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Rethinking economics using complexity theory

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Abstract
In this paper we argue that if we want to find a more satisfactory approach to tackling the major socio-economic problems we are facing, we need to thoroughly rethink the basic assumptions of macroeconomics and financial theory. Making minor modifications to the standard models to remove "imperfections" is not enough, the whole framework needs to be revisited.[1] Let us here enumerate some of the standard assumptions and postulates of economic theory.

1. An economy is an equilibrium system. In other words, it is a system in which all markets systematically clear at each point of time, but where the equilibrium may be perturbed, from time to time by exogenous shocks.
2. Selfish or greedy behaviour of individuals yields a result that is beneficial to society – a modern, widespread, but inaccurate reformulation of the principle of the "invisible hand".
3. Individuals and companies decide rationally. By this it is meant that individuals optimize under the constraints they are facing and that their choices satisfy some standard consistency axioms.
4. The behaviour of all the agents together can be treated as corresponding to that of an average or representative individual.
5. When the financial sector is analysed, it is assumed that financial markets are efficient. Efficiency here means that all the relevant information concerning an asset is reflected in the price of that asset.
6. For financial markets it is assumed that they function better if their liquidity is greater.
7. In financial markets, the more connected the network of individuals and institutions the more it reduces risks and the more stable and robust is the system.

Below, we discuss the fundamental problems with these assumptions and outline some of the policy implications of improved assumptions.

At a recent meeting at the OECD, the question arose as to whether the economy is currently just experiencing one of its recurrent shocks or whether it is experiencing a "phase change" ("systemic shift"). If the latter is correct, the discipline of economics may well need to undergo a paradigm change.[2] (See Section 1.2).

[1] David Colander, Michael Goldberg, Armin Haas, Katarina Juselius, Alan Kirman, Thomas Lux and Brigitte Sloth, The Financial Crisis and the Systemic Failure of the Economics Profession, Critical Review, Volume 21, Issue 2-3, 2009, Pages 249-267; Alan Kirman, The Economic Crisis is a Crisis for Economic Theory, CESifo Economic Studies (2010) 56 (4): 498-535; Andrew G. Haldane and Robert M. May, Systemic risk in banking ecosystems, Nature 469, 351-355 (2011); Paul Krugman, How Did Economists Get It So Wrong?, The New York Times Magazine (September 2, 2009); Thomas Lux and Frank Westerhoff, Economics crisis, Nature Physics 5, 2-3 (2009); W. Brian Arthur, Complexity economics: A different framework for economic though, to appear in Complexity Economics, Oxford University Press (2013); Neil Johnson and Thomas Lux, Financial systems: Ecology and economics, Nature 469, 302-303 (2011); Paul Ormerod and Dirk Helbing, Back to the drawing board for macroeconomics, in What is the Use of Economics?, edited by Diane Coyle (September 2012); see also the video recording of the talk "Rethinking macro-economics based on complexity theory" at the Latsis Symposium 2012: "Economics on the Move",
http://www.multimedia.ethz.ch/conferences/2012/latsis/04_wednesday?doi=10.3930/ETHZ/AV-de04e25c-2106-45f2-a4ba-3d0e8e1ebeda&autostart=false

[2] Note that the paradigm shift from a geocentric to a heliocentric worldview facilitated modern physics, including the ability to launch satellites. In the same way should a paradigm shift from a component-oriented to an interaction-oriented, systemic perspective (as promoted by complexity science) enable us to find new solutions to urgent societal problems.

Whilst earthquakes, floods and famines produce dramatic losses, it can be argued that the social and economic losses due to the current financial, economic and political crisis are even more severe. Millions of people now see that, what they considered to be a safe future, is endangered by lost savings and pensions and disruption of their normal lives. Besides this, crime, violence and political extremism may increase as well. In the worst-case scenario, further developments could seriously diminish our quality of life, our social capital (particularly trust and cooperativeness), and even our cultural values and achievements. The developments in the past 5 years have made it possible that single countries or even the European Union could become unstable over time, not only economically, but also socially. This worrying development calls for new recipes and concerted actions, and also for contingency plans. It is time to explore new ways of managing our economy, oriented at sustainability and resilience rather than only at the often destructive pursuit of competition, efficiency, and growth.

It is tempting in situations such as the current one to find scape-goats and to lay the blame at their door. But this is misguided. As Voltaire remarked:

> "In an avalanche no single snowflake feels itself responsible".

… nor should it. Because what we have observed is a *systemic crisis* in which the participants were acting in accord with the incentives given to them by the system without realizing the global consequences of their acts.

This becomes particularly clear in a letter of the British Academy to Her Majesty The Queen, dated 22 July 2009:[3]

> "MADAM,
>
> When Your Majesty visited the London School of Economics last November, you quite rightly asked: why had nobody noticed that the credit crunch was on its way? **…** So where was the problem? Everyone seemed to be doing their own job properly on its own merit. And according to standard measures of success, they were often doing it well. The failure was to see how collectively this added up to a series of interconnected imbalances over which no single authority had jurisdiction. This, combined with the psychology of herding and the mantra of financial and policy gurus, lead to a dangerous recipe. Individual risks may rightly have been viewed as small, but the risk to the system as a whole was vast."

This strongly contrasts with the widely propagated paradigm of the "invisible hand", which has been commonly (mis)interpreted as "greed (or maximizing personal benefits) is good and will maximize social welfare". In contrast, however, as the participants in the economy pursued their goals, their complicated interaction and the consequences of their acts led the system to self-organize into a critical state. Such an evolution is not envisaged in standard economic models, and this is what motivated Jean-Claude Trichet, the ex-president of the European Central Bank to make the following statement:[4]

> "When the crisis came, the serious limitation of existing economic and financial models immediately became apparent. Arbitrage broke down... markets froze... market participants were gripped by panic. Macro models failed to predict the crisis and... [to explain] what was happening... ."

[3] See the letter from the British Academy at http://www.britac.ac.uk/templates/asset-relay.cfm?frmAssetFileID=8285

[4] Speech of Jean-Claude Trichet, President of the European Central Bank, on November 18, 2010

> "[In] the face of crisis, we felt abandoned by conventional tools. ...The key lesson... is the danger of relying on a single tool, methodology or paradigm. The atomistic, optimising agents underlying existing models do not capture behavior during a crisis period. Agent-based modelling... allows for more complex interactions between agents. ...we need to better integrate the crucial role played by the financial system into our macroscopic models."

> "I would very much welcome inspiration from other disciplines: physics, engineering, psychology, biology. Bringing experts from these fields together with economists and central bankers is potentially very... valuable."

> "A large number of aspects of the observed behaviour of financial markets is hard to reconcile with the efficient market hypothesis... But a determinedly empirical approach – which places a premium on inductive reasoning based on the data, rather than deductive reasoning grounded in abstract premises or assumptions – lies at the heart of these methods... simulations will play a helpful role."

In response to this call to arms, we argue that we have to develop a new economic thinking based on complex systems science and find new ways to overcome (or mitigate) our current problems.

Before proceeding we should emphasise that there is a very basic reason why many economists were quite surprised by the onset of the crisis and had difficulties to make successful proposals to overcome it in an efficient way. In recent years, as the discipline of economics developed further, most of the effort to explain empirical facts was devoted to modifying the existing theories in various, but relatively minor ways. However, little consideration was given to the structural changes that might have emerged as the economy evolved. For example, the idea that the economic system could, and maybe should, develop towards a system which is more democratically and less selfishly oriented is one that has received little attention simply because the concept of participatory decentralised organisation has been regarded as incompatible with efficient economic outcomes. Yet, the economy in which the thinking in terms of competition, free markets, homogenisation and global control developed has, in reality, evolved into a very different system.

Indeed, we argue that the increasing degree of complexity of our economic system is not in conflict with decentralisation, but will promote a tendency towards it, which is already visible in the way the internet is organized, the way smart grids are now being organized, and the way modern traffic systems will be managed. Furthermore, decentralisation will be promoted by technologies enabling bottom-up participation of consumers in production processes. Participatory platforms and social media of all kinds, but also 3D printers, are such technologies. They will enable local production and remove the old separation between consumers and producers, such that a new class of "prosumers" (co-producing consumers) will emerge. We believe that all this will pave the way for a new organization of economic systems – a participatory, diverse, bottom-up kind of economy, which we propose to call the "democratic economy" or "participatory market society". The emerging digital economy is the best indication of this, and the advent of the age of Big Data will fuel it even more. In fact, some envision "Big Data" to be the "Oil of the 21st Century".

Many would argue that standard economic theory enabled us to analyse and understand the

economy as it used to be, with long stable periods punctuated only by occasional crises. However, the recent evolution of the global economy should drive us to pursue ways of expanding economic theory such that it encompasses the new structures and organization emerging as we globalize and network our world. But let us first ask: what are the empirical characteristics of modern economies that pose problems for modern economic theory?

1. Are our present financial and economic systems in a stable equilibrium?

A fundamental assumption of many economic models is that the system is in equilibrium and will only be disturbed by exogenous shocks, e.g. due to innovations. Note that this is an assumption and not a conclusion. If one tried to endogenize innovations into economic models, it would become clear that they are, by their very nature, examples of systemic instabilities, which are fundamentally incompatible with a system in equilibrium. Therefore, it is important to discuss what are the implications of and evidence for economic systems that are not in equilibrium.

We say that a system behaves in an *unstable* way, if a small perturbation can drive it further and further away from its previous or "normal" ("equilibrium") state. This is, for example, the case if the system exhibits a breakdown or another systemic shift, if a quantity continues to grow, if the distribution of a quantity keeps changing over time, or if chaotic dynamics or cascade effects occur. Any of these characteristics indicate that the corresponding systems are *not* in an equilibrium or stable state. So, how do our financial and economic systems behave in reality?

1.1. Can we rely on the equilibrium paradigm of economics?

As we have said, current economic thinking is based on the assumption that the economic system is in equilibrium or at least, if disturbed, has a tendency to move back to a state of equilibrium. This idea was originally inspired by 19th century physics, specifically the fields of classical mechanics and thermodynamics.[5] However, it does not fit the framework of modern physics, particularly statistical non-equilibrium physics, and the theory of complex systems.

According to the equilibrium paradigm, there are optimal (or efficient) states of an economy, to one of which the system would automatically and quickly evolve, driven by "market forces". This idea is thought to be enshrined in the parable of the 'invisible hand', according to which social welfare is improved in an economic system, when everybody acts in his or her own best interest. However, Adam Smith, who is often seen as the originator and propagator of the paradigm of the invisible hand,[6] was much less dogmatic than his heirs. He argued that, while his vision of individuals as selfishly pursuing their own interests captured some grain of truth, social considerations were also important for everybody's behaviour. To cite him:[7]

> "How ever selfish man may be supposed, there are evidently some principles in his nature, which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it. Of this kind is pity or compassion, the emotion which we feel for the misery of others, when we either see it, or are made to conceive it in a very lively manner. That we

[5] Later Samuelson, in particular, used the analogy with thermodynamics.
[6] The idea that individual selfish optimization would create a social optimum seems to actually originate from a poem of Bernard Mandeville entitled "The Grumbling Hive" (1705). It was re-edited in 1714 under the title "The Fable of the Bees", which spread the idea and made it famous.
[7] Adam Smith (1759) *The Theory of Moral Sentiments.*

> often derive sorrow from the sorrow of others, is a matter of fact too obvious to require any instances to prove it; for this sentiment, like all the other original passions of human nature, is by no means confined to the virtuous and humane, though they perhaps may feel it with the most exquisite sensibility. The greatest ruffian, the most hardened violator of the laws of society, is not altogether without."

Not only did Smith see man as much less self-interested than the vision usually attributed to him, but he also saw a role for government intervention and control. Nevertheless, the widespread and over-simplified (or even wrong) interpretation of the 300-years-old idea has been used to justify a much more radical position, namely that government regulation automatically makes markets *less* efficient and *reduces* societal well-being. This vision is the main justification of the continued calls for free and unregulated markets.

We will return to the principle of the invisible hand in Section 2.5. At this point, we simply want to stress that it is hard to believe that current economic systems are systematically in equilibrium, considering that the conditions of today's global markets tend to change more quickly than the time that would be necessary to converge to an equilibrium. This time is determined, in part, by the time companies need to adapt to new market conditions, changing investment opportunities, and fluctuating demand for their products. It is important to recognize that, under conditions of delayed adaptation, unstable, non-equilibrium system behaviour may result even if each system component displays a stable dynamics.[8]

Furthermore, sustained high unemployment rates do not seem to be consistent with the clearing of labour markets that should happen in equilibrium. The volatility of financial markets and their loose coupling with the real economy also casts doubts on the notion of an economy in perpetual equilibrium. Particularly the phenomenon of excess volatility has stirred some debate about over-reactions of markets.[9] Furthermore, the occurrence of flash crashes[10] in financial markets cannot be reconciled with an equilibrium picture.

Finally, an important argument systematically raised by Mandelbrot[11] is the existence of power law statistics in financial markets. Such power laws are usually features of critical phenomena, i.e. phase transitions or self-organized criticality, which are both related to cascade effects and fundamentally incompatible with equilibrium concepts (Helbing[12] 2013).

1.2. Are economic systems instead complex dynamical systems?

A more natural picture of our economic system rather seems to be that of a complex dynamical system with many non-linearly interacting components (where non-linearity implies

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[8] D. Helbing and S. Lämmer (2005) Supply and production networks: From the bullwhip effect to business cycles. Page 33-66 in: D. Armbruster, A. S. Mikhailov, and K. Kaneko (eds.) *Networks of Interacting Machines: Production Organization in Complex Industrial Systems and Biological Cells* (World Scientific, Singapore).

[9] D. Helbing, Dynamic decision behavior and optimal guidance through information services: Models and experiments, in M. Schreckenber and R. Selten (eds.) Human Behaviour and Traffic Networks (Springer, Berlin, 2004), pp. 47-95.

[10] The most well-known example of a flash crash occurred on May 6, 2010, where the Dow Jones dropped by about 1000 points within minutes, before it more or less recovered again, but flash crashes have happened repeatedly, see http://en.wikipedia.org/wiki/2010_Flash_Crash

[11] See e.g. Mandelbrot, B., Sur certains prix spéculatifs: faits empiriques et modèles basés sur les processus stables additifs non Gaussiens de Paul Lévy. Comptes-Rendus à l'Académie des Sciences, Séance du 4 Juin 1962, 3968–3970.

[12] D. Helbing, Globally networked risks and how to respond. *Nature* **497**, 51-59 (2013).

that causes and effects are not proportional to each other). The components in this case are the market participants: companies, banks, consumers, and other players such as regulatory institutions.

Typical properties of such complex dynamical systems are:[13]

- The system may spend long periods of time far from equilibrium, even when an equilibrium in principle exists.
- The system may have multiple equilibria.
- The equilibria may be unstable.
- The system cannot be strictly optimized in real-time, even with the biggest supercomputers.
- Feedback and unexpected side effects are common.
- The system exhibits self-organized dynamics.
- The system may have emergent properties, i.e. properties that cannot be understood from the properties of the system components, but rather from the interactions between them.
- The system behaviour is often counter-intuitive.
- It may be probabilistic and hard to predict (not just due to randomness).
- The system may feature cascade effects and extreme events. The probability of extreme events is higher than expected according to a normal (Gaussian) distribution, and their impact may have almost any size (in particularly it may be global in scale).
- The system behaviour is hard to control in a centralized or top-down way.
- Stakeholders (and even countries) will often fail to behave as they prefer or as they should, because they cannot act independently.

These characteristic properties of complex, strongly coupled system need to be considered when trying to find successful solutions to the 21st century challenges facing humanity.

1.3 Efficient markets or herding behavior?

> "I can calculate the motion of heavenly bodies, but not the madness of people", said Isaac Newton.

All the above features can be observed in our financial and economic system, and this casts doubt on the classical equilibrium picture. The latest manifestation of the equilibrium perspective is reflected, in particular, by the theory embodied in standard macroeconomic models and, in particular, in Dynamic Stochastic General Equilibrium (DSGE) models. According to these models, market instabilities such as bubbles and crashes should not happen.[14]

While many people believe that bubbles and crashes actually *do* occur, the equilibrium paradigm, when applied to financial markets, is based on the efficient markets hypothesis that was first developed by Bachelier[15] (1900) and later exploited by Fama (1965)[16]. This

[13] D. Helbing (2011) New science and technology to manage our complex, strongly connected world, preprint http://arxiv.org/abs/1108.6131, see also D. Helbing and A. Carbone (eds.) Participatory Science and Computing for Our Complex World, *EPJST* **214**, 1-666 (2012).
[14] These traditional models also neglect banks as separate, self-interested stakeholders in the system, while they may affect an equilibrium in reality.
[15] Bachelier, L. (1900) *Theorie de la Speculation*, Paris: Gauthier-Villars.

hypothesis – and it is no more than that – asserts that all the available and relevant information as to an asset is contained in its price. There is an obvious paradox here underlined by Grossman and Stiglitz[17] (1980) who observed that, if the efficient markets hypothesis were valid, nobody would have any incentive to gather information and therefore it could never become public in prices.

It is worth reflecting a little on this fundamental problem. What Bachelier in effect postulated was that individuals, independently of each other, gather pieces of information about an asset, and that these arrive randomly. Once they have obtained their information, they act on it by purchasing or selling the asset in question and, by so doing, have an influence on its price and it is in this way that the information becomes public. It is conceivable that markets may function in this way. For example, Hayek (1945)[18] was convinced that they satisfy the principle of the "wisdom of crowds", where many individuals make judgements about some variable and, as each finds some potentially relevant information, they collectively arrive at an accurate judgement. However, this principle works only, if the market participants take independent decisions, which is certainly not a realistic assumption and, as the mathematician Henri Poincaré (1908)[19], who was the referee of Bachelier's thesis, stated:

> "Quand des hommes sont rapprochés, ils ne se décident plus au hasard et indépendamment les uns des autres; ils réagissent les uns sur les autres. Des causes multiples entrent en action, et elles troublent les hommes, les entraînent à droite et à gauche, mais il y a une chose qu'elles ne peuvent détruire, ce sont leurs habitudes de moutons de Panurge. Et c'est cela qui se conserve." [When people are in close contact they do not act randomly and independently of each other; they react to each other. Many factors come into play, and they perturb people, and move them right and left, but there is one thing that they cannot destroy, which is people's tendency to act like sheep. And, it is that which is conserved.]

Indeed, information feedbacks create herding effects, which are amplified under conditions of information overload, risk, and uncertainty. Such herding behavior (also characterised as "animal spirits", see Akerlof and Shiller[20] 2009) can produce undesirable correlations in the markets, which are a typical feature of bubbles and crashes, and thereby undermine the efficiency of markets. In fact, ECB president Jean-Claude Trichet pointed out:

> "A large number of aspects of the observed behaviour of financial markets is hard to reconcile with the efficient market hypothesis."

1.4 Is it useful to have more and more liquidity?

It is generally argued that a lack of liquidity is harmful for the economy, since – if funds are not readily available – this prevents new investments from being made and, more generally, an economy from reaching an equilibrium between supply and demand. However, the willingness of market participants to invest in new real-world business activities is conditioned by their expectations as to the future state of the economy. Even if the interest rate at which

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[16] Fama, E.F. (1965). "The Behavior of Stock Market Prices", *Journal of Business*, Vol. 38, No. 1, pp. 31-105.
[17] S.J. Grossman and J.E. Stiglitz, On the impossibility of informationally efficient markets. American Economic Review 70(3), 393-408 (1980).
[18] Hayek, F.A. (1945). "The use of knowledge in society". American Economic Review 35, 519-530.
[19] Poincaré H (1908) *Science et Methode*, Paris.
[20] Akerlof George A. and Robert J. Shiller (2009) *Animal Spirits: How Human Psychology Drives the Economy, and Why It Matters for Global Capitalism* (Princeton, Princeton University Press).

they can obtain capital is low, real investments will not be forthcoming, if economic growth is weak and uncertain. Under such conditions, financial speculation may seem to be a more attractive alternative. Therefore, as long as business and investment banking are not well separated, a lack of real investments may occur even when enough liquidity is available. Moreover, the availability of too much liquidity, as it can occur when cheap money is provided by central banks to fight the financial crisis, may amplify bubbles and crashes. Commercial banks may prefer to borrow at low rates from the central bank and then invest the funds in government bonds, for example. Since, in times of crisis, some of the latter yield a high rate of return, the banks can make a substantial, though risky, profit without financing any real investments.

Financial transactions on foreign currency exchange markets now amount to 3000 to 4000 billion dollars each day, which is many times the Gross World Product (i.e. the sum of the Gross Domestic Products of all countries). It is hard to imagine that such an amount of financial activity is really needed for markets to perform their basic functions well. Recall that the role of financial markets is to match as effectively as possible those who wish to invest with those who wish to borrow. However, if people invest because of their speculation on the change in asset prices rather than on the basis of the profitability of the activity that these assets represent, the situation changes. In fact, consider a situation in which many market participants are borrowing money at relatively cheap rates in the hope of earning higher profits by speculation. Because of the positive feedback (or as George Soros (1998)[21] described it, “reflexitivity” of their acts), stock prices will be driven up. This can then result in stock prices that are increasing much faster on average than economic growth. In this way, profits become “virtual” rather than real. The value of the resources on which all the holders have claims no longer corresponds to the apparent market value. Thus the owners of these assets can individually liquidate them at current prices, but if people try to do this collectively, the price of the assets will fall sharply.

While increasing stock prices allow individual investors to make large profits or to earn large bonuses, they are not sustainable in the long run. These profits are *real* for those who sell the assets when they have reached higher prices, but they are *virtual* for others, who wait for a good moment to sell. The latter, on the basis of their apparent increase in wealth, continue to buy assets or to make real investments without liquidating their financial assets. This is what economists refer to as the “wealth effect”. People act in this way in the belief that, if problems arise, they will simply be able to sell their assets at high prices, which are however artificially inflated. Hence, financial investments based on borrowing money at lower rates than the expected gain (when the latter is not based on any real increase in resources or returns) can create bubbles that are destined to burst, afterwards creating an even worse economic situation than before, as the “wealth effect” becomes negative. Influenced by their apparent loss of wealth, individuals now start to save more and to spend less, thus reinforcing the crisis.

The premise that more and more liquid financial markets are good for our economy must therefore be abandoned, particularly when the money involved goes mainly into financial speculation rather than into real economic investments. Again, we should add a caveat here, since the desire to invest the gains from financial speculation can have a significant effect on the prices of *real* assets. This is particularly evident in the case of real estate, where individuals purchase homes in the belief that their investments will be justified by an increase in house prices and, for the same reason, banks are willing to lend to risky purchasers with a

[21] Soros G, (2008) *The Crash of 2008 and what it means,* Public Affairs New York, New York.

limited capacity to repay.

Note that the faith in the benefits of increasingly liquid financial markets has often been used to justify controversial financial strategies such as:

1. high levels of leverage (which not only means that financial actors such as hedge funds were taking very large positions with very limited funds, but also that households borrowed nearly 100% of the price of their home, and that banks lent with little cash reserves);
2. "naked" short-selling (i.e. selling of financial assets or buying insurance on losses of such assets without actually owning them, which is like taking out fire insurance on someone else's home);
3. high-frequency trading (which has been greatly accelerated by the introduction of computerized, algorithmic trading).

These mechanisms have been blamed by various stakeholders for creating or amplifying instabilities in financial markets, for example, by creating "strategic distrust". In fact, all these innovations could not prevent the flash crash on May 6, 2010, and computerized trading was responsible for this event to a considerable extent. During that brief crash, stocks of some big companies were devalued by a factor of about 100, which could have completely changed the ownership structure of companies within minutes.

1.4.1 What is the role of leverage, opaqueness, and Ponzi schemes?

Leverage effects[22] have contributed to a disproportionate growth of the financial sector. There are now some 150 multi-national companies, which account for nearly half the total capitalisation of all firms.[23] Three quarters of these belong to the financial sector. This group of transnational corporations, which are strongly interlinked, poses a "too big (or too connected) to fail" problem[24] (i.e. a situation in which the failure of any of these companies might have a systemic impact on the world economy). While many other aspects of recent developments are also responsible for the shift in the control of the economy to the financial sector, the acceptance of high levels of leverage was certainly a major component in the development of hedge funds, for example.

The instability of the financial system is further increased by the lack of transparency (opaqueness). In addition to over-the-counter trades, which are never recorded in a public order book ("shadow banking"), the increased complexity of financial products largely contributes to this opaqueness. Therefore, hedging risks does not necessarily reduce those risks. It is an error to believe that an increasing number of financial instruments will increase market performance. It can, on the contrary, produce systemic instability.[25]
In fact, the complexity of financial products creates new risks, as the case of credit default

[22] For a comprehensive critical discussion of the role of leverage in exarcebating the current crisis see John Geanakoplos (2009) "The Leverage Cycle". *Cowles Foundation Discussion Paper* No. 1715 (Cowles Foundation, Yale University).
[23] S. Vitali, J.B. Glattfelder, and S. Battiston, The network of global corporate control. PLoS One 6(10), e25995 (2011).
[24] Bank for International Settlements (2011) Global systemically important banks: assessment methodology and the additional loss absorbency requirement. Available at http://www.bis.org/publ/bcbs207.pdf.
[25] F. Caccioli, M. Marsili, and P. Vivo, Eroding market stability by proliferation of financial instruments. EPJB 71, 467-479 (2009); F. Caccioli and M. Marsili, Information efficiency and financial stability, The Open-Access, Open-Assessment E-Journal 4, 20 (2010).

swaps has made very clear. Many of these financial instruments are constructed like a house of cards (with a close linkage between those who are borrowing and lending). It can collapse due to unexpected disruptions (such as the default of Lehmann brothers), but can also simply unwind as the connections cause contagion.

Warren Buffet warned of this possibility long before the current crisis emerged (see below), and he was not alone. Martin Mayer (1999) said[26]:

> "Why are such derivatives dangerous? The one lesson history teaches in the financial markets is that there will come a day unlike any other day. At this point the participants would like to say all bets are off, but in fact the bets have been placed and cannot be changed. The leverage that once multiplied income will now devastate principal."

But what did Buffet tell his shareholders?

> "Many people argue that derivatives reduce systemic problems, in that participants who can't bear certain risks are able to transfer them to stronger hands. These people believe that derivatives act to stabilize the economy, facilitate trade, and eliminate bumps for individual participants. On a micro level, what they say is often true. I believe, however, that the macro picture is dangerous and getting more so. Large amounts of risk, particularly credit risk, have become concentrated in the hands of relatively few derivatives dealers, who in addition trade extensively with one other. The troubles of one could quickly infect the others. On top of that, these dealers are owed huge amounts by non-dealer counter-parties. Some of these counter-parties, are linked in ways that could cause them to run into a problem because of a single event, such as the implosion of the telecom industry. Linkage, when it suddenly surfaces, can trigger serious systemic problems. The derivatives genie is now well out of the bottle, and these instruments will almost certainly multiply in variety and number until some event makes their toxicity clear. Central banks and governments have so far found no effective way to control, or even monitor, the risks posed by these contracts. In my view, derivatives are financial weapons of mass destruction, carrying dangers that, while now latent, are potentially lethal." (Warren Buffet, Chairman's letter to the shareholders of Berkshire Hathaway Inc. February 2003.)

Such problems apply even more to Ponzi schemes, i.e. schemes where obligations to earlier investors have to be fulfilled by using later investments. This can only be sustained for a limited time until the supply of new investors dries up. It has been argued that pay-as-you-go pension systems, which have been adopted in many countries, also have this sort of characteristic. However, if the population remains constant and life expectancy does not increase, there may always be enough newcomers to ensure the payments, while in a Ponzi scheme the number of newcomers has to be continually expanding, since all of the "oldest" investors always have a claim. Indeed, it is the very fact that life expectancy is increasing in most countries that creates anxieties over the viability of today's pension schemes.

1.4.2 The role of high-frequency trading and transaction fees

An argument that is often advanced is that the increased speed and reactivity of markets is, at

[26] Mayer M, (1999) "The dangers of derivatives", Opinion, *Wall Street Journal* May 27th 2009.

least in part, a solution to the problem of improving the efficiency of the financial sector. However, there must be fundamental concerns about systems, which run faster than humans can take qualified decisions, especially when such systems can have global impacts. In this connection, it must also be observed that each of the three financial developments mentioned in Section 1.4 have the potential to destabilize financial markets.[27] As an illustration, it may be helpful to take an example from physics, where it is known that friction may have positive sides, and where increasing liquidity corresponds to reducing the viscosity of a fluid (i.e. its internal friction). This can turn a stable, laminar flow into a turbulent flow, very much like what we observe in volatile markets. Therefore, friction in markets, as it would be produced by transaction fees (such as a Tobin tax or variants of it), should not necessarily be thought of as a problem. However, this does not, of course, mean that introducing large amounts of friction would be beneficial, since this could bring markets to a halt. The appropriate amount of friction would therefore have to be carefully and adaptively chosen.[28]

1.5. Does networking reduce risks?

An additional feature of modern economies is the rapid development and increasing connectivity of the network, which links individuals and institutions. This has frequently been cited as indicating that the diversification of risk is better and that the system is less vulnerable. However, as the observations of Warren Buffet cited in the previous section indicate, this is far from being obvious. The essential point is then, that the degree of networking and interdependency may contribute to the instability of the financial system (not just to the afore-mentioned degree of opaqueness). Thus, while some networking can distribute the risks among many market participants and reduce them (according to the statistical law of large numbers), this requires the participants to act independently. That is why a large amount of network interdependencies can create systemic risks, i.e. the danger of so-called domino or cascade effects.[29] In Section 5.1, we will further argue that too much networking can also reduce the ability to establish cooperation in the economic system, creating a situation in which the economy, society, and every single market participant can suffer losses.

1.6. The increasing spread of the wealth distribution

Finally, it is useful to point out that market instabilities can also have other important consequences, e.g. to redistribute money between market participants and create large

[27] Such instabilities are certainly increased by the possibility of circumventing "conservation laws" (by, for example, creating new credit).

[28] It is well-known that many physical systems work well only due to some degree of friction, but to avoid misunderstandings, we wish to note here that we refer to physical models and use physical analogies only in contexts where we believe we can learn something from them. In the above case, the concept of friction might be considered as a reasonable metaphor for the introduction of the Tobin tax and variants of it. We do not, however, propose to transfer physical concepts one-to-one into a financial systems setting. The use of loose analogies can generate very misleading conclusions. One always needs to systematically explore under what conditions financial or economic systems display similar dynamics, and where physical concepts need to be generalized or where it would be more appropriate to use concepts from other disciplines. A good account of the usefulness of concepts from statistical physics is given by Jean-Philippe Bouchaud (2008) in "Economics needs a scientific revolution", *Nature* **455**, 1181 (2008).

[29] A general model of this is P. Ormerod and R. Colbaugh, 'Cascades of Failure and Extinction in Evolving Complex Systems', J. Artificial Societies and Social Simulation, 9(4)9 (2006) http://jasss.soc.surrey.ac.uk/9/4/9.html; S. Battiston, D. Delli Gatti, M. Gallegati, B. Greenwald, and J.E. Stiglitz, Credit chains and bankruptcy propagation in production networks. Journal of Economic Dynamics and Control 31(6), 2061-2084 (2007); G. Tedeschi, A. Mazloumian, M. Gallegati, and D. Helbing (2012) Bankruptcy cascades in interbank markets. *PLoS ONE* **7**(12): e52749.

differences in wealth and power within a short time.[30] This may actually be a reason, why effective measures to reduce these instabilities have not yet been taken. Whether a highly unequal wealth distribution is necessary to ensure large investments or economic and societal progress, or whether it endangers social well-being, is still a matter of debate and needs to be further explored. There are clearly policies which can reduce inequality *and* promote growth whilst in other cases the two aims may be in conflict. As a recent report from the OECD explains:[31]

> "Despite a vast theoretical literature on the link between inequality and growth, no consensus has emerged and the empirical evidence is inconclusive. Still, specific structural reforms that aim at raising living standards also influence the distribution of income. Taxes and transfers, for instance, do not only affect the distribution of income; they also impinge on GDP per capita by influencing labour use and productivity. Some tax reforms appear to be win-win options – improving growth prospects while narrowing the distribution of income. Others, however, may imply a trade-off between these objectives".

Note that the existence of an unequal wealth distribution does not necessarily imply that some individuals possess special prerequisites or skills.[32] Indeed, consider the following thought experiment: Assume that at each point in time individuals make economic transactions, and that some of them are losers and some of them winners. Furthermore, suppose that it is essentially a matter of chance, who loses and who wins. Of course, it is a basic tenet of economic theory that exchanges, into which partners enter voluntarily, are beneficial to all. However, as soon as there is uncertainty, this is only true in expectation and some individuals may lose in reality. Our argument holds also when the partners all gain, as long as the gains are unequal, in which case those who we describe as "losers" are simply those who gain less. Then, in the course of many transactions, there will be some richer and some poorer market participants, just due to the laws of statistics. Of course, the richer will eventually gain more power and furthermore as a result of their wealth will have a better chance to succeed in the future,[33] and this will provide them with special opportunities that their poorer counterparts do not have. All of this means that the rich tend to get richer ("Matthew effect"). As a result of such mechanisms, even if everybody were equally wealthy in the beginning, a hierarchical organization would eventually evolve in the system, with a few rich and many poorer market participants. This corresponds to what is known as Zipf's Law[34]. This simple process, by which those who have most acquire more, is a fundamental mechanism. It can explain many distributions, not just those of income and wealth, but also the size distribution of cities, for example. If those who choose a city to live in, have a higher probability of choosing a *larger* city, this will lead to a skewed city size distribution (see Krugman (1996)[35] for a treatment of

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[30] The WEF report on "Global Risks 2012" (http://www.weforum.org/reports/global-risks-2012-seventh-edition), for example, concludes: "Economic imbalances and social inequality risk reversing the gains of globalization…", see also the following videos for some statistical facts: http://mashable.com/2013/03/02/wealth-inequality/, http://www.youtube.com/watch?v=uWSxzjyMNpU

[31] OECD (2012) "Income inequality and growth: The role of taxes and transfers", *OECD Economics Department Policy Notes,* No. 9. January 2012.

[32] See the chapter on the "Outcome Bias" in the book by Rolf Dobelli, The Art of Thinking Clearly: Better Thinking, Better Decisions. Sceptre (2013).

[33] See the section on "Multiplicative asset exchange" in S. Ispolatov, P.L. Krapivsky, and S. Redner, Wealth distributions in asset exchange models, EPJB 2, 267-276 (1998).

[34] See Aaron Krowne, "Zipf's law" (version 4). *PlanetMath.org*. http://planetmath.org/ZipfsLaw.html

[35] Krugman, P. (1996) *The Self Organizing Economy* (Wiley-Blackwell, Oxford).

this phenomenon).

If one wanted to change this natural tendency towards increasing inequality (even though no political system has succeeded with this so far), one would have to implement other mechanisms to share gains. For example, in the cake-cutting example of Sec. 4.3, the power would seem to be in the hands of the person who divides the cake. However, as soon as one allows the other participant(s) to choose the preferred piece(s) of the divided cake first, the power shifts from the divider to the chooser(s). Thus, the outcome of the 'redistribution game' discussed above depends crucially on the rules of the game.

Again, it is often said that everyone gains from free trade, and that when the tide raises all the boats rise with it. However, this is not correct. What can be shown in rather simple models is that those who gain from free trade could compensate those who lose and would still be better off. So far, however, no such general mechanism has been developed for this to happen. Hence, despite the potential gains, many individuals are losers.

However, it should not be taken for granted that inequality itself is intrinsically harmful. An unequal initial wealth distribution and the related hierarchy of power might, together with tax-based or philanthropic or other ex post redistribution measures, overall have more positive than negative effects (it may, for example, help to promote investments and coordination, and stimulate a healthy degree of competition in society). But there is an important debate on the causality here (see e.g. Kuznets (1955), Barro (2000), Banerjee and Duflo (2003), Piketty and Saez (2003), Berg and Ostry (2011), and the OECD (2012) report to which we have already referred[36]): Is greater inequality the cause or result of growth?

2. Can we rely on our current understanding of the economy?

Economics has long had the ambition to become an "exact science". Indeed, Walras, usually recognised as the father of modern economic theory, said in his *Lettre no. 1454 to Hermann Laurent in Jaffe (1965)*[37]:

> "All these results are marvels of the simple application of the language of mathematics to the quantitative notion of need or utility. Refine this application as much as you will but you can be sure that the economic laws that result from it are just as rational, just as precise and just as incontrovertible as were the laws of astronomy at the end of the 17th century."

Furthermore his successors openly declared themselves as having the same goal. However, two things raise doubts as to whether the pursuit of this ambition has achieved meaningful

[36] Kuznets, S. (1955). "Economic Growth and Income Inequality," *American Economic Review* 45, 1–28. Piketty, T., and E. Saez, 2003, "Income Inequality in the United States, 1913–1998," *Quarterly Journal of Economics*, Vol. 118, No. 1, pp. 1–39. Barro, R. J., 2000, "Inequality and Growth in a Panel of Countries," *Journal of Economic Growth,* Vol. 5, No. 1, pp. 5–32. Banerjee, A. V., and E. Duflo, 2003, "Inequality and Growth: What Can the Data Say?" *Journal of Economic Growth*, Vol. 8, No. 3, pp.267–99. Berg Andrew G. and Jonathan D. Ostry (2011) "Inequality and Unsustainable Growth: Two Sides of the Same Coin?" IMF working paper SDN/11/08 *OECD* 2012, "Income *inequality and growth*: The role of taxes and transfers", *OECD*. Economics Department Policy Notes, No. 9.

[37] *Jaffé W, (ed) (1965) Correspondence of Leon Walras and related papers, Vols I-III. North Holland, Amsterdam.*

results (see Kirman,[38] 2012). First, as in any science, models have to be built on assumptions, and it is a standard procedure to develop those assumptions on the basis of a careful analysis of the observed empirical facts. This inductive approach, however, is not the one prevailing in economics, where widespread assumptions are based on the introspection of economists. This has been acknowledged by many distinguished economists from Pareto[39] (1916) to Hicks[40] (1939) to Koopmans[41] (1957), for example. Second, and perhaps worse, the reference model in economics is one with isolated optimizing individuals. This model of "perfect competition" is considered as a useful idealization, and features such as the aggregate effects of the direct interaction between individuals are thought of as inconvenient "imperfections". However, deviations between economic theory and reality may be of crucial importance in practice, and the consideration of the links between individuals and institutions cannot be written off as being of little relevance to the behaviour of the system as a whole. This is a lesson that is clear to all those, who are familiar with the analysis of complex systems. Given the systemic impact of certain financial instruments (such as large leverage effects, the market for credit default swaps, etc.), it would seem to be unreasonable to put too much trust in conventional economic models, in which the structure of the interactions between the participants in the system is not included in the underlying assumptions.

2.1. Is it rational to believe in the 'homo economicus'?

The assumption behind the concept of the 'homo economics' is that humans behave like perfect egoists, and Poincaré (1996)[42] criticized Walras for this. However, the rational, strictly optimizing behaviour behind this assumption can be questioned for a number of reasons. This includes the fact that many optimization problems cannot be solved in real-time, even with supercomputers. Further problems result from a lack or uncertainty of information, or limited memory and processing capacities of humans. Furthermore, as a matter of principle, it is impossible to have an exact representation and simulation of the whole world and its future (including the states of the brains of all other people) in one single brain. Besides, there are many empirical and experimental studies that question the assumption of strict rationality as formulated by economists, and some of this critical work has even been rewarded with Nobel prizes in economics.[43]

This suggests that the assumption of isolated optimising agents is at best questionable and that one can, furthermore, not rely on the idea that a system of such agents will automatically self-organise in an *efficient* way. This leads naturally to the next question.

2.2. Are financial markets efficient?

The basic role of financial markets is to ensure the best possible matching between those who wish to place their money and those who need to borrow it to finance their projects. To achieve this, it is argued that markets should ensure the transmission of all the information

[38] "Walras' Unfortunate Legacy" in Bridel P (ed) *General Equilibrium Analysis: A Century after Walras* (Routledge Studies in the History of Economics) 2012.
[39] Pareto, V. (1916) Trattato di sociologia generale, 2 vols., Florence: Barbera; 2nd edn, 3 vols., Florence, 1923; transl. A. Bongiorno and A. Livingston, The mind and society, 4 vols., London: Cape, 1935.
[40] Hicks, John (1939) *Value and Capital*, Oxford, Oxford University Press
[41] Koopmans, T. (1957) Three essays on the state of economic science, New York: McGraw-Hill.
[42] Letter appended to Walras, L. (1960), ÉCONOMIQUE ET MÉCANIQUE. Metroeconomica, 12: 3–11. doi: 10.1111/j.1467-999X.1960.tb00510.
[43] See D. Helbing and S. Balietti (2010) Fundamental and real-world challenges in economics. *Science and Culture* **76**(9-10), 399-417, where also further theoretical inconsistencies are discussed.

necessary to the parties involved. Indeed, the efficient market hypothesis assumes that this will be the case and market mechanisms will guarantee that all the information relevant for the value of an asset will, at any point in time, be contained in the price of that asset. Indeed, it is assumed that any possibility to make systematic profits will be neutralized immediately by trades exploiting this opportunity. Moreover, with little theoretical justification, it is assumed that the arbitraging away of profitable opportunities will be a stable process and that the market will immediately return to equilibrium. Both behavioural and experimental economics, however, have shown that there can be "excess movements" in positive and negative directions, even when the fundamental value of the asset is well defined and known to all market participants.[44] Such herding is not necessarily "irrational", since following the trend can be profitable in the short run, especially if one is among the first to notice and profit from a switching trend. (Note that many traders in financial markets are paid on the basis of their short run profits and may even be forbidden to take long positions.)

However, if the efficient market hypothesis were satisfied, herding effects, bubbles and crashes should not occur. This is because of the implicit assumption of the underlying theory that traders will make investments based on their own, independent observations and will not infer information from the behaviour of others. Unfortunately, the information feedback through stock markets promotes trend following and correlated decisions, which may undermine the wisdom-of-crowd effect and affect the efficiency of the market.[45]

The random walk hypothesis underlying the theory of efficient financial markets goes back to Bachelier[15] (1900), who assumed that individuals would act independently of each other. However, as we pointed out, already the distinguished French mathematician Poincaré (1900)[46] warned that this was not the case. He rather said that people have a natural tendency to act like "sheep", see also Akerlof and Shiller (2009)[47] or Chamley (2004)[48]. This undermines the whole idea on which the efficient markets hypothesis is based. In fact, most financial traders do not seem to believe in efficient markets, as they are theoretically postulated and do not see their activity as being to arbitrage away opportunities created by small deviations from fundamental values. They rather tend to take positions based on their anticipation of trends in the market, or based on attempts to trigger such trends.

2.3. Are emotions and social factors irrelevant?

The assumption of the isolated "homo economicus" acting according to some abstract assumptions governing his rationality also tends to neglect cognitive, human and social factors, such as individual learning, emotions, and conformity to social norms. For a realistic understanding of individual behaviour, it is necessary to take such factors into consideration. For example, most individuals have a tendency towards fair behaviour, as Adam Smith, in his less widely cited work, "The Theory of Moral Sentiments"[49] emphasised. However, this is not

[44] C. H. Hommes, Modeling the stylized facts in finance through simple nonlinear adaptive systems. Proceedings of the National Academy of Sciences of the USA (PNAS) 99, Suppl. 3, 7221-7228 (2002).
[45] J. Lorenz, H. Rauhut, F. Schweitzer, and D. Helbing (2011) How social influence can undermine the wisdom of crowd effect. *Proceedings of the National Academy of Sciences USA (PNAS)* **108**(28), 9020-9025.
[46] Poincaré H (1900) Rapport sur la these de Louis Bachelier Université de Paris Sorbonne.
[47] Akerlof, G. and R. Shiller (2009) Animal spirits: How human psychology drives the economy, and why it matters for global capitalism (Princeton, NJ: Princeton University Press).
[48] Chamley, C. (2004) *Rational Herds* (Cambridge: Cambridge University Press).
[49] Smith, A. 1976 (1759) *The Theory of Moral Sentiments* (eds). D. Raphael & A. L. Macfie). Oxford, UK: Oxford University Press.

consistent with the assumption of strict maximization of narrowly defined self-interest.[50] In fact, recent research indicates that other-regarding preferences can spread even in a competitive evolutionary setting, in contrast to what has been assumed in the past.[51] Recent work by Seabright (2004)[52] and by Bowles and Gintis (2012)[53] follows an evolutionary approach to economic cooperation as well. The adoption of social norms can also overcome the tendency to "free ride" – an inherent feature of a number of social dilemmas. Perhaps surprisingly, restricting individual selfishness by complying with social norms can not only lead to a better *systemic* performance, but also to better *individual* performance in the long run (Grund, Waloszek, Helbing[51] 2013). This idea is at the heart of the notion of "team reasoning" developed by Bacharach (2006)[54].

2.4. Can the collective behaviour of agents be understood from a "representative" individual's behaviour?

Another widespread assumption in macroeconomic theory is that the economy or some sector of it can be thought of as behaving like a 'representative agent'. According to this, the behaviour of the economy can be analysed by considering the aggregate economy as if it were one typical agent reacting to aggregate economic variables. This basically implies that the differences between agents of the same kind (e.g. traders, companies, institutions or other stakeholders) are unimportant or cancel out on average. Therefore, it suffices to analyse one average agent who effectively represents the behaviour of all of them.

The reasons for making this assumption are clear: With our usual, highly restrictive assumptions on agents, we cannot be sure that economic equilibrium, which is the focus of most economic models, is either unique or stable[55]. This makes the analysis of the effects of changes in the economy or of policy measures analytically intractable. By adopting the representative agent approach, this problem is avoided, but by doing so, heterogeneity in individual preferences as well as local, network and context effects are neglected. Thus the representative individual is just the average of many individuals, each responding rationally to the full set of information.

This "mean field approximation" would probably work reasonably well, if all individuals would only interact with each other globally, for example through a shared market. However, the approximation is likely to fail in other contexts. In social dilemma situations or public goods problems, for example, global interaction can lead to the breakdown of cooperative behaviour due to selfish optimization, a scenario that is known as the "tragedy of the commons". Local interactions, in contrast, may promote cooperation under otherwise identical conditions.[56]

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[50] E. Fehr and K. M. Schmidt, A theory of fairness, competition, and cooperation. *The Quarterly Journal of Economics* **114**(3), 817-868 (1999).
[51] T. Grund, C. Waloszek, and D. Helbing, How natural selection can create both self- and other-regarding preferences, and networked minds. Sci. Rep. 3: 1480 (2013).
[52] Seabright, Paul (2004). *The Company of Strangers*: A Natural History of Economic Life. Princeton and Oxford: Princeton University Press.
[53] S. Bowles and H. Gintis (2012) *A Cooperative Species: Human Reciprocity and Its Evolution* (Princeton, N.J.: Princeton University Press).
[54] M. Bacharach (2006) *Beyond Individual Choice: Teams and Frames in Game Theory* (Princeton, NJ: Princeton University Press, 2006).
[55] This was shown by Sonnenschein, Mantel, and Debreu in the mid '70s. For a summary of their findings and how this led to the use of the representative agent, see A. Kirman (1992) 'What or whom does the representative individual represent?' *Journal of Economic Perspectives* **6**(2): 11-36.
[56] D. Helbing, A. Szolnoki, M. Perc, and G. Szabó (2010) Evolutionary establishment of moral and double moral standards through spatial interactions. *PLoS Computational Biology* **6**(4), e1000758.

2.5. Does the 'invisible hand' really exist and work?

Finally, it is important to point out that, for an economic system to work well, it is not sufficient that all the individual components are well designed and behaving optimally. In contrast to what one might expect according to the modern (re)interpretation of the principle of the "invisible hand", the interactions of the components of a system with network interdependencies can lead to coordination failures or to a malfunctioning of the system and its components.[57]

Of course, instances of "market failure" are well-known in economics, but it is usually argued that they constitute an exception, resulting for example from market power (such as "monopolies"), externalities, or information asymmetries. In contrast to this, there is also a possibility that market systems fail when all market participants have *equal* power and there are no asymmetries or negative externalities. Even if all the interacting partners have the very best intentions, their interactions can produce undesired outcomes, such as crowd disasters (Helbing[12] 2013).

In fact, the interaction of components that individually try to optimize their expected outcome (i.e. behave perfectly rationally from their own point of view, as assumed for the "homo economicus") can lead to a situation, where the system gets stuck in a suboptimal state. The tragedy of the commons mentioned above is a good example of this. The approach used to analyse that problem is non-cooperative game theory, and it is one of the few areas of economics that takes the consequences of the direct and conscious interaction between individuals explicitly into account. It is important to note that, for most equilibria of non-cooperative economic games, the result is socially suboptimal.

If we pay attention to dynamical issues, it turns out that the system may also behave in an *unstable* way. To take a well-known example, a spontaneous breakdown of free traffic flows can happen even in the absence of bottlenecks or other external reasons, as delayed adaptations to small variations in the traffic flows may cause over-reactions and chain reactions that finally force drivers to stop. Interestingly, traffic flows tend to destabilize when the system reaches its greatest efficiency, i.e. the maximum flow. This instability causes a considerable reduction in the effective freeway capacity. In other words, dynamic interactions can cause a loss of capacity, just when the system reaches the point of maximum capacity!

Such unstable behaviour is quite unexpected, particularly as it happens despite everybody's best efforts to prevent it (Helbing[12] 2013). Nevertheless, similar phenomena may also occur in economic systems, for example, recession periods or sudden meltdowns in the financial system. One of the insights from this is that the financial system may be affected even in the absence of external shocks and even when all the individual stakeholders in the system appear to be in good order. This may explain why most economic experts did not see the financial crisis coming. A familiarity with complex systems analysis would have shown that it is not enough to examine the state of the individual components of a system, but one also has to examine the network that links them, if one wants to be able to understand and detect systemic problems such as a possible cascade effect. These factors have not been considered by banking regulations for a long time. The initial Basel agreements just focused on the vulnerability of individual banks rather than on their role in the system. Recently this

[57] C. Roca, M. Draief, and D. Helbing, Coordination and competitive innovation spreading in social networks. In: D. Helbing (ed.) Social Self-Organization (Springer, Berlin, 2012).

attitude is changing, particularly as result of the work on financial networks conducted by the Bank of England (see Haldane and May[58] 2011).

3. Can we stop domino effects in our financial system?

3.1. Domino and cascade effects

Given the various sources of instability, which we have discussed in the previous sections, the question of the systemic impacts of such instabilities occurs. In fact, a problem in one sector of an economy can trigger problems in other sectors of that economy, and a weakness of one financial asset can trigger the weakness of related financial assets.[59] For example, what started as a US real estate bubble (when more and more people were buying houses with bank loans with little or no down payment and often no guaranteed income, based on the expectation of rising prices) eventually ended in a global crisis. Even though the subprime mortgage problem was substantial, it could have been easily covered by the American government (or tax payer). Clearly, the decision to support banks (instead of house owners) through a historical bailout plan, was insufficient to prevent the crisis. Instead, the US subprime mortgage crisis became a crisis of mortgage companies, of lenders, of home builders, of financial markets, of the US economy, of the world economy, and of political and social systems in various continents all over the world. In other words, trouble in one part of the system can affect other parts of the system through cascade effects, and this can turn a local problem into a costly global crisis.

3.2. Is there a chance to cope with financial crises?

So far, the financial, economic and public spending crisis has created losses of many trillions of US dollars worldwide, and it is far from evident that the worst has passed. Only few would argue that the macro economy during the crisis has just performed a shift to a new equilibrium. Therefore, it is both necessary and urgent to develop non-equilibrium models allowing one to explore the consequences of certain economic policies (such as austerity measures to reduce public spending deficits). Cascade failures such as the one described above are more difficult to imagine than a system which is generally in a steady state, but occasionally gets knocked off its equilibrium by some unexpected exogenous shock. This is true, because such cascades have a probabilistic nature, and moreover, they are based on complicated, delayed feedback effects and network interdependencies, which can lead to counter-intuitive system behaviours. As a consequence, the same cause can have different effects, and the same effect can have different causes. Moreover, each further step in the cascade effect leads to a deterioration in the situation and diminishes the chances of recovery further, so that larger and larger parts of the system are affected. Note that, due to the network nature of cascade effects, the next “act” of the crisis can be triggered by many different events, or even by minor random variations (and correlated responses to them) (Helbing[12] 2013).

However, although the exact timing of major events in failure cascades cannot be predicted, the symptoms of systemic weaknesses can be recognized, and possible onsets of the deterioration can often be anticipated. This in itself can help to identify possible

[58] Andrew G. Haldane and Robert May, Systemic risk in banking ecosystems**.** *Nature* 469, 351-355 (2011).
[59] Preis, T., Kenett, D.Y., Stanley, H.E., Helbing, D., and Ben-Jacob, E. Quantifying the behaviour of stock correlations under market stress. *Scientific Reports* **2**: 752 (2012).

countermeasures.[60] To stop successive cascades before the worst-case scenario has happened, one needs to strengthen the robustness of those system components, which are likely to be endangered next, thereby potentially endangering others. In addition, effective crisis management requires one to elaborate and exercise contingency plans (a "plan B", a "plan C", etc.), to act quickly[61], and to have a backup system (such as a second financial system), see the discussion below.

3.3. Can the financial system cope with cascade effects?

The dramatic failure in stabilizing the financial system seems to be due to a number of causes:

1. The architecture of the financial system lacks mechanisms to stop cascade effects, while such mechanisms are standard, for example, in our electrical system. The latter has in-built circuit breakers to stop local problems from propagating. Similarly, our computer systems have firewalls.
2. According to the dominant paradigm of equilibrium economics and efficient markets, such instabilities and cascade effects should not happen at all. Therefore, it may not have seemed necessary to work out contingency plans and to implement suitable safety precautions.

The basis for this attitude was a model, which assumed that all the market participants have a complete (or at least sufficient) understanding of how the economy works while, as Bernanke observed:

> "I just think it is not realistic to think that human beings can fully anticipate all possible interactions and complex developments. The best approach for dealing with this uncertainty is to make sure that the system is fundamentally resilient and that we have as many fail-safes and back-up arrangements as possible." (Ben Bernanke in an Interview with the IHT, 17 May 2010)

Banks in the current system are very closely interlinked both through transactions and loans and through joint ownership. Most of the current discussion focuses on which banks are "too big to fail" and this now involves considerations of the banks' role in the network as contributors to systemic risk. However, one way to make the system more resilient might be to put in place regulations, which encourage the establishment of several independent or weakly coupled, parallel banking systems, which compete with each other. Most of current regulatory practices are focused on competition *within* the existing system, without envisaging competition *between* systems. In each such banking system, the participating banks could be strongly interdependent; however, the dependence on banks of competing systems should be weak.

Historically, the tendency has been in the opposite direction: the banking systems of different countries have become increasingly interdependent and, by 1994, the Riegle-Neal Act had effectively removed the remaining barriers to interstate banking within the United States. Later, the passage of the Gramm-Leach-Bliley Act (GLBA) on November 12, 1999 was

[60] D. Helbing, H. Ammoser, and C. Kühnert (2005) Disasters as extreme events and the importance of network interactions for disaster response management. Pages 319-348. in: S. Albeverio, V. Jentsch, and H. Kantz (eds.) *Extreme Events in Nature and Society* (Springer, Berlin).
[61] K. Peters, L. Buzna, and D. Helbing (2008) Modelling of cascading effects and efficient response to disaster spreading in complex networks. *Int. J. Critical Infrastructures* 4(1/2), 46-62.

enthusiastically greeted as a move towards a more efficient banking system. Based upon an analysis of more than 60 countries differing widely in location and economic development, Barth, Caprio and Levine (2000, p. 26)[62] found that

> "…the tighter the restrictions placed on this [securities] activity... the more inefficient are banks and the greater the likelihood of a banking crisis. The likelihood of a banking crisis is also greater... the tighter the restrictions placed on bank ownership of nonfinancial firms."

They further conclude that:

> "…none of these [securities, insurance, real estate and ownership] restrictions produce any beneficial effects with respect to financial development, nonbank sector and stock market development, or industrial competition. Nor is it found that any of them lessen the likelihood of a banking crisis or enhance bank efficiency."

The crisis has shown how misguided this judgement was. What is needed now is a set of positive measures such as those we have proposed to enable a certain separability of the system. Thus, rather than restricting oneself to strategies which are trying to stabilize the financial system but effectively entail bigger and bigger systemic risks, one should develop suitable decoupling strategies to stop possible cascade and contagious spreading effects.

Currently, the financial system does not seem to have the in-built decoupling strategies (such as reliable "breaking points"), which would allow one to separate affected parts of the system from the rest. In the current system some components become "too big to fail", but as two recent books by Blinder (2013) and Admati and Hellwig (2013) have pointed out, this only incentivises banks to take actions that make the system increasingly fragile. Both argue for regulation to substantially reduce the vulnerability of both the components and the system.[63] Note, however, that the financial system has had a more resilient architecture before. The Glass-Steagall Act had regulations in place, which successfully counteracted systemic problems, until this law was terminated by banking deregulation. It would seem to be necessary to have a modern successor to such regulations. In fact, after the Volker report in the US and the Vickers report in the UK, which both envisage a clearer separation between commercial and investment banks, France was also envisaging similar measures but seems to have retreated to a more passive position.

A separation of banks into commercial banks and investment banks seems to be one reasonable step towards a better decoupling of system components. This should, contrary to the assertions of those in the banking sector, improve the allocation of capital and risks in the financial system. Of course, there would still be a financial exchange between commercial banks and investment banks, but this could be adaptively regulated (and taxed) according to needs, thereby providing central banks with additional control parameters (see Section 4.2). The important point is that banks, whose investments outweigh GDP in some countries, should not have the risks of their trades borne by governments. Whilst commercial banking, which is essential to the functioning of the economy, merits some public insurance, the same argument cannot be made for investment banking. John Kay indicates in his report to the UK government that, in terms of stimulating real activity, the financial sector's role has been, at

[62] Barth, James R., Gerard Caprio, Jr. and Ross Levine. 2000. "Banking Systems Around the Globe: Do Regulation and Performance Affect Performance and Stability?" NBER Conference on Prudential Supervision: What Works and What Doesn't. Islamorada, Florida, January 13-15.
[63] Admati, A. and M. Hellwig (2013), The Bankers New Clothes, Princeton, Princeton University Press. Blinder, A. (2013), After the Music Stopped, New York, The Penguin Press.

best, limited. It is worth quoting Kay at length since he indicates that the build-up of confidence, on which all markets ultimately depend, is far from being the product of simple financial incentives.

> "Financial intermediation depends on trust and confidence: the trust and confidence that savers who invest funds have in those they choose to manage these funds, and the trust and confidence of investors in the businesses they support. Trust and confidence are the product of long-term commercial and personal relationships: trust and confidence are not generally created by trading between anonymous agents attempting to make short term gains at each other's expense.
>
> Trust and confidence, or their absence, are the product of the prevailing culture. Incentives matter: not because, as some people crudely think, financial rewards are the only human motivation – although there are some people of whom that is true, and many of them are to be found in the financial sector. Most people have more complex goals, but they generally behave in line with the values and aspirations of the environment in which they find themselves. We must create cultures in which business and finance can work together to create high performing companies and earn returns for savers on a sustainable basis. These themes – the dependence of successful financial intermediation on trust and confidence, the importance of incentives – are central to this Report. Taken together, rather than separately, they imply a financial world different from our recent experience." [64]

4. Is our current financial system manageable?

4.1. Can competition in one dimension work?

Currently, Europe is facing a serious financial, spending, and political crisis. This crisis still seems likely to endanger the stability of the EURO currency, and it may even challenge the stability of the European Union. The cause of this crisis is generally seen to be the lack of budgetary discipline. This, however, explains only part of the problem. It was, maybe, unavoidable that this situation would sooner or later occur, because of a fundamental weakness in the design of the economic union: it seems logical that competition in a single dimension (the gross national product per inhabitant) will sooner or later lead to winners and losers, and that losers would eventually need help.

It is common practice in economics to reduce complex outcomes to a single variable. Index numbers such as inflation are a mapping of many dimensions to a single dimension, but this is like comparing apples with pears. In doing so, as has frequently been observed, one treats inflation, for example, as if it were the same for everyone. But, of course, those whose expenditure is concentrated on a limited number of goods tend to be affected most. People at or close to subsistence level are primarily concerned with the evolution of food prices and home rents, and the latter are only part of the overall consumer price index.

We consider this desire to reduce measures of economic success to a one-dimensional

[64] Department for Business Innovation and Skills. The Kay Review of UK Equity Markets and Long-Term Decision Making, Final Report, July 2012.

criterion of monetary value to be a fundamental problem. It forces the multi-dimensionality of our world into one single dimension. Recently, however, it is more and more recognised that, for example, measuring the welfare of a nation by its GNP per capita is highly misleading. Indeed the report of a committee led by Joe Stiglitz and Amartya Sen, involving five Nobel prize winners in economics, gives weight to the view that such a simple measure is inappropriate. The commission states specifically,

> "To define what well-being means, a multidimensional definition has to be used. Based on academic research and a number of concrete initiatives developed around the world, the Commission has identified the following key dimensions that should be taken into account. At least in principle, these dimensions should be considered simultaneously:
>
> i. Material living standards (income, consumption and wealth);
> ii. Health;
> iii. Education;
> iv. Personal activities including work;
> v. Political voice and governance;
> vi. Social connections and relationships;
> vii. Environment (present and future conditions);
> viii. Insecurity, of an economic as well as a physical nature.
>
> All these dimensions shape people's well-being, and yet many of them are missed by conventional income measures." [65]

As the report emphasises, what is important is societal well-being and not the monetary value of production. What matters is people's perception of well-being, and this involves many aspects such as people's perception of their absolute and relative situation. Thus, a simple measure, which mixes the monetary value of production and the psychological aspects of well-being, is a highly inadequate criterion. Even apparently satisfactory quantitative measures such as individual wealth in terms of holding financial assets can be influenced by psychological considerations. For example, a breakdown of trust among the participants in financial markets can cause huge market losses in a very short time. (While possibly to the benefit of a few, it generated a rapid decline in the perceived wealth of many individuals.)

Note that attempts to reduce complicated problems to the measurement of one-dimensional indices results in efforts to use monetary incentives for the management of many societal challenges, but these are often ineffective. Monetary incentives or disincentives are used to control many processes in economics and society at the same time: for example, governments try to influence the behaviour of people through various taxes and benefit schemes, and companies through taxes and subsidies. It must be recognized, however, that it is impossible to control many different types of behaviour in this way at the same time. Trying to influence many different behavioural dimensions with just a single variable will typically lead to situations, where improvements in one dimension imply deteriorations in other dimensions. In fact, this problem appears to be quite common and is also mentioned specifically by the Stiglitz-Sen commission. Challenges such as sustainable development are generally not manageable by simple one-dimensional measures.

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[65] Report by the Commission on the Measurement of Economic Performance and Social Progress to the French Government April 19th 2009, pp. 14-15, see http://www.citymaking.com/wp-content/uploads/2010/01/19784660-Happiness-and-Measuring-Economic-Progress-by-Joseph-Stiglitz.pdf

Thus, would our economic system be better controllable and more sustainable, if we replaced one-dimensional monetary incentives by multi-dimensional value and incentive systems? The fact that social systems have many different reward mechanisms suggests that this may actually have added value.[66] It is obvious that these different dimensions cannot be freely converted into each other, but they would probably not exist if they would not be favourable for the functioning of social systems. Therefore, it might be beneficial to replace the largely one-dimensional incentive system in our economy by an explicitly multi-dimensional one. In fact, the existence of many currencies and varieties of budget spending rules can be thought of as ways to compensate for the deficiencies of a unified, freely convertible, currency. Moreover, money that is too easily convertible may tempt its users to move their investments around rapidly, constantly searching for the slightest return and thus diminishing longer-term investments.

Introducing multi-dimensional money or value ("qualified money")[84] would be feasible in practice. It may be imagined as being akin to having several different 'bank accounts', but each with different rules and with limited possibilities of conversion. Some of these dimensions would relate to economic capital, but others to "human capital" (such as individual skills), and again others to "social capital" (such as cooperativeness, trust, and other network-based variables that contribute to the fabric of society).

Multi-dimensional criteria would make it possible to influence each single dimension separately, not just their weighted sum. In the simplest case, such influence could be exerted by incentives or sanctions (but there are also more sophisticated mechanisms such as reputation systems). Instruments like these could also be used to adaptively influence *conversions* between the *different* dimensions. Furthermore, such instruments would allow one to decouple the dynamics in different socio-economic dimensions, if needed. From a control-theoretical perspective (see Section 4.2), the system would become better manageable in ways that are compatible with individual decision-making and self-organization of the system.

Note that the approach of multi-dimensional value offers not just *one* way of being successful. It offers *many* ways. In the virtual worlds and economies created by information and communication technologies of the future, it might be possible to realize thousands of different dimensions. Keeping a multi-dimensional indicator means that one can reward the specific contributions of individuals rather than judging them all by the same criterion. This would allow one to make sense of the notion of heterogeneity or "socio-diversity", as we might refer to it. The recognition of the differences between individual contributions is, as it has been argued, the basis on which innovation thrives. In contrast, homogeneity, as it is sometimes promoted by businesses, political systems and academic institutions with the goal of making comparative assessments or standardization easy, can endanger a flourishing socio-economic ecosystem. In this connection, it is important to remember that a rich ecosystem lives on many nutrients and resources, not just one.

4.2. What are the possibilities and limits of management and control?

In Section 1, it was pointed out that complex dynamical systems are difficult to control. That is why regulators have so much difficulty in taming financial and economic systems. This is not

[66] A. P. Fiske, Structures of Social Life: The Four Elementary Forms of Human Relations (The Free Press, 1993).

just a matter of opacity (i.e. a lack of transparency). It also results from the collective dynamics that is characteristic for systems with strongly interdependent components. In fact, while loosely connected systems are characterized by the properties of their components and can be satisfactorily controlled by managing them individually, strongly coupled systems are fundamentally different. They show emergent collective behaviour, which results from the interactions of their components. In other words, the interactions dominate the system behaviour. Feedback effects, network interactions, and counter-intuitive behaviour make complex systems difficult to understand and to manage. In many of these systems, cascade effects and extreme events occur much more frequently than would be expected in systems with less interdependence. Due to interaction-based systemic instabilities, the system behaviour may get out of control even if all system components behave close to optimally (Helbing[12] 2013).

Issues of controllability of systems are studied by the science of cybernetics. Controlling a system requires the ability to measure and influence particular variables of the system, so-called control parameters. In most systems, such as chemical production systems, it is not enough to control *one* variable. System control can be quite subtle, and a lack of certain pieces of information can imply a loss of control.

Recently, the application of control-theoretical methods to networks has attracted considerable attention.[67] The good news is that taming complexity seems to be possible, if the system design is appropriate. The bad news is that this needs sophisticated algorithms to identify the control variables that influence large parts of the system, and also suitable means ("instruments") to influence these variables. Successful system management, furthermore, requires the right kind, amount, and quality of measurement data in real time.

Indeed, in order to be efficient, regulatory institutions need to be able to act globally, to collect all the relevant data required to monitor and judge the state of the system, and to have suitable instruments at their disposal to influence the system dynamics. Today, there is a lack of global institutions, a lack of data (e.g. regarding the mutual interdependencies of companies that might have a systemic impact), and a lack of knowledge regarding possible control variables that would potentially allow one to manage the complex systems humans have built. Moreover, some systems (including the current financial architecture) have evolved in a way that makes a global-scale loss of control quite likely.

However, it would be possible, for example, to create new instruments to reduce excessive volatility in the market dynamics. In this connection, one should evaluate the usefulness of transaction fees (for money transfers between business and investment banking and for financial trading) such as variants of the "Tobin tax"[68]. A more unconventional idea would be to influence the level of fluctuations in stock markets.[69] The latter could be reached by a certain rate of random buy and sell transactions of currencies or assets. This would increase the risk of trading these, thereby reducing the appetite for mere financial speculation. Such and approach would suggest that the pre-crisis "Great Moderation" fuelled greater risk taking.

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[67] Liu, Y.-Y., Slotine, J.-J., and Barabasi A.-L. (2011) Controllability of complex networks. *Nature* **473**, 167-173.
[68] Eichengreen, Barry; Tobin, James; Wyplosz, Charles (1995). "Two Cases for Sand in the Wheels of International Finance". *Economic Journal* **105** (428): 162–72.
[69] Physics for Financial Markets, AlphaGalileo, January 27, 2011, see http://www.alphagalileo.org/ViewItem.aspx?ItemId=94550&CultureCode=en

4.3. Can one promote beneficial self-organization and self-regulation?

The question now becomes: if regulation, as currently defined and practiced, is not suited to control financial and economic systems, how is it then possible to manage their complexity? One may try to find and establish (after previous testing) a set of rules for the various economic stakeholders and their interactions in such a way that it is likely to promote a self-organization towards optimal and stable system behaviour. This would build on the idea of mechanism design (see Hurwicz and Reiter,[70] 2006), and take it further to the level of "integrative systems design",[71] with its particular focus on the emergent properties resulting in complex systems.

Note, however, that small details of interaction rules aiming at better coordination may be quite decisive. For freeway traffic, for example, it has been shown that slightly modifying the interactions between successive vehicles can avoid many traffic breakdowns.[72] Changing the car-following behaviour in certain ways allows one to stabilize traffic flows and, to some extent, even compensate for traffic bottlenecks. In this way, congestion and its negative impacts on environment can be significantly reduced, and annoying increases in travel times even more. Along similar lines it has been argued that limiting high-speed trading would be beneficial for the stability of the financial system. While traffic flowing at maximum capacity on roads might seem to reflect efficiency, it can lead to sudden capacity breakdowns and consequential traffic jams. Measures to limit speed can often be beneficial. A similar approach in financial systems might help to counter recessions and other kinds of economic instabilities.

Analogously, modifying the economic "rules of the game" might have positive systemic impacts (meaning, for example, that markets would indeed become more efficient and that the principle of the invisible hand would work). Let us discuss a simple example on sharing behaviour[73] that illustrates how changing the rules governing interaction can change the outcome: if the person who is supposed to cut a cake is allowed to choose first, he or she will tend to take the biggest piece or even the whole cake. In contrast, if he or she is supposed to take last, this will promote a fair sharing of the cake. In fact, as shown by many experiments, people seem to have a preference for fairness (see Fehr and Schmidt[74] 1999 and the body of work on the "ultimatum game"). Fair behaviour also seems to promote social welfare (Grund, Waloszek, Helbing[51] 2013). Quite generally, symmetrical interactions have a tendency to drive a system towards its optimum,[75] while asymmetries tend to promote local optima and market failures.

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[70] Hurwicz L and S Reiter (2006) *Designing Economic Mechanisms*, Cambridge, Cambridge University Press.
[71] Helbing, D. and Balietti, S. (2011) From social simulation to integrative systems design. *EJP Special Topics* **195**, 69-100.
[72] A. Kesting, M. Treiber, M. Schönhof, and D. Helbing (2008) Adaptive cruise control design for active congestion avoidance. *Transportation Research C* **16**(6), 668-683.
[73] Carvalho, R., Buzna, L., Just, W., Helbing, D., and Arrowsmith, D.K. (2012) Fair sharing of resources in a supply network with constraints. *Phys. Rev. E* **85**, 046101.
[74] Fehr, E. and Schmidt, K.M. (1999) A Theory Of Fairness, Competition, And Cooperation, *The Quarterly Journal of Economics* **114**(3), 817-868.
[75] Helbing, D. and Vicsek, T. (1999) Optimal self-organization. *NJP* **1**, 13.

5. Do companies and banks really maximize their benefits?

5.1. Can coordination and cooperation fail spontaneously?

One might expect that financial institutions, like any other privileged institution in our society (such as political parties, religions, etc.), should benefit society, and not exploit it. If an institution fails to perform its function properly, it makes sense to reform or replace it. In the case of the economy, it is time to revise the more than 300 year old paradigm of the 'invisible hand', according to which, when every market participant acts selfishly in his or her best interest, this will also improve social well-being. In fact, scientific studies show that, even for an idealized coordination problem (where people have to decide between two or more alternatives and would benefit from a consensus), a system-optimal solution is not obtained when there are network interactions and transaction costs.[76] The situation is even worse in social dilemma situations. There, everybody does very well if everyone cooperates, but any single individual is even better off by *not* cooperating, while the others do so. In other words, in social dilemma situations there is a temptation to be non-cooperative (a "free rider"). Consequently, there is a tendency for cooperation to erode. The logical consequence is a so-called "tragedy of the commons" (Hardin[77] 1968), where everybody ends up in a situation that is much worse than if everybody cooperated. Such tragedies can be overcome and cooperation restored by a number of mechanisms. These mechanisms include repeated interactions, reputation mechanisms, sanctioning of non-cooperative behaviour, and local neighbourhood interactions.[78]

When regional interactions are replaced by global interactions, or if the interaction network in the system becomes too dense, cooperation may be endangered (see Dalton and Rohrschneider[79] 2002; Helbing[12] 2013). The expected result is a self-destabilization of cooperation. Similar destabilization phenomena are observed, when fluid traffic flows break down, or if orderly pedestrian flows turn into crowd disasters. It is likely that transforming the banking system from a regional organization into a "global financial village" was a root cause of the financial crisis. In fact, the banking network became more and more tightly connected in the decade before the financial crisis (see Haldane[80] 2009). Complementary to this we would like to mention the work of Nobel Prize winner Elinor Ostrom, which suggests that a decentralized, local decision-making can lead to better outcomes, if properly organized (see Ostrom *et al.*[81] 2010).

Our globalized financial and economic system instead seems to have created various "tragedies of the commons". For example, the global trading of goods produced under lower social and environmental standards than required in Western countries has poisoned the environment around the production sites even though these sites may be producing for international firms who, in their own countries have to respect higher standards. Furthermore,

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[76] C.P. Roca and D. Helbing (2011) Percolate or die: Multi-percolation decides the struggle between competing innovations. Preprint http://arxiv.org/abs/1101.0775. See also: D. Helbing, Social Self-Organization (Springer, Berlin, 2012).
[77] Hardin, G. (1968). "The Tragedy of the Commons". *Science* **162** (3859): 1243–1248.
[78] D. Helbing and A. Johansson (2010) Cooperation, norms, and revolutions: A unified game-theoretical approach. *PLoS ONE* 5(10), e12530.
[79] Dalton Russell and R Rohrschneider (2002) A Global Network? Transnational Cooperation among Environmental Groups. *Journal of Politics* **64**(2), 510-533.
[80] Haldane, A. (2009) 'Rethinking the financial network', Speech delivered at the Financial Student Association, Amsterdam.
[81] Ostrom E, Amy R. Poteete and Marco A. Janssen *Working Together: Collective Action, the Commons, and Multiple Methods in Practice*, with Princeton, NJ: Princeton University Press, 2010.

in many Western countries, globalisation has endangered reasonably paid jobs and weakened the social benefit systems (if any), since there are currently no mechanisms by which those who gain from cheaper imports compensate those who become unemployed. This has also damaged the social fabric on which our societies are built (e.g. social capital like cooperativeness and trust).

Another emergent problem seems to be that food, water and other essential resources increasingly become unaffordable for the poorer inhabitants of the world, even though most of these resources could be available in sufficient quantities. This is in part due to increasing demand from emerging countries, in part due to financial speculation, but also due to climate change and biofuel production trying to confront it. Financial speculation has, to a large extent, been in commodity futures and has produced significant spikes in the prices of agricultural products recently. These developments may deprive people who used to own the same resources (e.g. land) before, thereby creating social and economic problems rather than reducing them. A striking example of this is the large-scale purchases of agricultural land in Africa by other countries, increasing the dependency of the local population (see Castel and Camara[82] 2009).

5.2. Are the ethically behaving ones always the stupid?

In our current economic system, it appears that moral behaviour is costly. Therefore, it is expected to disappear due to the pressure of evolutionary competition ("survival of the fittest"). It seems that we cannot afford ethical behaviour, as it reduces the set of behavioural options and puts people trying to meet ethical standards at a disadvantage compared to others, who do not put such constraints on their actions.

However, many market participants may be willing to submit their decisions to ethical rules, if the same constraints are imposed on all the others. Such a system would be fair in the sense that the same rules would apply to everyone. In a society where the same people interact with each other continually, norms can be sustained and cooperative behaviour can be the standard. However, there is a realistic danger that such an equilibrium may be undermined by the temptation to "free ride" on the good behaviour of others. Nevertheless, as is well known from the "folk theorem" of game theory, if people interact regularly with each other, a sanctioning of non-compliant behaviour might sustain the norm.

If taken literally, without the caveats Adam Smith imposed, the principle of the 'invisible hand' suggests that it would not be beneficial for our economy to put any constraints on individual actions. But is this really true? For the case of social dilemmas (see Sec. 5.1), it has been demonstrated that individual profit maximization neither guarantees an optimal systemic outcome, nor optimal individual results (Hardin[77] 1968). However, recent scientific results show that cooperative, fair and friendly behaviour can significantly outcompete behaviour that tries to maximise individual profits (Grund, Waloszek, Helbing[51] 2013). This can happen if cooperative, fair or friendly individuals predominantly interact among each other and avoid interactions with selfish individuals. An important objective then is to work towards the establishment of an ethical code for the economy (such as the Hanseatic business honour), to promote friendly, fair, and responsible action.

[82] Castel, V., and Kamara, A., 2009, Foreign Investments in Africa's Agricultural Land: Implications for Rural Sector Development and Poverty Reduction, *African Development Bank Development Research Brief*, Number 2.

To this end, one might create an independent international participatory reputation platform that collects ratings, opinions and complaints. This platform could conduct surveys and collate and publish information on companies, products, banks, bankers, politics and politicians, and every type of organisation, including the current financial rating agencies. Reputation is one of the mechanisms which can stabilize cooperation in social dilemma situations even in a globalized world.[83] In fact, the spreading of commenting and recommender systems shows that users consider such evaluations useful, and in many fields such evaluations are now published by organisations – from consumer protection groups to non-governmental organisations such as Human Rights Watch. What individuals need is information on trustworthiness. Platforms like *eBay* make it possible for users to identify those who have predominantly made fair transactions in the past. As recent studies show (Przepiorka[84] 2013), such an information feedback can promote a trustable and more profitable exchange. Note, however, that evaluation mechanisms and recommender systems should be implemented in a differentiated way, on a multi-criteria scale (see the discussion of deficiencies of systems with one-dimensional competition in Sec. 4.1). Such a multi-dimensional public evaluation system should help to promote a flourishing and self-regulating 'socio-economic ecosystem'.

Summary

In conclusion, we have created a strongly coupled and strongly interdependent world, which poses new challenges. While it is probably unrealistic and undesirable to dismantle the level of networking and globalization we have reached, there is a great potential to develop new management approaches for our complex world based on suitable interaction rules, favourable institutional settings, and novel adaptive concepts (including temporary decoupling strategies similar to circuit breakers), based on real-time monitoring and measurements.

Nevertheless, it must be emphasised that our current financial and economic problems cannot be properly addressed by remaining within the current mainstream economic paradigm. We need to change our perspective on the financial and economic system and pusue innovative policies. We would like to make the following recommendations:

1. to make large-scale investments in new economic thinking (as INET has already started to do), particularly multi-disciplinary research involving knowledge from sociology, ecology, physics, and cybernetics; in this connection, we particularly emphasize the need of a theory of "networked minds" to describe the behaviour of a "homo socialis" characterized by other-regarding behaviour (Grund, Waloszek, Helbing[51] 2013);
2. to divert a certain share of the profits generated in the financial sector into research and other activities destined to improve social well-being;
3. to support diversity in the system, responsible innovation, and multi-dimensional competition;
4. to require advance testing of financial instruments and innovations in order to avoid, as much as possible, undesirable systemic impacts (e.g. a destabilization of the financial system) by setting institutional constraints;
5. to develop new measurement concepts and adaptive feedbacks via suitable "control parameters", which allow one to make markets function better and to serve their

[83] M. Milinski, D. Semmann, and H.-J. Krambeck, Reputation helps solve the 'tragedy of the commons'. Nature 415, 424-426 (2002).
[84] Przepiorka, W. (2013) Buyers pay for and sellers invest in a good reputation: More evidence from eBay. *The Journal of Socio-Economics* **42**, 31-42.

original purpose;

6. to create new indices to guide political decision-making, which consider environment, health, social capital, and social wellbeing;
7. to identify and establish a proper institutional framework for interactions (suitable "rules of the game") in order to facilitate beneficial self-organization;
8. to adjust the perspective of our world to the fundamentally changed properties of the globalized, strongly interdependent techno-socio-economic-environmental system humans have created and its resulting complex, emergent dynamic system behaviour;
9. to recognize the value of local and regional interactions for the creation of social capital such as cooperativeness, fairness, trust, etc., which are an important factor of economic value generation;
10. to implement better incentive systems to foster more responsible action and to establish, for this, a universal, decentralized and independent reputation system to promote fair behaviour and allow ethical behaviour to survive in a competitive world;
11. to develop new tools to facilitate the assessment of likely consequences of our decisions and actions (the "social footprint"). These tools may, for example, include (Helbing[12] 2013):
    - a "Planetary Nervous System" to enable collective awareness of the state of our world and society in real-time, which would mean to have a detailed and constantly updated picture of the economic and social system at every point in time,
    - a "Living Earth Simulator" to explore possible and likely consequences of human decisions and actions,
    - a "Global Participatory Platform" to extend opportunities for social, economic and political participation,
    - an "Open Data Platform" to foster creativity, an "innovation ecosystem", and the creation of new business opportunities,
    - a trustable Web and reputation system to facilitate safe and fair exchange, and
    - information and communication systems supporting value-oriented interactions.

In summary, the socio-economic system envisaged in this paper is characterized by the following features:

1. it is based on individual decisions and self-organization,
2. it uses suitable incentives to support sustainability and to avoid coordination failures, tragedies of the commons, as well as systemic instabilities,
3. it recognizes heterogeneity and diversity as factors promoting well-being, innovation, and systemic resilience.

The concepts in our paper are further elaborated and formalized in a recent manuscript.[85]

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[85] D. Helbing, Economics 2.0: The natural step towards a self-regulating, participatory market society, Evolutionary and Institutional Economics Review, in print (2013), see http://arxiv.org/abs/1305.4078