to say, what is a risk is also an opportunity. The opportunity to position to capture the moment of adjustment as it draws nearer. It may happen faster and more brutally than most anticipate. The signposts are scattered around us, in plain sight. Our thoughts are expanded upon in this video slideshow.

Whoever has ears, let them hear. Matthew 13:9-16

What to do: the pursuit of resiliency for Complex Markets: Recommendations for Macropru policymaking aiming towards a Resilient Financial System

A number of measures can be thought of in the pursuit of a financial market system that aims at detecting early signals of severe fragility and seeks to exhibit more resilience against major perturbations of a Lehman-type magnitude.

In the discussion around what can be done to build a more resilient financial system, a few talking points can be considered, both at the macro and the micro level. This is intended to be food for though, work-in-progress, intentionally provocative so to stimulate a discussion on the topic.

At the macro level:

a. **Isolate fake narratives and plausible deniability in finance**:

    a. As a starter, intellectual efforts should be made by policymakers, academia and market practitioners at large to isolate, whenever possible, flaky market narratives and issues of plausible deniability
    b. ''It is impossible to spot a bubble'' and 'a bubble can be known only in retrospect', is jargon for 'I am not paid to spot a bubble' or 'bubble has then even better odds of building up'. Human nature is the real driver of crises, invariantly over history.
    c. As a general principle, the defense of free-market functioning cannot be invoked as a pretext for no-action. It cannot be that free-market functioning can be affected for longer than a decade by overwhelming external agents such as QE/NIRP without the willingness to detect the collateral effects and do something about them.
    d. ''There Is No Alternative'' and ''There Is No Place To Hide'' should read/include ''from systemic risk''. Unless you are paid to stay invested regardless (like most institutional accounts / banks), stay out or go short.
    e. As Tail Risk disseminates across the financial system, it may well be that no asset class whatsoever provide value, at times during the cycle. Relatively better than ugly is still ugly. An Asset Management industry that keeps going no matter what, and is incentivized to be long at all times is by definition inefficient and potentially dangerous, itself a key source of systemic risks. An institutionally acceptable way should be imagined to monitor agents of the Hedge Fund or Alternative Asset Management industry that are spotted having high Beta for extended periods, for them to be categorized accordingly, in an effort to increase transparency across the system.
    f. Conceptually, there may be a time where there is no bull market left out there (Jim Cramer-type), no anti-bubbles to spot (Rob Arnott-type). While it may sound obvious, neither the Asset Management industry nor policymakers have ever spotted such periods, across history, nor have they admitted to their theoretical existence. Quite the opposite. 'Be fearful, not greedy' is nowhere institutionalized in the industry of finance.
    g. As Fat Tail risk has easily a probability of 25% in 2018/2019, it hardly qualifies as a Tail risk anymore ('Fat' yes, a 'Tail' no). It has been so for 2 years now, despite sugar rush of tax cuts / late stage monetary stimulus / investors positive hysteresis. An ailing condition hidden in plain sight.

b. **Introduce a complexity framework**. The analysis of past systemic crises showed the flaws in the Efficient Market Hypothesis, which were only partially filled in with what we learnt in studies of Behavioral Finance. A move to a Complex Markets Hypothesis can help shed light on the life cycle of a market system, as it naturally degrades and systemic risk compounds. A more realistic representation of reality should include key concepts from complexity theory, such as, for example:
    a. The whole matters more than the single parts, what makes sense and is rationale at the individual level can become a systemic risk at the aggregate level if all do the same at the same time,
    b. Markets are 'complex dynamic adaptive systems', they adapt to local conditions as emerging properties arise, and the system evolves. In the words of Complexity Labs, they are 'open and self-organizing, where overall functionality and desirable outcomes are an emergent phenomenon of local interactions between members'. As such, they typically exhibit non-linear dynamics, and the dynamics of criticality. A chief lesson from complex theory is that there is not one single trigger, no cause and effect relationship. Human brain tends to look for one, forgetting the system as a whole. In analogy, Mike Tyson lost not to Buster Douglas, but when he was ready to go. Subprime mortgages in 2007 were an issue, but the system was ready to transition beforehand; subprime was just the trigger jumpstarting the autolytic reaction function and chain effect. When the system is tight in all

directions of potential expansion, hitting capacity constraints in synchronicity, it becomes brittle, it is acting weirdly, ready to snap.

c. The need for using and enriching agent-based modelling, in an ever-evolving effort to represent the various interactions of a complex network across a large number of nodes. Agent based unsupervised machine learning algorithms can be used to monitor the complex dynamic behavior of market participants, clustering them according to both pre-identified and emerging risk factors, analyzing crowding effects as they evolve.

d. Such analysis should critically encompass the Asset Management industry, as one that has been left behind by most analysts, too narrowly focused on the credit nature and the banking channel of past major crises.

e. A framework of analysis which encompasses the key elements of Complex Markets can also be considered:

   i. **Tipping Points Analysis ('TPA'), specifically designed to identify** synchronicity in capacity constraints for the financial system**. A model effort to isolate and monitor the key areas of expansion for any given system and their saturation points, which become points of no return when they materialise in synchronicity.**

   ii. **Early Warning Signals Analysis ('EWSA'): crash hallmarks.** If and when we have reasons to believe that the financial system has ran into an unstable equilibrium, where it is inherently fragile, structurally saturated, then the analysis of the universal properties of systems in transition can help assess a broad probability for critical transformation, and the vicinity to a severe market rupture (the cliff of the basin of attraction).

   iii. **Butterflies Analysis ('BA'). This is the active lookout for triggers.** Normally a fragile system can run into disorder for small changes in initial conditions, the so-called butterfly effects. It is clearly impossible to know all triggers, but an active monitoring of known major fault lines can contribute to studies of market fragility.

a. **Model a Low-Diversity Indicator, a Broad Financial Markets Resilience Index**: to help detect the approaching of a systemic risk danger zone, at which point special macropru policy is desirable

b. **Include top-10 Asset Managers in the list of G-SIFI** - Globally-Systemically Important Financial Institutions. Not only banks, but also asset managers cover a key social function: a severe market crash can provoke a recession, where jobs are lost, standards of living get affected (most severely so for low- and middle-classes), structural unemployment can ensue, deflation threats can be reborn. No asset manager should be allowed to get too big: the basic benefits of diversification apply to agents in the system so well as they apply to any financial portfolio (before any system-wide effect and correlation of business models is taken into account).

c. **Prolonged periods of extremely low (vs trend) volatility should be policed against**. Moderate volatility is a healing process, it is the lubricant of a system as it learns and evolves. Perhaps it is too much (and politically unpalatable) to say that regular crashes, here and there, are healthy; but surely a non-extreme level of volatility is healthy. As mentioned earlier on in this piece, several studies come in confirmation: from Hayman Minsky, in his "Financial Instability Hypothesis" in 1977,"stability is destabilizing" to Jon Danielsson, Director of the Systemic Risk Centre at the LSE, who finds unambiguous support for the 'low volatility channel', insofar as **prolonged periods of low volatility have a strong predictive power over the incidence of a banking crisis, owing to excess lending and excess leverage**). In addition to, more prosaically, the well-known 'boiling frogs analogy', the fable of the frog being slowly cooked alive.. Extreme volatility is indicative of systemic risk, more so when it is extremely low (and for long) than when it is extremely high. If anything, from a system perspective, high volatility works as a self-stabilising negative feedback loop, which may factually help contain financial excesses (SRC's studies also confirm that **high volatility has little predictive power**: very interesting, when the whole finance world at large is based on retrospective VAR metrics, and equivocates high volatility for high risk).

d. **New technologies such as Blockchain, and Artificial Intelligence-powered Blockchain, can help** key areas of the financial system in becoming more resilient and less affected by sequential failures and bankruptcies. For example, it can help ameliorate counterparty risks on loans and derivatives, it can help contain knock-on effects following idiosyncratic failures, it can help boost cyber security, it can help incentivise macropru monitoring.

e. **Level-playing field for passive vs active players – avoid regulatory overdrive, no tax advantages**, boost fair competition, no market silos or protected compounds. Passive agents, in the form of ETFs and index funds, are a great financial innovation destined to succeed and further expand, and are in no need of preferential treatments – differently than what happens today, where they enjoy significant tax advantages. At the same time, an overwhelming share of wallet of passive vis-à-vis active agents has undesired consequences in terms of fair value assessment for publicly traded securities, impairing the key market function of price discovery, thus resulting in systemic risk when applied over a long enough timeline.

At the micro level:

a. **Introduce 'skin in the game' mechanism for asset managers across a full market cycle**. A full market cycle should be defined in a definite and broadly agreeable form; for example, from a recession to the next, however long the period. At present, there is limited skin in the game for most asset managers, best epitomised by the **'Bob Rubin trade'** theorized by Nassim Nicholas Taleb: 'a system that does not have a mechanism of skin in the game will eventually blow up and fix itself that way. For instance, bank blowups came in 2008 because of the hidden risks in the system: bankers could make steady bonuses from a certain class of concealed explosive risks, use academic risk models that don't work, then invoke uncertainty after a blowup, some unseen and unforecastable Black Swan, and keep past bonuses, what I have called the Bob Rubin trade. Robert Rubin collected one hundred million dollar in bonuses from Citibank, but when the latter was rescued by the taxpayer, he didn't write any check.' In a nutshell, total compensation should be calculated across a full market cycle, in an effort to contain moral hazard and align utility functions for managers and investors.
b. **Anti-bubble measures: policing fake diversification and fake liquidity for ETFs, be on the lookout for price anomalies**. Institutional ways to do so should be assessed and tested. Taxation can be a lever; private rating agencies could help, so much as bonds are rated for credit quality, ETF and index funds should be rated against measures of true diversification and true liquidity, using a pre-agreed set of rules of the game, involving agent-based modelling and stress testing. Too often today, ETFs and other passive vehicles are over-stating and mis-stating their liquidity and diversification. Concept as 'evanescent liquidity' and 'expected liquidity during shortfalls' should be included, in an effort to increase transparency and curb information asymmetries.
c. **Anti-crowding measures: a rating could be used to isolate the True Beta of a strategy, measured against both Trend and Volatility**. Across fund natures, be it Behavioral Risk Premia, Risk Parity, Quant funds, low-vol vehicles, CTAs, etc. All should produce and keep updated stress test scenarios. The existing market-based mechanisms (the classic redemptions for bad performers) should be joined by a more punitive taxation, once and if the scenario is proven wrong by market events. Those managers convinced that they are producing real alpha should not be worried in having the duty to quantify it ex ante (like carbon emissions for German diesel cars) and be taken the prize away if proven wrong (like anti-doping tests for athletes running the Olympics). The inability to quantify the Beta unambiguously ex-ante is evident, and makes it best dealt with by private actors, to be later sanctioned (or prized) by both market dynamics (redemptions/subscriptions) and taxation. **Passive managers, but active taxation**. With the benefit and limitation of insight, as can only be applied after a market event. Still, bad behavior can be sanctioned during a minor market event, whereas now only a major crash can help see who is 'swimming naked'.

Previous Write-Ups on the Subject

Positive Feedback Loops and Financial Instability | The Blind Spot of Policymakers
A Dangerous Market Structure is More Worrying than Expensive Asset Valuations and Record Debt Levels
Fasanara Capital ltd
November 20th, 2017
Link

Investor Presentation: Market Fragility | How to Position for Twin Bubbles Bust
Fasanara Capital ltd
October 11th, 2017
Link

Investor Call – video recording: Market Fragility | How to Position for Twin Bubbles Bust
Fasanara Capital ltd
October 11th, 2017
Link

Changing Market Structure: A Review of Market Players
Fasanara Capital ltd
October 11th, 2017
Video Recording

The Positive Feedback Loop between Fake Markets and investors creates System Instability, and Divergence from Equilibrium
Fasanara Capital ltd
July 25th, 2017
Link

Fake Markets: How Artificial Money Flows Kill Data Dependency, Affect Market Functioning and Change the Structure of the Market
Fasanara Capital ltd
May 3rd, 2017
Link

The narratives that drive global markets
Fasanara Capital ltd
June 28th, 2017
Video

Measuring the Equity Bubble: The 'PEAK PEG' ratio: price to peak earnings, adjusted for trend growth. The S&P has never been this expensive before in history
Fasanara Capital ltd
August 24th, 2017
Link

Measuring the Bond Bubble: The REAL RATE to GROWTH ratio. German Bunds have never been this expensive before in history
Fasanara Capital ltd
September 11th, 2017
Link

How Bad a Damage If Volatility Rises: The Bear Trap of Short Vol ETFs
Fasanara Capital ltd
July 20th, 2017
Link

References

Ay N, Bertschinger N, Der R, Güttler F, Olbrich E (2008)
Predictive information and explorative behavior of autonomous robots.
Eur Phys J B 63:329–339
Read

Beggs JM (2008)
The criticality hypothesis: how local cortical networks might optimize information processing.
Phil Trans R Soc A 366(1864):329–343
Read

Beggs JM, Plenz D (2003)
Neuronal avalanches in neocortical circuits.
J Neurosci 23(35):11,167–11,177
Read

Marten Scheffer (2009)
Critical Transitions in Nature and Society,
Princeton University Press
Read

Joschka Boedecker, Oliver Obst, Joseph T. Lizier, N. Michael Mayer, Minoru Asada (2012)
Information processing in echo state networks at the edge of chaos
Theory in Biosciences
Read

Christian Torres-Sosa, Sui Huang, Maximino Aldana (2012)
Criticality Is an Emergent Property of Genetic Networks that Exhibit Evolvability
PLOS Computational Biology
Read

Kauffman, S. (1995)
At Home in the Universe: the Search for Laws of Self-Organization and Complexity.
New York, NY: Oxford University Press.
Read

Bilder, R. M. (2012).
Executive control: balancing stability and flexibility via the duality of evolutionary neuroanatomical trends.
Dialogues Clin. Neurosci. 14, 39–47.
Read

Rothenberg, A. (1983).
Psychopathology and creative cognition. A comparison of hospitalized patients, Nobel laureates, and controls.
Arch. Gen. Psychiatry 40, 937–942.
Read

R. M. Bilder, K. S. Knused (2014)
Creative cognition and systems biology on the edge of chaos
Front. Psychol
Read

Brandon Keim (2014)
Biologists Find New Rules for Life at the Edge of Chaos
Wired
Read

Corentin Herbert, Freddy Bouchet (2017)

Predictability of escape for a stochastic saddle-node bifurcation: when rare events are typical

Phys. Rev. E 96, 030201(R)

Read

Brian Walker, (2007)
Evolution of Resilience — In Theory, and in Social-Ecological Systems
Stockholm resilience centre
Read

Roger Lewin (2000)
Complexity: Life at the Edge of Chaos
University of Chicago Press
Read

Erik Townsend, Jeffrey Snider, Mark Yusko and Luke Gromen (2017).
Anatomy of the U.S. Dollar End Game.
MacroVoices Podcast
Listen

Kaufman, S. B. (2014)

The Controlled Chaos of Creativity in Beautiful Minds.

New York, NY: Scientific American.

Read

Kauffman, S. A. (1993)
The Origins of Order: Self Organization and Selection in Evolution.
New York, NY: Oxford University Press
Read

----

www.fasanara.com

40 New Bond Street
London, W1S 2RX

Authorised and Regulated by the Financial Conduct Authority ("FCA")