Trade-Off

Financial System Supply-Chain Cross-Contagion:

a study in global systemic collapse.

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Overview

This study considers the relationship between a global systemic banking, monetary and solvency crisis and its implications for the real-time flow of goods and services in the globalised economy. It outlines how contagion in the financial system could set off semi-autonomous contagion in supply-chains globally, even where buyers and sellers are linked by solvency, sound money and bank intermediation. The cross-contagion between the financial system and trade/production networks is mutually reinforcing.

It is argued that in order to understand systemic risk in the globalised economy, account must be taken of how growing complexity (interconnectedness, interdependence and the speed of processes), the de-localisation of production and concentration within key pillars of the globalised economy have magnified global vulnerability and opened up the possibility of a rapid and large-scale collapse. 'Collapse' in this sense means the irreversible loss of socio-economic complexity which fundamentally transforms the nature of the economy. These crucial issues have not been recognised by policy-makers nor are they reflected in economic thinking or modelling.

As the globalised economy has become more complex and ever faster (for example, *Just-in-Time* logistics), the ability of the real economy to pick up and globally transmit supply-chain failure, and then contagion, has become greater and potentially more devastating in its impacts. In a more complex and interdependent economy, fewer failures are required to transmit cascading failure through socio-economic systems. In addition, we have normalised massive increases in the complex conditionality that underpins modern societies and our welfare. Thus we have problems seeing, never mind planning for such eventualities, while the risk of them occurring has increased significantly. The most powerful primary cause of such an event would be a large-scale financial shock initially centring on some of the most complex and trade central parts of the globalised economy.

The argument that a large-scale and globalised financial-banking-monetary crisis is likely arises from two sources. Firstly, from the outcome and management of credit over-expansion and global imbalances and the growing stresses in the Eurozone and global banking system. Secondly, from the manifest risk that we are at a peak in global oil production, and that affordable, real-time production will begin to decline in the next few years. In the latter case, the credit backing of fractional reserve banks, monetary systems and financial assets are fundamentally incompatible with energy constraints. It is argued that in the coming years there are multiple routes to a large-scale breakdown in the global financial system, comprising systemic banking collapses, monetary system failure, credit and financial asset vaporization. This breakdown, however and whenever it comes, is likely to be fast and disorderly and could overwhelm society's ability to respond.

We consider one scenario to give a practical dimension to understanding supply-chain contagion: a break-up of the Euro and an intertwined systemic banking crisis. Simple argument and modelling will point to the likelihood of a food security crisis within days in the directly affected countries and an initially exponential spread of production failures across the world beginning within a week. This will reinforce and spread financial system contagion. It is also argued that the longer the crisis goes on, the greater the likelihood of its irreversibility. This could be in as little as three weeks.

This study draws upon simple ideas drawn from ecology, systems dynamics, and the study of complex networks to frame the discussion of the globalised economy. Real-life events such as United Kingdom fuel blockades (2000) and the Japanese Tsunami (2011) are used to shed light on modern trade vulnerability.

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I. Introduction

A networked society behaves like a multicellular organism…random damage is like lopping off a chunk of sheep. Whether or not the sheep survives depends upon which chunk is lost….When we do the analysis, almost any part is critical if you lose enough of it…. Now that we can ask questions of such systems in more sophisticated ways, we are discovering that they can be very vulnerable. That means civilisation is very vulnerable.

Yaneer Bar-Yam[1],
New England Complex Systems Institute

I.1 The Living Fabric of Exchange

The Irish economy, the German economy and the UK, US and Chinese economies do not exist, except by virtue of their integration in the globalised economy. Conversely, each is a localised expression of a global system. At any moment a myriad of final and intermediate goods, commodities, information and people is moving back and forth across borders. Without those flows, which maintain socio-economic function and complexity, economies would quickly collapse.

Here we make a distinction between our imagined communities, in particular the nation state and the psycho-drama within and across nations, and our real dependencies, which are globalised. National economies can have local character and limited degrees of freedom, but they exist inter-dependently, just as a heart or lung cannot exist apart from the body and still retain its original identity.

The nature of this integration has been evolving in ways that are reflected in common conversations about the world becoming so much more complicated, globalisation, '*the world being flat'*, and the speed of change in the world. Broadly, we can say that the globalised economy has been growing in complexity. This can be associated with growing connectedness, interdependence and speed. There are many definitions of socio-economic complexity and quite a bit of debate as to its nature. At the most general we could start with the following:

Complexity is generally understood to refer to such things as the size of a society, the number and distinctiveness of its parts, the variety of specialised roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organising these into a coherent, functioning whole. Augmenting any of these dimensions increases the complexity of a society.

Joseph Tainter[2]

We can catch a fragmentary glimpse of this via Eric Beinhocker who compared the number of distinct culturally produced artefacts produced by the Yanomamo tribe on the Orinoco River and by modern New Yorkers. The former have a few hundred, the latter, tens of billions[3]. John Gantz notes the massive increase in the "internet of things" such as cars, ovens, payment and ordering systems, electric grids and water systems, rather than people. The number of connected devices has risen from 2 billion in 2005, to 6 billion in 2010, and is projected to be (conditions allowing) 16 billion by 2015[4].

Consider that a modern auto manufacturer has been estimated to put together 15,000 individual parts, from many hundreds of screw types to many tens of micro-processors. Imagine if each of their suppliers put together 1,500 parts in the manufacture of their input to the company (assuming they are less complex), and each of the suppliers to those inputs put together a further 1,500. That makes a total of nearly 34 billion supply-chain interactions (15,000 x 1,500 x 1,500), five times the number of people on the planet. This is a highly imperfect example but it signals the vast conditionality upon which modern production depends.

The globalised economy is a singular recursive network or fabric of relationships between people and things. Let us take a more discursive example. Mobile devices, now ubiquitous, represent the culmination of 20th-century physics, chemistry and engineering. They signify thousands of direct - and billions of indirect - businesses and people who work to provide the parts for the phone, and the inputs needed for those parts, and the production lines that build them, the mining equipment for antimony in China, platinum from South Africa, and zinc from Peru, and the makers of that equipment. The mobile device encompasses the critical infrastructures that those businesses require just to operate and trade - transport networks, electric grids and power-plants, refineries and pipelines, telecommunications and water networks - across the world. It requires banks and stable money and the people and systems behind them. It requires a vast range of specialist skills and knowledge and the education systems behind them. And it requires people with income right across the world, not just as producers, but also as consumers who can afford to share the costs of the phones and associated networks - there are economies of scale right through the diverse elements of the globalised economy. Those consumers can only afford the devices because they ply their trade through integration in the globalised economy.

The mobile device feeds back into the globalised economy, re-shaping and transforming it. It is the building block for new levels of complexity when it combines with other things to form new businesses and new economies of scale. It co-adapts with societies and economies, intertwining, shaping how we live in and understand the world. The mobile device is not a thing in the globalised economy, but a dependent expression of it.

The speed of interaction between all these parts of the globalised economy has been getting faster. Automatic trading occurs over milliseconds, and financial and credit shocks can propagate globally in seconds. Within a minute of deciding to talk to a friend on the other side of the world, our conversation can begin. One of the major transformations in business is that lean inventories and tight scheduling means many businesses and industries hold hardly any stock. Automatic signals go from check-out counters, to warehouses, to suppliers who ramp production up or down to meet demand. That supplier too sends signals to their suppliers who also run *Just-In-Time* logistics (JIT).

It has been estimated that a modern industrial city only has about three days of food for its inhabitants *in situ*. Later we will consider in more detail the blockade of fuel depots in the UK in 2000, when the UK Home secretary Jack Straw accused the blockading truckers of “threatening the lives of others and trying to put the whole of our economy and society at risk”. This was not hyperbole. As the protest evolved over about ten days, the UK's Just-in-Time fuel distribution system started to break down. Supermarkets, which had also adapted to Just-in-Time re-supply, began to empty. Supplies and staff could not reach hospitals, forcing emergency-only admission. If it had gone on for only a few days longer, large parts of UK industry would have shut down as the normal operation of re-supply ground to a halt. One of the most advanced and complex societies on the planet was within days of a food security crisis. In section II, various examples will be used to demonstrate how growing complexity, interdependencies within socio-economic systems and the increased speed of processes can cause widespread and rapid contagion if the 'right' critical piece fails.

In all the vast complexity of the globalised economy, there is no person or institution in control, or who knows how it all fits together, for it is far beyond our comprehension. Facebook, for example, does not need to know how to make an electric grid work, or how to process antimony, yet nevertheless they are all connected through diverse and unfathomable relationships. Each person, business, institution and community acts within their own niche; with their evolutionary heritage and their common and distinct histories; with their acquired skills and assets; and through physical and cultural networks. What emerges at a large scale is the globalised economy. We are both contributors to, and dependent upon, the functioning of that economy.

This is just Adam Smith's *invisible hand* at work, or in modern scientific parlance, an example of *self-organisation* in a complex non-equilibrium system. In particular, the globalised economy is an example of a *complex adaptive system (*CAS). A non-equilibrium system is one prone to change and transformation. It is a system, because there is a level of overall integration and identity, and co-dependence between parts. They are complex and adaptive because they are composed of dynamically (not static) interacting parts (sometimes called *nodes*) that change their individual and collective behaviour over time. A person is a CAS, so too is a collection of them (at a sporting event, as part of traffic or as a nation), so is a company, and so is an electric grid. An ant colony is a CAS, as is the evolution of the earth's biosphere. They exist interdependently, mixing chance and necessity over a universe of scales. What maintains a CAS is its internal stability and the transformation of energy and resources.

Despite the ostensible change over our own lives - indeed, we live in a culture that prizes, and an economy that delivers continual novelty - what is remarkable is how stable that evolution has been. How can we talk of stability when there has been so much change: new technologies, the rise of China and evolving social mores? But we would not make such on-trend assumptions (technological evolution, economic growth), nor invest as though we expect them to continue (how society educates its children, new infrastructure, pensions), unless we felt comfortable that there was some form of macro-system stability. Within that intuition of stability, we can have booms and busts, break-out technologies and bloody wars, but over the medium to long term we can assume there is reversion to the trends embodied in the macro-system evolution. Without such stability the high complexity de-localised JIT integration could not have occurred: try crocheting on a roller-coaster.

Stepping back, what can be observed is that a new *phase* in global growth began to take off in the early 1800s. It was faster and more sustained than ever before[1]. Because the growth was exponential, each year's 3% growth added more goods and services than the year

[1] Maddison estimates that Gross World Product grew 0.34% between 1500 and 1820, 0.94% (1820-1870), 2.12% (1870-1993), 1.82% (1913-1950), 4.9% (1950-1973), 3.17% (1973-2003), and 2.25% (1820-2003).

before. Rising economic growth was in a reinforcing cycle with growing complexity. That stability provided the narrative arc that has taught us to assume economic growth will continue, technology will evolve in complexity, food will be in the supermarket tomorrow and the lights will remain on. We have adapted to its normalcy.

Mostly we do not notice these high-speed de-localised complexities that underpin the normal functioning of our lives, businesses and societies. Our understanding of the world is captured in its constituent parts, by what is novel, and by what gains our attention, framed by intra-human dramas. The complexity is attenuated in simple things: my mobile phone works, money is accepted for bread, and my train arrives. We notice the immediacy of things, not the living fabric of conditionality from which it emerges. We can generally take for granted the *operational fabric* of our society. These are the given conditions in time and space that maintain system-wide functionality, such as functioning markets, monetary stability, supply-chain replenishment, critical infrastructure, trust and socio-political stability. What we do not see so clearly are constraints, because mostly we have become habituated to them.

The general stability of the globalised economy and the operational fabric has provided the conditions for goods and services, socio-political structures, critical infrastructure, companies, global markets and a myriad other systems adaptive to that environment to evolve and maintain their local stability over time.

This is just like an animal adapted to its ecological niche. The niche is dependent upon the wider ecosystem operating within the range of conditions (or *stability domain)* that maintain the niche and so keep in check the animal's security (food, shelter, disease vectors, symbiotic relationships and predators).

As a society we have largely ignored the implications of rising complexity because we are adaptive to it. At its core, furthermore, grasping the vast conditional complexities of our dependencies is an intuitive exercise, which strives for a picture of the whole when we can see only the parts. This is an anathema to the analytic culture that prizes computable precision.

I.2 Complexity & Risk

A complex networked society can in many ways be remarkably resilient. If there is crop failure in one place, food can come from another region. If there is a break in a company's supply-chain, a replacement part can come from elsewhere. Increased complexity and its twin, growth, have allowed the displacement and reduction of risk in space and time. Insurance, pensions, sewage systems, wealth, healthcare, and socio-political systems have all contributed to an era of huge reductions in the risk to an individual's daily welfare, especially in the most advanced economies.

The individual risk can sometime be removed, or it sometimes is pooled or displaced over space and time. The green revolution of the 1950's-70's staved off the risk of major famine by a deep integration of food production into the innovating platform of the globalising economy. That macro-system turned fossil fuels into increased production through fertilisers, pesticides and machinery. It drove efficiencies through interconnection and economies of scale, and de-localisation through packaging, additives and transport. It also enabled the more than doubling of the human population, each individual on average consuming more year-on-year, and habituating to that. The cost of the revolution, in greenhouse gas emissions and degraded fertility could be displaced onto a future generation.

However, now there are now more people dependent upon a less diverse and more ecologically vulnerable resource base. Further the globalised economy, which mediates between our welfare and *in-situ* resources is more and more unstable. It is that which enables food production, distribution and affordability. Thus the green revolution could be said to have displaced and magnified risk into the future. That future is likely soon upon us.

In a more complex and tightly coupled economy, rather than absorbing shocks, the economy can amplify and transmit them: we have seen this as the financial crisis has evolved. We are now dependent upon many more interactions to maintain our welfare. More complexity and connectivity means there are many more points where failure or breakdown can occur. More interdependence between nodes means that the failure of one node can cause cascading failure across many nodes. De-localisation means that there are many more places and events that can transmit failure, and major structural stresses can build at a global scale. There is less local resilience to failure, in that we cannot repair or replace many critical elements from local resources. The rising speed of processes means that failure for even a short time can, for example, overwhelm tiny inventories, causing cascading failure along supply-chains. In addition, the high-speed spreading of such failure if it were to spread at the speed of financial markets or inventories could outrun our ability to bring it to a halt or even slow it down. So at first glance, rising complexity should lead to increased systemic risk. While this has been recognised at the fringes of academic work for many years, it has only recently begun to come in to more mainstream thinking with reports addressing some of the issues from the World Economic Forum[5] including in its *Global Risks 2012* report[6], and Chatham House[7].

There is another factor that has increased systemic risk. In many ecosystems there are keystone species - a generalist pollinator for example - whose removal could collapse the whole ecosystem. Likewise, the operation and integration of the globalised economy is dependent upon a small number of interdependent keystone-hubs, where a significant failure of any one of them could cause rapid catastrophic socio-economic failure to spread globally. These keystone-hubs are themselves becoming more vulnerable. Just two will be considered in this section: the *financial and monetary system keystone-hub,* and the *production flows keystone hub*.

i) The financial and monetary keystone-hub: The financial and monetary keystone-hub has virtually no general system diversity, which is always a danger in an ecosystem. Whatever bank one cares to consider, whatever form of country financing, whatever monetary system - they all share the same platform of fiat money and credit-money creation by fractional reserve banking. The whole of the financial and economic system is dependent upon credit dynamics and leverage.

Such credit dynamics helped to entrench the imbalances that built up in the global economy between countries running trade surpluses and those absorbing ever-rising credit flows. Without the level of de-localisation, complexity, and open connectivity, it is doubtful that such high levels of debt could have built across so many countries. Debt is now not just a feature of countries and banks - it is a system stress in the globalised economy as a whole.

The banking system has become less and less diverse too: there are many banks in the world, but banking activity has become more concentrated in only a tiny fraction of them; these are the ‘too-big-to-save, too-big-to-fail’ banks. The connectivity between retail banks, merchant banks and the shadow banking system has further removed system diversity and buffers to the spread of contagion.

Further, the response to the financial crisis has been to stave off a global banking collapse by releasing some of the tension onto sovereign states, where credit expansion could be maintained, at least for a while. This is particularly true of countries within the Eurozone which cannot print their own currency. This has reduced the system diversity of the financial system, and removed buffers to the spread of contagion, by coupling sovereign financing and the banking system ever more tightly. By enabling further credit expansion, which is part of why there was a problem in the first place, the risk of systemic failure has increased. The risk of systemic failure is further increased by the process of debt deflation, itself the direct result of credit over-expansion.

The shortening ‘relaxation time’ - the time markets remain confident between new crisis points in the Eurozone and political-economic reaction - suggests a growing inability of the interacting systems to absorb risk displacement in space and time. We are likely to be impelled to respond faster and faster as the socio-economic environment becomes riskier, more unpredictable and high speed.

Referring to Bar-Yam’s quote at the top of this section, the survival of the sheep depends upon which part and how much of the animal is damaged. The financial system, because it links almost everything in the economy, could be compared with the heart or lungs. We also need to consider the potential scale of damage, and the ability of the animal to absorb that damage. Thus, a healthy sheep could survive a shock that a weakened animal might not.

Consider the default of Argentina on its sovereign debt a decade ago. In the most general terms, the potential cascading effects on the global economy were dependent upon the size of the default relative to the global economy, the relative importance of Argentina’s economy and confidence within the globalised economy. The world economy easily absorbed the impact: indeed, this was not the first time that Argentina and countries of similar size had defaulted. With its newly devalued and competitive currency, it could re-equilibrate with *the stable surround* of a strong, confident, globalised economy, and soon returned to growth.

What if Ireland followed Argentina’s example and defaulted, as some commentators have suggested it should? First there is the huge complexity and uncertainty of being in the Euro, but for the moment however, let us assume a new *punt* is introduced without a hitch (this is an imaginative exercise), with the hope that the devalued punt would allow renewed growth and exports. However, now there is much reduced resilience within the globalised economy. There is more debt in the system than four years ago, and confidence in central banks and governments’ ability to handle the situation is almost gone. That is, Ireland is far more tightly coupled to the very much weakened heart of the globalised financial system. The *resilience* within the global economy is so reduced that the nudge that is Ireland's default could cause the whole system to cross a *tipping point*, causing cascading failure that would devastate the globalised financial system. Ireland could not re-equilibrate with what was falling apart.

The stress within the globalised economy arose out of its internal dynamics. However, even if we were to restore and invigorate global growth, we would still be on the edge of an environmental constraint with profound implications. That constraint would expose in an even starker manner the inherent instability of the global financial system.

There is an acknowledged risk that we are now at the peak of global oil production. That is, the amount of affordable oil that can be brought on stream in real-time time is hitting constraints and will decline. Economic and complexity growth are predicated on rising and adaptive energy flows. Constraints on energy flows that cannot be substituted affordably, adaptively, and in real-time, are expressed through constraints on economic activity.

If the global economy cannot grow and starts to contract, feedback processes drive further contraction. A contracting economy is incompatible with the credit backing of the globalised economy and the value of all financial assets because it undermines the ability to service debt in real terms. Monetary stability, bank solvency, intermediation and credit are all dependent upon confidence in continuing credit expansion and rising economic activity. That is, the financial and monetary systems that we have come to take for granted were adaptive within a particular set of conditions. When those conditions change, the financial and monetary system keystone-hub may slip out of its historical equilibrium.

Generally, we tend to assume that change is gradual; a dependent condition changes and the system responds proportionally. Our assumption of gradual change tends to imagine that the effects of economic contraction, debt deflation, climate change, energy depletion, or biodiversity loss will gradually grind us down, snipping away at our wealth and welfare over years or decades. This may be so. However, all those changing conditions need to do is drive the globalised economy, or keystone-hubs within it, out of their stability domain, after which the system's internal interdependencies come out of synch with what they have adapted to and the system can be at risk of collapse. The speed of that collapse is related to the levels of integration and complexity in the system.

One of the effects of massive credit over-expansion and/or the peaking of global oil production is the growing risk of a global systemic financial shock. The likelihood, as with so many financial crises of the past, is that the breakdown of the global financial system will be sudden and catastrophic, marked by complacency and hope turning to fear and panic. It would happen over hours and days.

ii) Production Flow Keystone-hub: We have briefly outlined the risks of failure in the financial and monetary system keystone-hub. However, its most critical function is to enable the flow of goods and services in the globalised economy, that is, it maintains the production flow keystone-hub. Production flows are enabled by money, credit and bank intermediation. It is this which keeps food in the supermarkets, businesses and production running, and critical infrastructure serviced.

Production flows determine our dependencies and the ability to maintain any form of socio-economic complexity. As production flows have grown in complexity, de-localisation, interdependence and speed, our vulnerability to any form of major financial shock has increased immensely. The implications of the fuel blockades in the UK would represent only a sub-set of the interactions immediately affected.

The societies that would be impacted most extensively and rapidly are the most complex ones. Being the most complex, they have the greatest number of critical inputs into keeping systems (factories, supermarkets, critical infrastructure) running. They have the highest levels of interdependence and are adaptive to leaner, JIT logistics.

Consider briefly a 'soft-to-mid-core' (Spain, Italy.....Belguim, France?), disorderly default and contagion in the Eurozone, coupled, as would be likely, with a systemic global banking crisis. There would be bank runs, bank collapses and fear of bank collapses; uncertainty over the next countries to default and re-issue currency; plummeting bond markets; a global market collapse; and a global credit crunch. Counter-party risk would affect trade, just as it would affect the inter-bank market. However, production and supply-chain networks are far more complex than the banking and shadow banking system.

Within days there could be a food security crisis, health crisis, production stoppages and so on within the most directly impacted countries, and the number of such countries would rise. Those with access to cash would clear out supermarkets in panic. Many would immediately suffer as we now hold little cash and have small home inventories. Supermarkets could not re-stock, and even if they could, there would be declining availability of fuel for transporting goods. Hospitals adapted to JIT would also run low on critical supplies and staff might not be able to get to work. Pandemic modelling has shown that removing at random only small numbers of a population can cause cascading failure of functions across an economy. Lack of inputs and people required for production would also begin to shut factories within days. Governments, emergency services, and the public would by and large be shell-shocked. Without serious pre-planning, a government would be unable even to provide emergency feeding stations for weeks. There would be growing risk to critical infrastructure.

Imports and exports would collapse in the most exposed countries and fall for those as risk. It would also cut global trade as *Letters of Credit* dried up. The longer the crisis went on the more countries would be at risk. But once the contagion took hold, it would be very difficult for the ECB/ IMF or governments to stop; it would be a large-scale cascading failure at the heart of the global financial system.

But the countries at the centre of the crisis are amongst the most trade-central in the world. That is, they are ‘hubs’ of global trade; there is concentration in production flows just as there is in banks. They also produce some of the least substitutable products in the world. What we know from real-life examples is that supply-chain contagion could be fast. The collapse in trade within some critical trade hubs would mean missing critical inputs for production processes across the world, stopping further production, which could cascade through production globally. The more supply-chains that were ‘infected’ the greater risk that any uninfected supply-chain would become infected. That is, supply-chains would start transmitting global contagion, which would accelerate and expand. Factories from Germany to China and the US would shut down, helping to spread further financial and economic fears within those countries.

Supply-chain contagion would feedback into deepening and spreading financial system contagion, which would in turn feedback into further supply-chain contagion. It would impact on the various key-stone hubs we shall consider later including critical infrastructure. It may mean that if the keystone-hubs were not re-stabilised, within weeks an irreversible global economic collapse could be underway.

We may hold off another month, a year or even a few years, but each attempt to maintain the stability of the system upon which we depend upon for our immediate benefit will most likely just displace and magnify risk into a nearer and nearer future. For we are dependent upon the very things we are undermining.

I.3 This study in context

This study has two broad aims. The first is analytic and expository - about how we might understand systemic and complexity risk in the globalised economy at a time when such risk is rising. The second is a probably futile plea for urgent risk management and a coming to terms with the possibility that within this decade we may see catastrophic failures in the socio-economic systems upon which we rely for our basic welfare.

The structural form of the globalised economy has been undergoing profound change that has barely been recognised in analysis; that complexity has been rising, and it really does matter. This is true even if it does not have its very own indicators or appear in economic models. Further, as our dependencies have grown in complexity, we have become more vulnerable to extreme economic shocks and stresses. Yet we take for granted those very dependencies. This is considered in section II when lessons are drawn from examples of real-life supply chain failure, and again in section V, when a collapse of the Eurozone is considered.

In order to help us shake off our cultural and economic conditioning, we need ways of seeing the globalised economy as a whole - one that make explicit the constituent parts of its functioning and our dependencies within it. In addition, if we are broaching the idea of a collapse in the globalised economy, we need simple ways of looking at stability and instability. One possible way of doing this is by drawing an analogy with other complex systems, and using the range of tools in systems dynamics, ecology and network theory. This is not metaphor. Just because it is 'our' complex society does not free it from well-understood general systems features such as thermodynamic constraints and path dependence, and generally applicable concepts such as preferential attachment and scale-free networks. All of this will be introduced in section III. Some of those ideas will then be applied in later sections.

In section IV two reasons for a looming globally destabilising financial shock are broadly outlined. The first is the outcome of decades of credit expansion and growing global imbalances. The most perplexing thing so far in this crisis is that there has been neither the anticipation of, nor the preparation for, a worsening of the crisis by those with most responsibility for dealing with the consequences. The inbuilt dynamics of credit expansion, debt deflation and the structure of the monetary and banking system make further deterioration inevitable. The break-up of the Eurozone, as has been emphasised elsewhere, would be a devastating shock, and one for which we have scant preparation. This is not to cast blame, merely to reflect on society’s inability to manage novel risks that threaten the foundations of their welfare.

The second reason is the manifest risk that ecological constraints, expressed as peak oil and food, are imminent. The casual retorts to such warnings are revealing. The assumption that technology, market mechanisms or shale gas will save the day is made so often, with such confidence and is backed by so little actual knowledge and expertise, that it leads one to suspect that the interlocutors are expressing a cultural mythology rather than offering a reasoned analysis. In addition, we are quite at a loss with respect to timing. These constraints are emerging now. More grandiose plans, more targets or investment in breakthrough technology, more well-meaning chatter about a green New Deal mostly miss the point, firstly, because imagining is really not a substitute for reality, and secondly, because in all probability, it's too late. There is of course room for plenty of disagreement, but good risk management can deal with a range of possibilities: it does not need certainty.

In section V a particular scenario of a Eurozone collapse is outlined. It is only of among many possible scenarios. Its purpose is to show how an intertwined sovereign and banking crisis in the Eurozone would affect trade directly, but the ideas could be applied to any large-scale financial crisis. It is shown how ideas such as the trade centrality of the most affected countries, their inherent complexity (level of JIT integration, low substitutability, interdependence) and a simple epidemic model can illuminate how supply-chain contagion could spread globally within a few weeks. This supply-chain contagion would then feed back into the growing financial system contagion. Finally, it is emphasised how the restoration of the financial system would not necessarily stop the supply-chain contagion for a number of reasons.

In the final section, VI, there are three loosely linked sections. The first is about risk management in general and an argument for more cognisance and space for heterodoxy, non-consensus, non-authoritative input into risk-management discussion and practice.

The second issue is about the constraints and limits on actions to deal with the evolving crisis. What largely unites the left, the right, and the green is the assumption that they could re-shape or re-order the economy and financial system (if only their respective bogeymen would get out of the way). This is probably an illusion. The concept of lock-in is used to explain why.

Finally, there is a short conclusion.

This study does not set out any risk-management planning. That is part of this project’s ongoing work.

II. Supply-Chain Failure & Repair

Real life examples of major supply-chain damage, from earthquakes say, show that the impacts can be transmitted globally through intermediate links in supply-chains. What is surprising is how vulnerable complex societies are to even a partial shut-down in trade for just a few days. Growing complexity and speed in processes has increased vulnerability. However, the globalised economy is remarkably resilient to such 'rips' in the fabric of trade, but when they do occur the economy can generally self-repair very effectively.

II.1 Natural disasters, blockading truckers, and the connectedness of things.

The disaster damaged these firms and stopped their production activities; it also stopped or diminished the production activities of non-disaster-affected firms that used the products of the disaster-damaged firms, because of the shortage of those intermediate inputs. This phenomenon of disrupted supply-chains amplified the impacts of the disaster on manufacturing production and expanded the impacts broadly to other (non-damaged) regions in the country.

Isao Kamata

The Great East Japan Earthquake: A View on Its Implication for Japan's Economy[8]

Amid the human suffering following the earthquake and tsunami in Japan in 2011, an economic shock was transmitted across the world.

This simple outcome, that production failure can be transmitted along supply-chains to companies across the world a long way from the primary impact of a crisis represents the first stage of supply-chain contagion. The economic benefits and competitive advantage from carrying low inventories with the evolution of just-in-time (JIT) logistics left companies with little resilience to shocks originating in distant production failures.

It is not surprising that some of the most complex production processes – those in the electronic and automotive industries - were affected. They carry the most extensive and diverse supply-chains into their production, and so carry a greater risk of any link being severed. They also have some of the most complex and specialised inputs, which are the hardest to substitute. For example, Toyota had difficulty obtaining 150 components six weeks after the tsunami, down from 500 components in the first weeks[9]. Another company produces 40 percent of the control microprocessors used by car manufacturers worldwide[10]. These are very complex and customised for particular cars, so substituting for them takes time to find other plants with free production capacity, and time for re-calibration of production lines.

Big supply-chain reverberations followed the eruption of the Eyjafjallajokull volcano in Iceland in 2010. Among the many implications across the world were job loss in Kenya and cancelled surgery in Ireland. Three BMW production lines in Germany shut down as re-supply was interrupted within days of the disruption.

The most resonant example of supply-chain destabilisation arose in the UK in 2000 from a blockade of fuel depots by truckers angry at rising diesel prices[11]. The protests ramped up, stabilised, and finished in a period of about ten days. Fuel deliveries were dependent upon JIT re-supply, with some petrol stations taking up to three deliveries a day. Towards the end of the blockade, half of the UK's petrol stations ran out of fuel and transport fleets were severely disrupted.

The level of interdependency and interconnectivity within the UK economy meant that severe disruption rapidly spread to almost every corner of society. Workers, customers, parts and finished goods were all increasingly affected. As the protest finished, serious food shortages were imminent, much of the manufacturing sector was on the edge of closure, and hospitals were beginning to offer only emergency services[12]. The London Chamber of Commerce estimated that 10 percent of the economy's daily output was being disrupted. Steel and motor manufactures would have had to close had the protest lasted only a few more days. Weapons and defence industries were within a week of "serious problems".

The fuel blockades were a wake-up call to the British government, and to a society who had never realised how quickly and thoroughly society could be destabilised from something that seems at first glance, of relatively minor significance. It showed how habituated society had become to very complex and time sensitive inter-dependencies. Alarmingly, people realised how little food actually existed in the system between production, distribution, retail and home. The sight of emptying shelves exacerbated the re-supply problems prompting panic buying: the grocery chain *SPAR* saw a 300% increase in sales, for example. Whatever about the seriousness of production stoppages for auto or electronics manufacturers, a general supply-chain failure that hits food supply goes to the heart of national welfare and is at the bedrock of our expectations of the state, even if those expectations have been obscured by years of abundance. No society wants to test the veracity of the old adage that we are only nine meals from anarchy.

In a desk study, Alan McKinnon explored the impact on a sudden week-long freeze in truck distribution by all trucks weighing over three tons across the UK[13]. The study was useful in pointing out just how road haulage tied together a myriad of casual complacencies, and how the failure of one thing can cascade across the economy. He wrote *"after a week, the country would be plunged into a deep social and economic crisis. It would take several weeks for most production and distribution systems to recover"*. Some vulnerable businesses would never recover.

In a report by the American Trucking Association the implications of a complete trucking shut-down were assessed for the US economy and society[14]. This report gives a timeline of the impacts (shown in Box:1). Again, it emphasises how the web of interdependencies that underpin our basic welfare can become unstuck if a fundamental hub of the economy fails, leading to rapid cascading failure.

Box 1
When Trucks Stop, America Stops
A Timeline Showing the Deterioration of Major Industries Following a Truck Stoppage

The first 24 hours
- Delivery of medical supplies to affected areas will cease.
- Hospitals will run out of basic supplies such as syringes and catheters within hours. Radiopharmaceuticals will deteriorate and become unusable.
- Service stations will begin to run out of fuel.
- Manufacturers using JIT manufacturing will develop component shortages.
- US mail and other package delivery will cease.

Within one day
- Food shortages will begin to develop.
- Automobile fuel availability and delivery will dwindle, leading to sky-rocketing prices and long lines at the gas pumps.
- Without manufacturing components and trucks for product delivery, assembly lines will shut down putting thousands out of work.

Within two to three days
- Food shortages will escalate, especially in the face of hoarding and consumer panic.
- Supplies of essentials such as bottled water, powdered milk, and canned meat at major retailers will disappear.
- ATMs will run out of cash and banks will be unable to process transactions.
- Service stations will completely run out of fuel for autos and trucks.
- Garbage will start piling up in urban and suburban areas.
- Container ships will sit idle in ports and rail transport will be disrupted eventually coming to a standstill.

Within a week
- Automobile travel will cease due to lack of fuel. Without autos and busses, many people will not be able to get to work, shop for groceries, or access medical care.
- Hospitals will begin to exhaust oxygen supplies.

Within two weeks
- The nation's clean water will begin to run dry.

Within 4 weeks
- The nation will exhaust its clean water supply and water will be safe only after boiling. As a result gastrointestinal illness will increase, further taxing an already weakened health care system.

Holcomb, R *When Trucks Stop, America Stops* American Trucking Association

Box 1: *A timeline of implications for society resulting from a shut-down in trucking.*

There are a myriad important things not included. For example, the inability to access key parts or staff, or to ship coal to power plants, could shut down the grid affecting water/sewage, telecommunications, emergency services, and command and control capabilities. Furthermore the population and government would most likely be completely at a loss as to how to begin managing personal and community welfare.

A recent report by Chatham House, London, looked at a range of events and noted both the vulnerability of JIT, and importantly, following the end to a disruption, the inability of companies to just pick up where they left off [15]:

Evidence from a range of recent events, notably the 2010 ash cloud, the March 2011 earthquake and tsunami in Japan and the floods in Thailand in 2011, indicates that key sectors and businesses can be severely affected if a disruption to production centres or transport hubs persists for more than a week. This was confirmed by a survey of businesses about the 2010 ash cloud – many said that had the disruptions continued for a few days longer, it would have taken at least a month for their companies to recover. It is also the case that planning by government and industry organizations for an ash-cloud event had failed to consider a time-frame of more than about three days. One week seems to be the maximum tolerance of the 'just-in-time' global economy.

There is something that is implied in the outcome of the fuel blockades and in the McKinnon study: the impact of the crisis becomes non-linear in time. That is, the damage caused by the disruption does not rise in proportion to the length of time the disruption occurs: rather it starts to accelerate. Later, we shall argue that this is firstly because inventories and buffer stocks cushion the early impact of the crisis, but as time goes on, those inventories are exhausted. Secondly, the level and structure of interconnections mean that the more people, businesses, goods and services (nodes) that are affected, the greater the chance of infecting the remaining unaffected nodes. Further, the more nodes that are infected, the greater the chance that 'hubs' such as critical infrastructure will be infected. Their failure has a disproportional effect on the general economy. Finally, as the crisis evolves, more businesses terminally fail due to loss of cash-flow, for example.

One result of the fuel blockade was a 2006 report commissioned by the UK's Department for Environment, Food, & Rural Affairs (DEFRA) exploring the risk and resilience of the food supply-chain undertaken by Helen Peck of Cranfield University[16]. This useful report looked at particular sources of large-scale supply-chain disruption, in particular a loss of fuel, loss of power, or the loss of people arising from a pandemic. One noteworthy lacuna in her report is that it does not consider a systemic failure of the banking or monetary system. Peck notes that a failure in fuel supply could mean that bank machines were not restocked or that a power failure could cripple the banking system, but in each case the financial system was fundamentally sound.

One outcome of the financial crisis of 2008 was the (re-)introduction of the concept of a systemic banking collapse, and even its link to supply-chains. For a moment, following the collapse of Lehman Brothers, there was a brief freeze in the issuance of *Letters of Credit*, a pillar of international trade, as banks hoarded liquidity and worried about counter-party risk. As a result the *Baltic Dry Shipping Index*, measuring bulk shipping demand, dropped by more than 90 percent. Only action by monetary and government authorities ensured that this was a passing moment.

And yet there is no pillar of the economy more all-encompassing than the financial and monetary system: it links almost every good and service in the world. The fabric underpinning the exchange of real goods and services is enabled by money, credit, and financial intermediation. Money and credit have no intrinsic value. We swap a piece of paper or entries in a computer for the real labours and skills of billions of strangers across the world. This works if they too believe that those digits can be exchanged elsewhere for real things or services at a later time. What is implicit in such trust is faith in monetary access, stability and bank intermediation.

In terms of impact, a large-scale financial collapse would far surpass the fuel blockades in impact and speed of onset. The movement of goods, people, and critical functions would be rapidly affected. The catastrophic impact arising from McKinnon's study would be merely a sub-set of the potential impact.

II.2 Rips & Repair

In a more complex production process or society there are many more functioning inputs required for a successful output. Some inputs are *critical*; such that a good or service cannot occur without them. So if a factory (or piece of infrastructure, socio-economic system or service function) has n critical inputs required to produce its output, it only takes one failure to stop production. So while there might have been $(n-1)$ inputs ready in abundance, failure still occurs. This is a version of *Liebig's Law of the Minimum*, a principle derived from 19th century agriculture in which plant growth is limited not by the total level of resources, but by the scarcest resource. Of course, the failed output of one company can spread through supply-chains causing further failure in production, or even meaning a spare part of the grid was not available so shutting down a whole swathe of industry, petrol pumps, bank machines, and so on. We can say that in a more complex society there are a greater number of failure paths for any system, and an increased likelihood that the loss of that system will cause cascading failure in wider integrated systems.

With increased complexity, not only are there more links, they are de-localised. There is more exposure to potential local monetary failures or banking collapses, localised grid failures, environmental shocks such as earthquakes or flooding, government collapse and lawlessness. Further, any local region is less resilient to the loss of a critical input as the resources required to fix or replace it is unlikely to be locally available.

Because we live in a Just-In-Time economy, interruption in any link for more than a few days may cause inventories to vanish, so propagating interruptions through supply-chains/networks. That is, we are dependent on much more time sensitive interdependencies.

With such amazing potential for failure, the astounding thing is that there is so little failure. Supermarkets are full with their usual brands, factories hum away and critical infrastructure is re-supplied, not just here or there, but right across the globalised world. Mostly things work, most of the time. When there is a failure, the globalised economy is highly adaptive to repairing localised damage. High speed communication, transport and long-range financial and monetary stability means that any shortage of a critical input can be quickly substituted from a range of sources.

But there are limitations. Some things are far easier to substitute than others. There are many bakers of bread and shops in which to purchase it. There are fewer makers of computers or cars. For very complex and specialised goods, there may only be one or two bespoke suppliers with very limited ability to ramp-up production outside of 'normal' parameters; otherwise very complex production systems would have to remain idle but ready outside of 'freakish' situations. This is a cost companies may not be able to carry, even if the externalised risk to society might be very high.

Such specialised and complex goods are more likely to be associated with high complexity systems such as those one might find in high technology. Broadly we can say that there is a wide variety of lower-complexity high-volume goods and thus considerable flexibility in substitution. As one moves towards the other end of the scale, there is a tendency towards increasing concentration, greater complexity, low volumes and less substitutability. In the latter case, the most advanced production is more likely to be in more developed countries with the appropriate skills and support infrastructure. Further, as such countries (EU, US, Japan) are more likely to have experienced decadal general system stability, they can be expected to have the most efficient JIT logistics. That is, there is habituation to normalcy exits in these countries.

There are also larger scale failures that can initiate a 'rip' in the fabric of the globalised economy - for example, state collapse (Somalia, USSR); monetary (Zimbabwean hyperinflation, Argentinean crisis, 1999-2002); financial (Trade Credit Collapse post-Lehman Bros.); infrastructure failure (US North-East grid failure in 2003, UK fuel blockades in 2000); or production flows (Icelandic volcano 2008, fuel blockades, & Thai flooding in 2011). The key systemic concerns are whether the rip can be repaired, how long it takes to do so, and the potential for a crisis spreading - in other words for the rip to become a tear or worse.

One of the foundations of repair is that a crisis, whatever its origin, can be stabilised internally and/ or by the surrounding operation of the globalised economy. Zimbabweans eventually latched onto the relative stability of the US dollar and Argentina was able to re-equilibrate with an independent monetary response coupled to a much larger, confident, growing globalised economy.

The time-to-repair issue is critically important; if the post-Lehman credit crunch had deepened and expanded, it could have caused cascading failure, quite possibly swamping the ability of central banks and governments to respond and repair/ re-stabilise. If the UK fuel blockades had gone on just days longer, it may no longer have been responsive to a *point crisis-point response* (fuel blockaders cause deepening crisis →government severely threatens blockaders →blockaders desist →system returns to normal). Instead it might have gone from a point crisis to a systemic crisis that outran government responses (fuel blockaders cause deepening crisis →cascading failure spreads to central hubs (general production, critical infrastructure, banking system) and abroad →government severely threatens blockaders →blockaders desist →cascading failure continues to spread →size and complexity of crisis beyond government response →system driven further and further from normalcy).

The general level of centrality, or 'hubness' of a rip clearly both affects the ease of repair and the potential for any crisis to spread. A hyper-inflating Zimbabwe could latch onto the US dollar, not vice-versa! A hyper-inflating Zimbabwe was not a spreader of global systemic risk: it was too small and weakly connected, and with connections that were easily substitutable. We saw this relationship in section 1.2 referring to Argentina and Ireland. A hyper-inflating US would cause massive damage globally. While this seems trivial, it is often ignored in the search for superficial similarities. The ability of the ‘core’ to help stabilise part of a weakened periphery also depends upon the health of the core. If the core is already weakened, the damaged periphery might tip the core over the edge (what we will later call a phase transition), causing cascading failure across the whole core-periphery.

This ability of the globalised economy to 'self-repair' is a feature of its normal operation, part of the intrinsic resilience of the system. But what if the damage was sufficiently severe, or hit just the right 'spot' in the globalised economy, so that not only was any process of repair undermined, but also normal functioning across the system became impossible?

III. **The Internal Ecology of the Globalised Economy:** stability, instability and collapse.

In this section the evolution and stability of the globalised economy is framed as an evolving CAS (complex adaptive system) that is maintained internally by keystone-hubs operating within their stability domains, and externally by energy and resource flows. Those keystone-hubs are adaptive to the conditions in which they co-evolved. But when those conditions change, particularly if economic growth is reversed, they undergo a critical transition and can collapse. Two of the supporting structures of the keystone-hubs, the banking system and trade networks, are highly concentrated: this can increase the risk of large-scale systemic failure. We should not be surprised that complex systems collapse, even if it is a globalised economy. The system features of such a collapse are outlined.

III.1 The Dynamic State of the Globalised Economy, Stability, & Critical Transitions

Civilisation is always and everywhere a thermodynamic phenomenon.

What Milton Friedman did not say.

The most significant changes in risk management have taken place in the past 7 to 10 years. Today it's not only about data gathering...but trying to figure out the relationship of things.

Joachim Oechslin Chief Risk Officer, Munich Re

We can think of the evolution of the globalised economy as the self-organising behaviour of a CAS in which regions with largely localised dependencies coalesced into a singular integrated system that spans the globe. This process is associated with global economic growth, increasing complexity, connectedness, interdependence and the speed of processes.

The fact that the globalised economy could weave together such de-localised, time-sensitive complexity is a reflection of the stability of the evolutionary process within the globalised economy. What we have seen to date is a remarkable 200-year period of global economic growth, centred on an expanding and ever more complex core integrating a wider periphery. Even through the Great Depression and World Wars, the globalised economy bounced back and continued to evolve.

The most important parameter for defining this transformation is energy flows through the globalised economy. All economic activity is subject to the laws of thermodynamics. By the transformation of low entropy energy (more properly, exergy) into higher entropy heat, work can be done. This work is the basis of GWP. GWP growth consequently requires increasing energy flows, see figure 1. Indeed, all complex adaptive systems are *open* thermodynamic systems, meaning they are maintained by energy and materiel flows through them. Thus energy flow, in the form adaptive to any particular system (food, light, fossil fuels), is generally a determining condition of the systems' stability.

Economic and complexity growth are mutually reinforcing. Growing economies of scale, innovation and specialisation link them. Increasing complexity in a system takes it further from the equilibrium to which all things tend. Maintaining complexity is a battle against entropic decay, and growing complexity is a battle against the universal tendency towards disorder. If you do not keep putting energy into something, it decays, and by decaying approaches equilibrium with its environment. Complexity growth is thus also dependent upon rising energy flows.

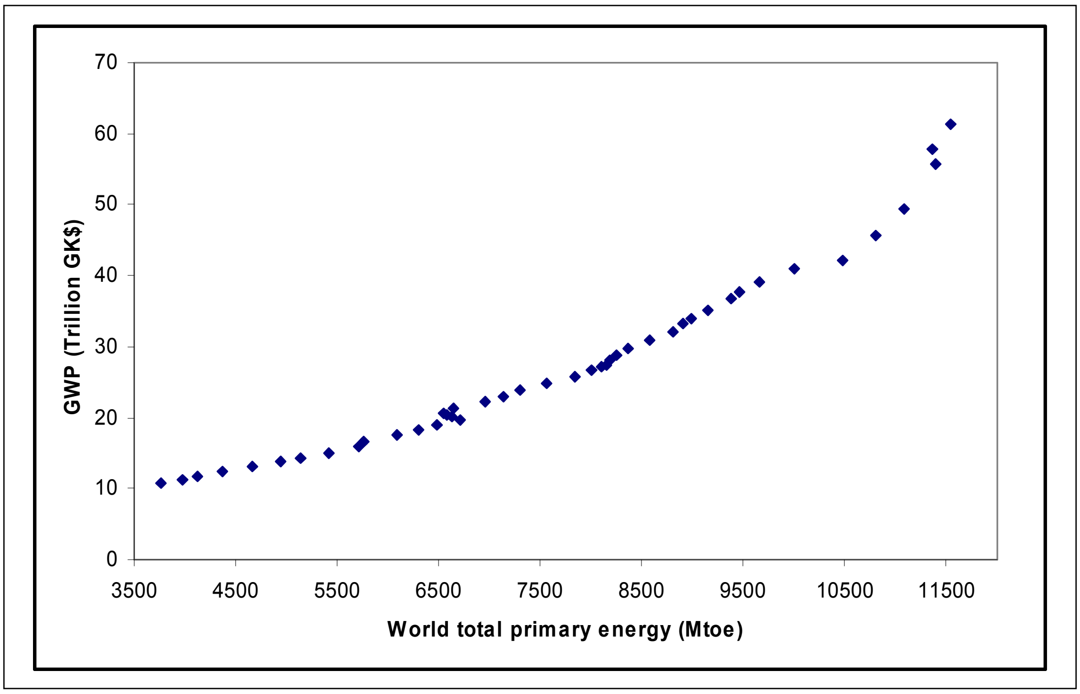

Figure: 1 *Total world primary energy consumption measured in millions of tons of oil equivalent (Mtoe) vs Gross World Product in Geary-Khamis dollars, 1965-2009. This should only be understood as a general guide: it is not energy that produces GWP, but the amount of it that can be converted into useful work. (Data: BP, IMF).*

The evolution of the global economy and all economic processes are non-equilibrium processes; there is always change. However, there is usually recognisable form and continuity in economic growth, as there is in a business, or a person. The continuity of form may occasionally be lost, like when the living person dies, the business undergoes a fundamental transformation, or an economy or civilisation collapses. We can describe as a dynamic local equilibrium those states about which form, continuity or identity are maintained.

With this in mind, we can define the dynamic equilibrium state of the globalised economy as adaptive economic growth of approximately ($\lambda<+2.25\%<\gamma$) per annum (averaged 1820-2003), where γ- λ is the range over which the growth rate can vary and system continuity and stability remain[17]. However, if (negative) growth was less than λ that would mean the globalised economy could not return to trend growth, rather it might remain broken or even collapse. We don't know γ or λ, only that such ranges of stability exist in many systems as we can expect them to in the globalised economy and in its internal sub-systems. Our society's sensitivity to growth rates that move too far from their normal growth rate is expressed in a general increase in anxiety over unemployment, depression or inflation. It is also within this stability domain that the cycle of booms and recessions occur, with an assumption of reversion to the long-term trend.

While systems show great diversity, from markets to crowd behaviour and ecosystems, they also share many similar dynamic features[18]. In figure 2 is a representation of a system, as a ball, at a particular time and in a particular state. The horizontal axis represents the range of states the system might be in. Points close together represent similar states or configurations. In the metaphor, the gravitational force represents the natural forces of change on the system. If some perturbation shifts the system, while it is in a valley, restorative forces bring it back to the valley's basin.

On the other axis are some changing conditions. As the conditions change, the 'landscape' is changed. As we move from left to right under the changing conditions, we see another valley appears — there are two alternative stable states. The valleys become more or less shallow, and a hill appears between them. It takes a smaller perturbation to push the ball from one state to another. The hill represents an unstable equilibrium, a *tipping point*, where only the slightest push can cause the state to jump into one state or another. The two basins represent distinct phases or regimes corresponding to different identities and dynamical behaviour. The distance between the bottom of the valley and the peak on either side corresponds to λ and γ in the previous paragraph. Their distance between peaks corresponds to the systems stability domains, or γ- λ.

So, the system can maintain its local equilibrium over a range of changing conditions, but those changing conditions can also change the system's resilience. At a certain point, a slight change in the conditions or a tiny perturbation can cause the system to pass a tipping point and the state to transform into something very different.

For example, the state of a shallow lake, its clarity and vegetation, can be unchanged by increasing nutrient loading caused by fertiliser run-off from farms say. However, at a particular level of loading, F1, in the bottom plane of the figure, there is a *critical transition*, and the lake suddenly switches to turbid, submerged vegetation and many fish die, *i.e.* it is in a new state[19]. Once in the turbid state, reducing the nutrient loading below F_1 will not return the system to its clear state: it may have to be reduced much further to do that, to F_2. This would be an example of hysteresis.

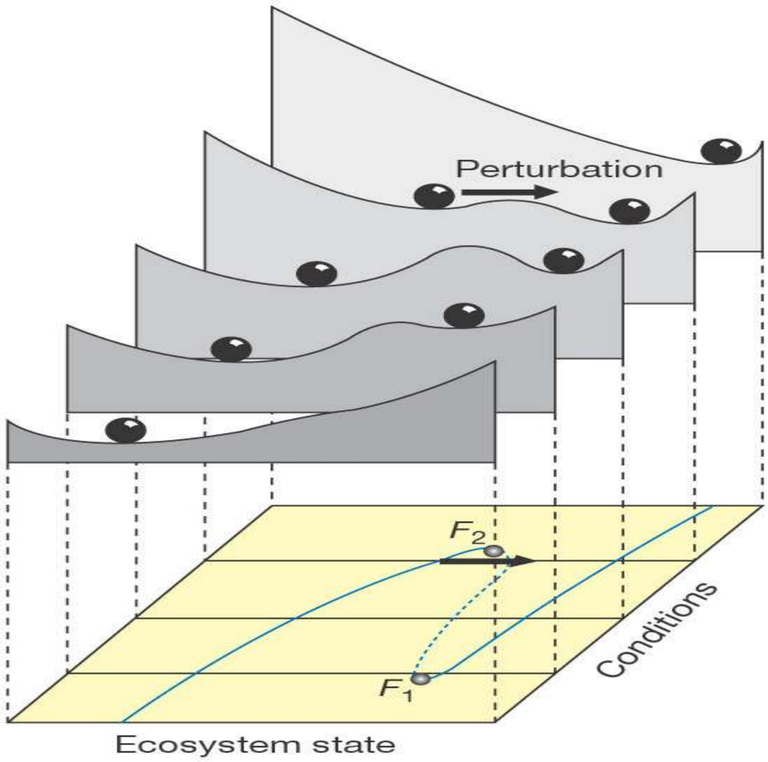

Figure:2 *The bottom plane shows an equilibrium curve, with the solid lines representing the range of conditions over which the state retains its identity. In the stability landscape, valleys depict the equilibria and their basins of attraction. The dotted line represents unstable equilibria, corresponding to the ball on a hill*[20].

When the ball experiences a perturbation driving it from its equilibrium at the bottom of the basin, but when it is still within its original stability domain, re-equilibrating forces - negative feedbacks - drive it back. This could be when governments use 'automatic stabilisers' when an economy slows down or heats up too much. Similarly, homoeostasis in humans comprises many negative feedback processes that keep our bodies within the correct range of temperatures, blood sugar levels etc. Or if a business were to be pushed into a loss by a competitor and so be at risk of dissolution, it may preserve its identity by cutting costs or introducing a new innovation.

It is not uncommon for complex systems to undergo a rapid transition to an alternative state, a critical transition. It could be a heart attack and death, abrupt climate change, the collapse of the northern cod fishery, the Arab Spring, the major market crash, an electric grid collapse, or the ongoing mobile communications revolution (on an appropriate time scale).

This can occur when the state of the system crosses a tipping point and undergoes a phase transition or regime shift. This is the point at which the system no longer undergoes negative feedback returning the system to its old equilibrium; instead positive feedback drives it away to a potentially alternative state. Positive feedback is a reinforcing cycle that amplifies a disturbance. A well known example would be if greenhouse gasses crossed a tipping point, leading to rising temperatures and large methane releases from melting permafrost, leading to even higher temperatures and greater methane releases, causing run-away climate change.

Such a critical transition could be due to a decline in the range of states over which a system was stable (lowered resilience) and/or increased responsiveness to changing conditions (lowered stability). Returning to the business example, if the company is already vulnerable in a recession, it takes only a slight push such as a fault on the production line to tip it into insolvency. Previously, when the economy was in better shape, the company could have taken such a fault in its stride.

We can understand the globalised economy as a myriad of interacting systems at various scales, coming in and out of existence - people, products, services, social and economic networks, businesses, infrastructures and so on. More broadly, we can think of a 'fuzzy' hierarchy of slowly changing states providing the context in which many more, smaller and faster states interact in more diverse ways. Thus climatic stability gave the conditions in which settled agriculture and human civilisation evolved. Our ability to exponentially increase energy and resource flows provided the stability through which the globalising economy could evolve. The globalising economy provided the stability for technological evolution. New technologies gave the stability needed for the new businesses, fashions and social relations to evolve. The use of the computer gives me high speed communication and processing power. This hierarchy of larger stable systems providing the 'nest' in which faster evolving smaller systems are born and die is common throughout natural systems. The interrelationships between hierarchical levels, and their birth and collapse share many features[21].

While we are open to the idea of businesses failing and stock markets collapsing, they are after all familiar features of our world: we generally assume systems respond proportionally to changing conditions. It is often a good assumption. However, there is a intuition that the whole of our globalised economy, under the prospective effects of energy and resource depletion, climate change, biodiversity loss, or debt deflation (the current condition within much of the Eurozone and elsewhere) will undergo a gradual if grinding contraction. This may be so. However, all those changing conditions would need to do is drive the globalised economy out of its stability domain, or weaken the resilience in such a way that the slightest obscure event could cause the tipping point to be passed, and the economy would be rapidly driven by a new set of negative feedback processes into a collapsed state.

Of course, such a situation would lie far outside our lived experience, so our intuition of proportional response might be a good heuristic. But our experiences of diverse system collapses, albeit on a smaller scale, should warn us to be cautious in our assumptions.

In the next section, it will be argued that the local equilibrium corresponding to the historical evolution of the globalised economy is internally maintained by the integration of a set of pillars, or keystone-hubs. Each pillar has its own local equilibria and stability domains. Once all of these remain within their stability domains, the globalised economy provides the conditions for normalcy.

III.2 Trophic Web Model of the Globalised Economy

Our understanding of economies, of the discipline of economics and of economic models has developed within the context of a particular type of socio-economic change they have been created within - long-range economic and complexity growth and stability. It has absorbed contingent assumptions, about technological change, the inevitability of growth, and the price system as a regulator of resources. More broadly, it has embodied wider cultural myths of progress and that we (or they) are in control.

One particular facet of this has been the reliance upon particular types of economic models to guide policy. These models are a reflection of past perceptions and understandings, and are parameterised by past economic conditions. They embody the dynamic stability of economies over generations. Even then, they have been often been very deficient.

But as the risk of major systemic change grows, those models will likely prove increasingly erroneous as the system moves out of its historical equilibrium. We need other ways of looking at systemic integration, stability, and even collapse. Nor do these models necessarily have to be mathematically precise to be useful. Indeed, what we need are different ways of looking at things that aid understanding, and such models can be very simply framed.

In the following the globalised economy will be framed in terms of dependency. That is, we start by asking what are the general conditions that must be in place so that the economy 'works' to make a mobile phone usable and a product or service accessible.

We can take a view of the globalised economy by drawing an analogy with the limited representation of a network in an ecological community, for example, trophic webs. They might represent food webs, which are essentially the energetic, resource and information relationships between members in a community. Often in such ecological communities there are keystone species, which have a disproportionate impact upon an ecosystem relative to the species' abundance. Removing the species, say a generalist pollinator, can fundamentally transform the whole ecosystem. In network theory the idea of a 'hub' serves a similar function. Hubs are highly connected nodes upon which the operation of many or most other nodes are dependent.

A hub for me and my city might be the electric grid or the banking system. This is because if either one failed the city would grind to a halt, because almost all nodes (people, factories, goods and services, transport) are directly and indirectly linked to both. The banking system and grid are of course are very tightly coupled. If the grid went down, failure would be rapidly spread to accounts and payment systems and ATM machines. That is, there would be high-speed cascading failure between hubs. Looking at the inverse, if the banking system were to fail it might take longer for the grid to fail, as running our grid does not depend upon real time financial transactions. However, one should be careful about being too definitive: the levels of interdependencies and complexity mean the failure of a hub could have unexpected and difficult to predict consequences.

The grid and banking hubs are really hubs for any complex society. We can also expand the list of primary keystone-hubs to the following list that together maintain the core functionality of the globalised economy.

- ***Financial & Monetary System:*** At the heart of the financial and monetary system we have fiat money, credit and bank intermediation.

  Our ability to trade and invest requires faith that the money we receive for our real resources and labours is accessible and will be acceptable elsewhere in space and time for the real resources and labour of others. Because fiat money has no intrinsic value, it exists through collective confidence in relative monetary stability.

  The interrelationships between money, credit and the banking system mean that the hub's stability is dependent upon the ability to service credit expansion, or in general the debt/GDP ratio. Credit hyper-expansion can destabilise this and/ or GDP destruction.

- ***Economies of Scale:*** People around the world share the costs of consuming what is produced in the world, which is affordable because people around the world are also producing what is being consumed. It is adaptive to levels of population, income and the evolving distribution between discretionary and non-discretionary expenditure. It is also related to the scale and structure of global aggregate demand.

- ***Production Flows:*** This includes factories and supply-chains. It's the chain of final and intermediate goods and services transactions and the combinations that produce things in the economy and move them through the economy.

  They comprise flows for final consumption, and flows to maintain and repair factories and infrastructure against the inexorable effect of entropic decay. As production has expanded (economic growth) and become more complex, more and more production tributaries are required to be maintained.

- ***Behaviour:*** This is the collective behavioural responses and expectations adaptive to economic and social conditionality. This includes the extent of those we cooperate with (social radius), social discount rates, habituation, herd behaviour, and our willingness to maintain institutions of trust (local law, international law, IMF, EU), popular consensus and radical social change.

- ***Critical Infrastructure:*** Generally the collectively shared infrastructure that provides critical services that support wider economic and social processes. It includes grids and power stations, IT networks, transport, the banking system, sewage & water systems, and emergency services.

- ***Energy & Resource Infrastructure:*** This is all the things between an *in situ* resource and the user of that input in the production system. This includes oil rigs, refineries, pipelines, farm machinery, fertilisers and mining systems. It sends food and energy and other resources into the globalised economy. Conversely, it channels the technical, productive and financial resources of the globalised economy to access and processes its own expanding requirements for the energy and resources.

All of the core keystone-hubs co-evolved together, and each supports the functionality of the others. Together they maintain the dynamic state of the globalised economy.

It will be noted that these keystone-hubs are very high level critical inputs for the globalised economy, and subject to Liebig's law of the minimum. If the financial and monetary system failed, so too would production flows and replacements for critical infrastructure while bank runs and food riots could bring down governments (behaviour). If critical infrastructure were to fail so too would banking systems, production flows, energy & resource infrastructure and behavioural response.

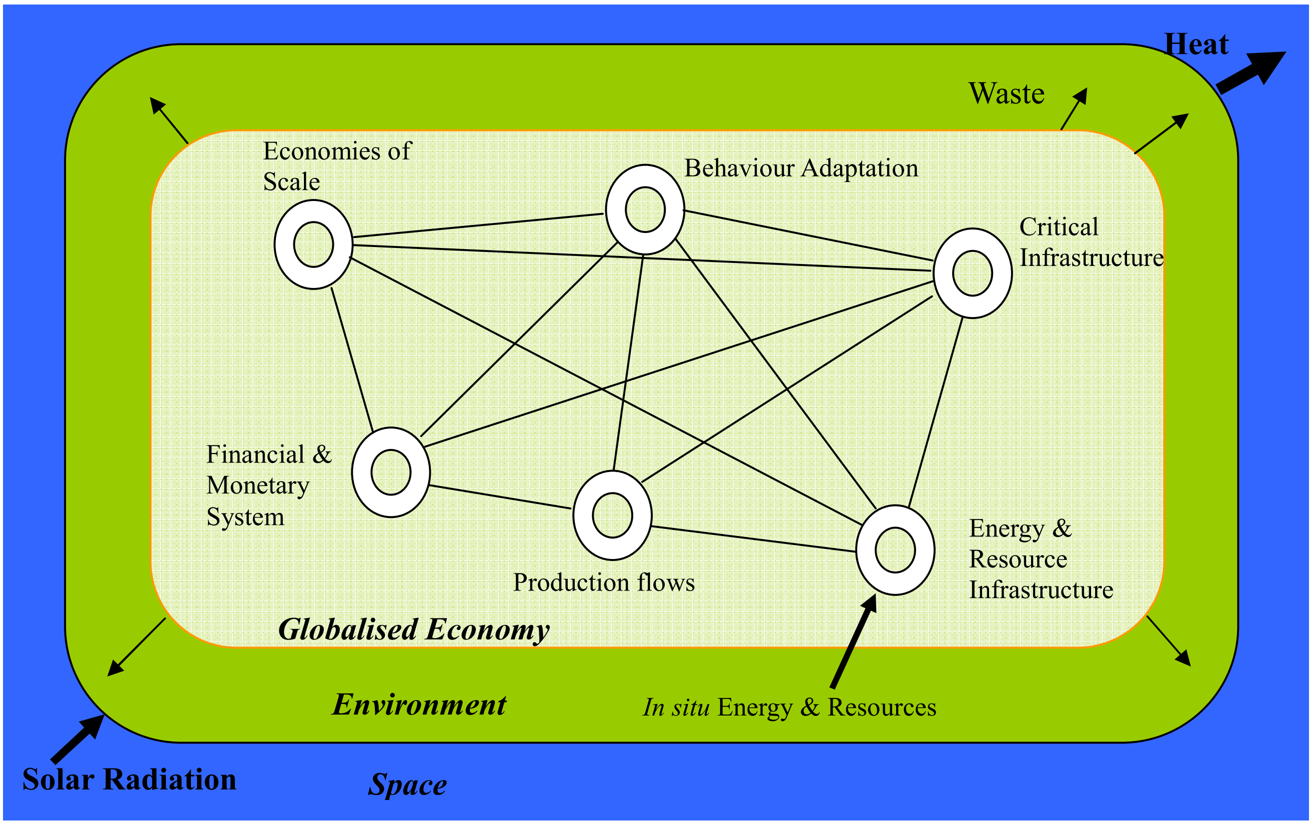

Figure:3 *Trophic web model of the expanding globalised economy. Six primary co-dependent keystone-hubs co-evolved and together maintain the general functionality of the globalised economy. The faster moving economy has evolved in the context of slower moving environmental conditionalities, which have evolved in the context of an even slower moving earth energy balance.*

A very important feature of these primary global hubs is that they tend to have little or no redundancy. That is, they have no substitutes at scale. For example, we are all dependent on fiat currency, fractional reserve banking, and credit. We have almost no resilience to a systemic failure of the financial system, as we hold little currency, no alternative delocalised trading systems, have little to barter (as our personal productivity is dependent upon the globalised financial system), and have little capacity to maintain ourselves at even subsistence level (low personal and community resilience).

Likewise, while we might have a choice of electricity providers, they share a common grid. If the grid were to fail there is no fall-back system. Diesel generators are limited. Further if grid failure initiated banking and IT system failure, diesel may be unobtainable.

A reason for the concentration on hubs and a lack of redundancy arises from what is known as *preferential attachment*[22]. That is, the greater the number of connections to a node, the greater the likelihood that any new connections will attach to the same node. For example, as the globalising economy grows, increased population, wealth and integration opens up the possibility of greater economies of scale and more diverse productive niches. When new technologies and business models emerge, they co-adapt and co-evolve with what is already present. Their adoption and spread through wider networks depends on the efficiencies they provide in terms of lower costs and new market opportunities. One of the principal ways of gaining overall efficiency is by letting individual parts of the system share the costs of transactions by sharing common infrastructure platforms (information and transport networks, electric grid, water/sewage systems, financial systems), and integrating more. Thus there is a reinforcing trend of benefits for those who build the platform and the users of the platform, which grows as the number of users grows. In time, the scale of the system becomes a barrier to a diversity of alternative systems as the upfront cost and the embedded economies of scale become a greater barrier to new entrants, especially where there is a complex high-cost hub infrastructure. Such economies of scale come to interweave whole socio-economic systems, such as road networks and settlement patterns. Thus, there is vigorous competition between mobile phone service providers but they share common information platforms and depend on electricity networks and the monetary system, both of which have little or no system diversity.

III.3 Path Dependence & Economic Contraction

The local equilibrium of the globalised economy was characterised by growing scale, integration and complexity. Likewise the keystone-hubs also have their characteristics, which share the features of the globalised economy, but they also have distinctive ones pertaining to their own function. A related feature of all of them is that they share *path dependency*. That is, their current form and structure is contingent upon historical conditions. Understanding this is critical, for it helps define the extent of their stability domains and their susceptibility to change.

To frame some examples that will be drawn upon later, the keystone-hub is imagined to be forced into the condition of a contracting economy, that is, the very opposite of its path dependent evolution. What will be shown is that this moves it out of its stability domain, it crosses a tipping point, and positive feedback drives it towards some form of disintegration.

What is implied is that the normal negative feedbacks that maintain the systems stability fail and become swamped by the effects of positive feedback. Thus the normal stabilisers in an economy to reverse a recession (devaluation, efficiency gains, exports, deficit spending) become impossible, of not enough scale, or too slow to drive the system back into its historical equilibrium. For example, credit is one of our economies' principal ways to inter-temporalise risk. Money in the bank and borrowing on all scales from people through to governments allow us to manage risk in recessions. But if the recession or depression is too deep this tool becomes increasingly vulnerable due to debt deflation, say, and the system loses resilience. The valley in the ball analogy becomes shallower. But driving deflation, if it is deep enough, can induce systemic financial failure, a fast and powerful positive feedback of cascading collapse.

III.3.1 Reverse economies of scale in critical infrastructure

As the globalised economy expanded in scale, larger and more complex critical infrastructure had to expand to service that growth. As infrastructure such as water/ sewage systems, telecoms networks, and power and grid infrastructure expanded, the fixed costs of maintenance and repair rose also. This reflects our eternal battle against entropic decay. The income a utility earns must cover the fixed costs of the maintenance and repair of its network plus normal running costs. Because infrastructure has amongst the largest scale and most complex physical structures in the economy, its fixed costs are very high. In a constant or expanding economy this can be afforded. The scale of our infrastructure is adapted to the economies of scale of the economy we have now. However, in a contracting economy it sets off a positive feedback of reduced demand, deteriorating networks, and growing economic damage to the wider economy.

As the economy contracts, then the customers of the utility have less to spend. A decline in revenue would mean that the utility income relative to the fixed costs would fall. If they want to maintain the network, they may have to raise the price of their service; this would drive away some customers, and cause others to use less services. Thus the utility revenue would fall further, requiring further price rises, spending falls and so on. If the utility cannot afford to maintain the network, the service deteriorates making it less attractive for customers, who drop out, reducing income and so on.

The infrastructure does not decline linearly with economic contraction, rather there is a positive feedback of accelerating infrastructure decline until it is no longer viable, and fails. Overall, it will have undergone a phase transition from a scale adaptive state where it operated well into a new collapsed state.

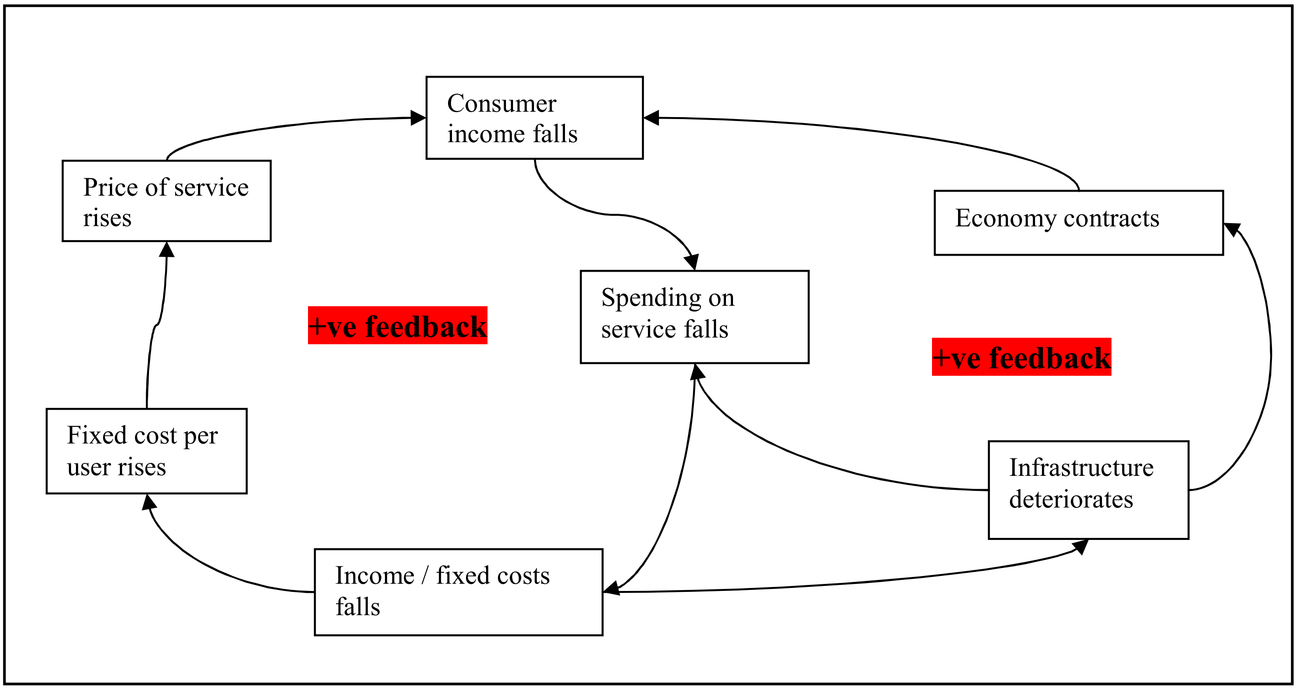

Figure:4 *Reverse economies of scale in critical infrastructure. The fixed costs of critical infrastructure are adaptive to scale and economic activity. As economy contracts and demand falls, fixed maintenance costs remain. A positive feedback of declining utility income and deteriorating infrastructure ensue. Eventually, the infrastructure fails.*

A useful analogy is that our bodies have adapted to their growing size. As we grow, we become dependent upon the total volume of resources needed to feed the body growing also. If an adult were to lose 20% of his blood, he would die. However, as a child he could have lived on 80% of the blood he had as an adult.

Complex critical infrastructure is very interdependent, see figure 14 in section V. Thus failure of an integrated grid-power station- water- sewage- telecoms - transport network under economic contraction would be set by failure of the weakest link. Further, because critical infrastructure is a keystone-hub, its failure can have cause cascading failure across other keystone-hubs, thereby driving the whole of the economy out of its stability domain. Here again, we see the operation of Liebig's law, this time operating on two linked scales.

The ability of the contracting economy to maintain critical infrastructure by subsidising it would be increasingly difficult as contraction undermined other keystone-hubs.

The failure of critical infrastructure in a small, weakly coupled part of the globalised economy would have a low chance of causing cascading failure globally. The chance of spreading global contagion would be dependent upon the centrality or 'hubness' of the failing infrastructure, and the resilience of the globalised economy to such a perturbation.

III.3.2 Debt deflation

Bank-issued interest-bearing credit is the source of almost all money in the economy. Because credit is charged at interest, credit expansion is required to service previously issued credit. In order for the issued credit-money to retain its value relative to goods and services in the economy, GDP must increase commensurate with credit-money expansion.

The amount of credit-money can fall in an economy because over-borrowed people and businesses cannot borrow any more while de-leveraging takes money out of the economy. In addition, people and businesses are more cautious, saving more and spending less, so the velocity of money falls also. Less credit-money in the economy flowing more slowly through the economy means less for businesses. Some businesses fail, leading to growing bad debts, rising unemployment, less taxation income, reduced confidence and investment. Asset prices fall, GDP declines, and the real cost of debt rises. Rising bad debts means bank capital is destroyed, risking bank's solvency, and the general economic outlook worsens. Bank issued credit-money and its velocity in the economy declines further. The cycle continues, and GDP falls further. The cost of credit on international markets for the country and banks rises due to fears of default, which increases the vulnerability of both. Confidence falls further.

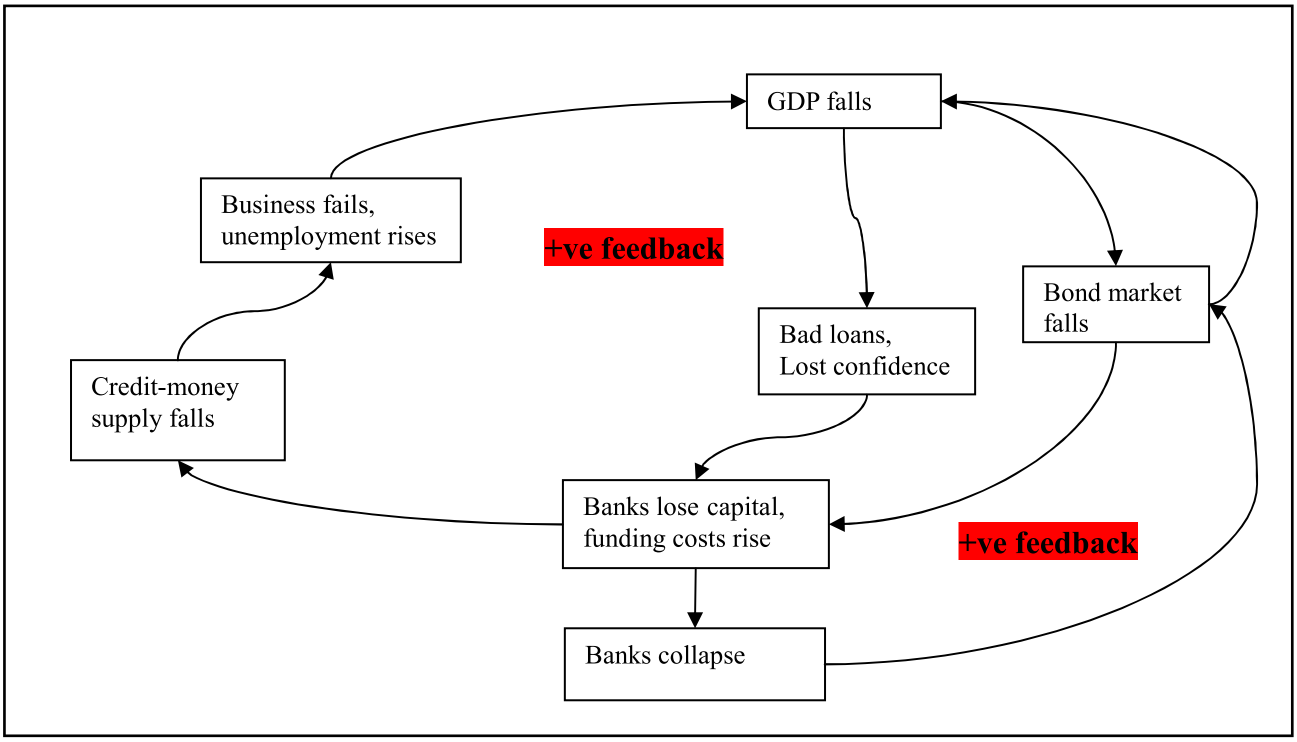

Figure:5 ***A part of the deflationary process.*** *In an economy where over-credit expansion relative to GDP occurs, a cycle of credit-money contraction and declining GDP ensues.*

Let us imagine some of the debt is written off. The country and investors can again go to the market and decide to borrow for real production that will grow GDP and hopefully allow the loans to be serviced in future. But producing GDP requires energy. Let us imagine that the energy to grow GDP is not there, rather it starts to decline.

At first glance, this again looks like the debt deflation described above. GDP would fall relative to outstanding debt - or equivalently, people and businesses would be over-borrowed relative to their income (GDP). Thus a debt deflationary cycle would begin. But what if we thought that energy constraints were to continue to contract growth for many years, how would that change things?

Declining economic activity means more unemployment, business failures and defaults. Those people and businesses in the economy that are able to, pay off loans. Defaults eat into bank capital. However, if GDP is expected to continue to decline, the banks would see that the real economic activity required to service outstanding debt could not be repaid in real terms. They would understand that as almost all money and deposits were issued into circulation as loans, all the money and deposits in the economy could not repay outstanding principal + interest. They would stop issuing new credit. The public and businesses might notice that as the economy declines, more and more of its shrinking productive output would have to go on servicing debt.

Indeed, we may not get far into this process. That is because banks have evolved in the expectation of continued growth. Their retained earnings and shareholder capital amount to only between 2-9% of their loan book. Only a small percentage of loans have to go bad before the bank is bust. So a contracting economy would mean, very soon into the process, that all banks failed. No amount of liquidity would change that. Bank intermediation required for economic life would stop. Because our monetary system is based upon bank issued credit-money, it too would come apart.

So rather than a continuing deflationary slide, a point would come when the banking system just collapsed, along with our monetary system. This tends to happen when reality finally shatters the delusions that supported the system up until that point. Then, in a wave of panic and fear, investors, depositors, bond holders and all the interlinked counter-parties would run to exit the financial system. This would also be a phase transition.

III.3.3 Trust Radii in Expansion & Contraction

The evolutionary economist Paul Seabright argues that trust between unrelated strangers outside our own tribal grouping cannot be taken for granted[23]. In an expanding economy, trade can be expected to increase into the future. To share in that future's good fortune, we and those within our own identified group need to be regarded by the distant others with whom we might trade as trustworthy. If we are untrustworthy (don't pay for goods received) we not only damage our own future benefit, but also our groups', so they too have an interest in preventing a free-loader on the groups' good name. From this has grown institutions of trust and deterrence ('good standing', international legal frameworks, the EU, IMF) to reinforce cooperation and deter free-loaders. Trust builds compliance, which brings benefits, which builds trust. This has been true in an era of global economic expansion.

In a contracting economy the situation might be expected to break down. If less and less is expected to be available in the future, the benefit of grabbing something now increases (because you are getting poorer), and the cost of breaking trust with a stranger across the world falls (because the benefits of future trade are going to fall anyway). Because it is with a far off stranger rather than someone within your tribal group, your reputation as a free-loader will be minimal to those within your group, where your reputation may remain of great benefit. But breaking away from compliance, encourages further defection from compliance. Importantly, trust takes a long time to build but can be lost rapidly. For Seabright, global trade hangs upon a thread as fine as trust.

A related issue is the contraction of trust radii, and a hardening of tribal feeling in times of stress and crisis. A suspicion of 'outsiders' and increasing nationalism are common features of an economic crisis.

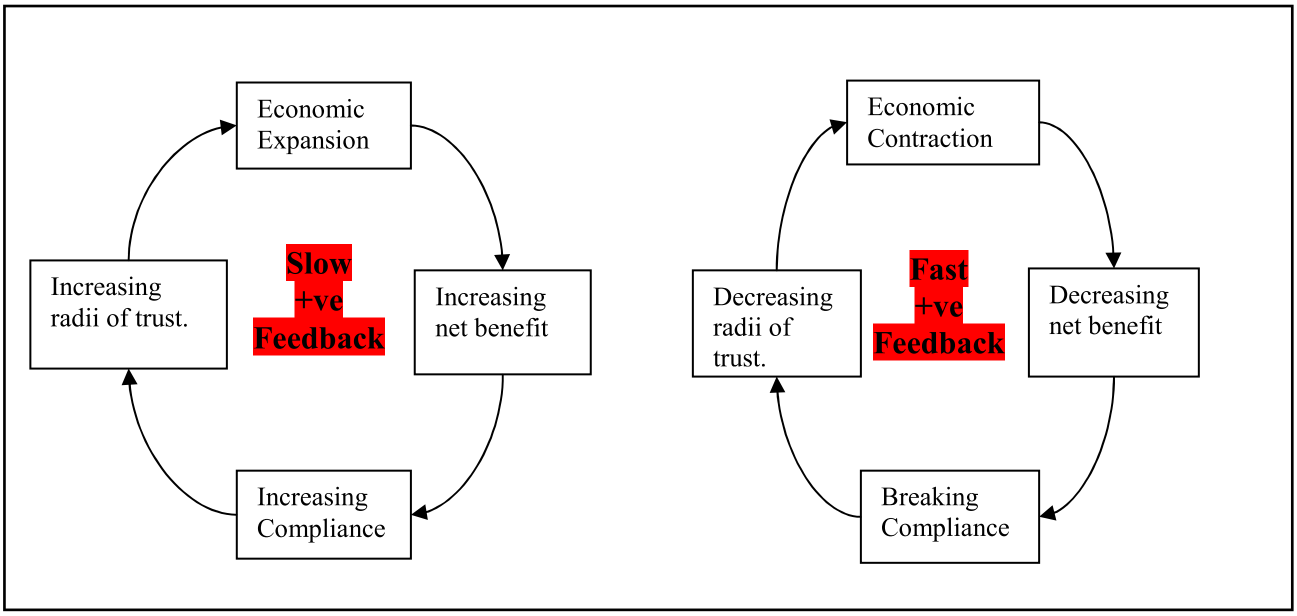

Figure:6 ***Trust Radius*** *The slow expansion of trust in an expanding economy, and its fast contraction in a contracting economy.*

III. 4 Secondary Keystone-Hubs and Scale-free Networks

At a level below these general keystone- hubs are a series of secondary hubs. These are hubs that support the operation of primary hubs. Two are considered, the banking system concentration associated with the Financial & Monetary System, and trade system concentration within Production Flows.

II.4.1 The banking system

Prior to the beginning of the financial crisis, risk management by regulators was focussed on individual banks. In addition it was common to hear how increased interconnection and integration between banks reduced systemic risk by dispersing individual bank risk over the whole system. The crisis prompted a wave of studies, drawing particularly upon ecology, emphasising how the structure between banks could increase systemic risk[24,25,26]. This included collective effects like herding, in which financial networks enabled imitative strategies in the search for yield, or transmitted collective euphoria or panic. They also showed how deregulation and connectivity had removed 'circuit-breakers' in financial systems such as the integration of retail banks into merchant banks trading on their own account. The effectiveness of fire-breaks and the vaccination of super-spreaders show how 'modularity' can inhibit contagion in natural systems. Indeed, the 'fire-break' of the non-free traded Chinese Yuan probably stopped the 1997 Asian financial crisis from being far more serious.

Further the nature of the connections between banks was explored. Each bank was not connected at random to other banks, rather a very small number of large banks were highly connected with lots of other banks, who had few connections to each other. These arrangements are sometimes known as *scale-free* networks[2]. Preferential attachment is a way of generating such scale-free networks - big banks have greater economies of scale and bargaining power, so can attract more business than their smaller rivals with better deals or market crowd-out, thus generating even greater economies of scale and so on.

For example, when the Federal Reserve Bank of New York commissioned a study of the structure of the inter-bank payment flows within the US Fedwire system they found remarkable levels of concentration. Looking at 7,000 transfers between 5,000 banks on an average day, they found 75% of payment flows involved less than 0.1% of the banks and 0.3% of linkages.

While this type of scale-free structure can reduce local risk, it can also help to displace and concentrate large-scale systemic risk. A random failure in a scale-free network is likely to affect a node of low connectivity, with small implications. However, the failure of a hub node has a disproportionate impact, especially if those hub nodes have high connectivity to each other. This concentration opened up the possibility of 'too big to fail' and 'too big to save' banks, that is, a small group of banks that were 'hubs' of the global banking system. Upon this small number of super-connected banks stand the operations of lots of small ones.

Thus we see the primary financial monetary keystone-hub with little or no redundancy, underpinned by a secondary banking system that comprises high, but not quite as high levels of concentrating hubs.

[2] In such a distribution, the number of banks (nodes) with a number of connections (degree, k) to other banks is, $N(k) \approx k^{-\gamma}$, where γ degree exponent, with generally $2 < \gamma \leq 3$.

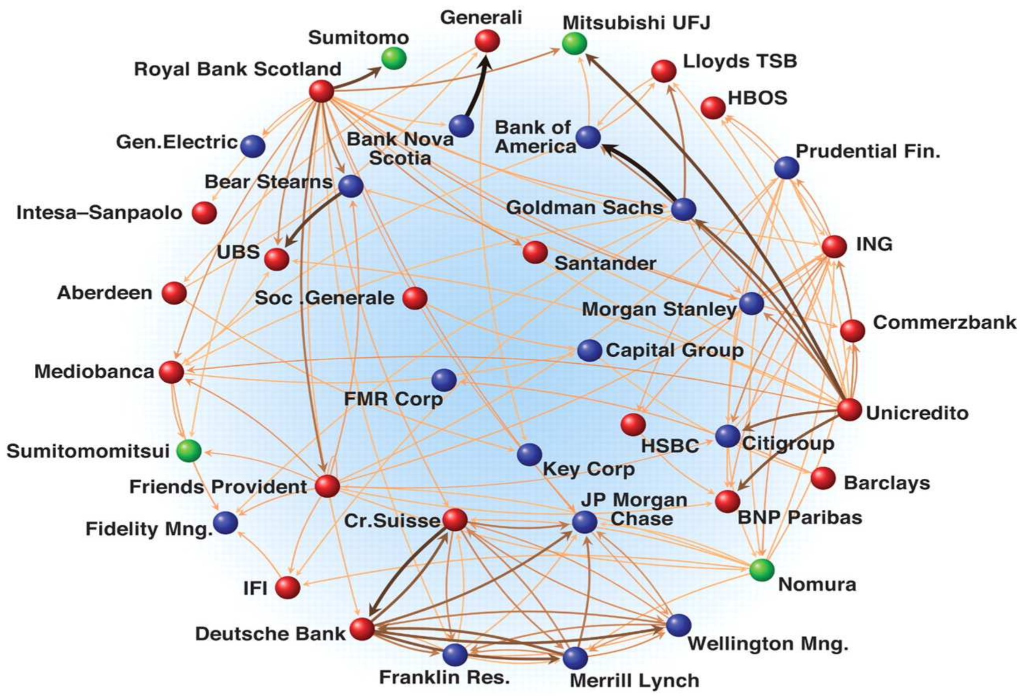

Figure:7 *The major banks hubs of the international financial network show high levels of connectivity and interdependence. The links are weighted to represent the strongest relations between banks. The colours represent different geographic areas, European Union (red), North America (blue), other countries (green)*[27].

III.4.2 Production Flows

Like the banking system, trade networks also show a scale-free property[28]. More generally, some countries' role in trade is far more important to the globalised economy than others. This is a trivial observation, but one with important implications.

Two studies are of note, both are based upon network analysis but take slightly different approaches to international trade data. The first, by Kali & Reyes[29] measures countries' influence on global trade, not only by trade volumes, but the influence a country has on the global trading system. They used an *Importance Index* to rank their influence. For example, they find that Thailand, which was at the centre of the 1997-1998 Asian financial crisis ranked 22nd in terms of global trade share, but 11th on their level of importance. That means its potential as a crisis spreader was higher than its trade volumes indicated. Their results are based upon 1998 data. We list them in terms of their Importance Index (Eurozone countries in blue): USA(1st), Germany, Japan, France, UK, Italy, Belgium-Lux, Spain, Russian Fed, Netherlands (10th).

In another study, Garas et. al.[30] used an epidemic model to look at the potential any country had to spread a crisis. One of their data sets is based upon international trade in 2007. It uses a measure of *centrality* to identify countries with the power to spread a crisis via their level of trade integration. Like the previous paper, the centrality in the network does not necessarily correspond to those countries with the highest trade volumes. There are 12 inner core countries, which are listed in no particular order (Eurozone in blue):

China, Russia, Japan, Spain, UK, Netherlands, Italy, Germany, Belgium, Luxembourg, USA, and France. The data sets used by both groups combine Belgium and Luxembourg data, both sets of authors have classified them together and separately respectively.

Hidalgo & Hausmann[31] used international trade data to look at two things - the diversity of products a country produces, and the exclusivity of what they produce. An exclusive product is something made by few other countries. Most countries in the world are non-diversified and make standard products. The most complex countries (such as those in the Eurozone) are diversified and make more exclusive products. More exclusive products have less substitutability. It can also be assumed that even a standard product, bread say, requires many more critical inputs in a complex country than in a less complex one.

While these studies have significant drawbacks, they do emphasise that the countries with the greatest importance in terms of their ability to spread contagion via their trade centrality to the world are at the very heart of growing financial-banking system stress. Further, any financial collapse in the Eurozone would bring not one, but a number of high centrality countries into being contagion ready.

III.5 What is Collapse?

As this paper is opening up a discussion about a collapse in the globalised economy, it would be useful to have a definition of what collapse might be. Following Tainter[32] and Homer-Dixon[33] we could associate collapse with a sudden loss of complexity. However, there has been confusion in such studies where collapse has been also identified with a break-up of empires but which did not significantly alter the socio-political complexity of the constituent parts.

The shock from a collapse depends upon the level of complexity lost. The Black Death which killed about one third of Europe's population in the middle of fourteenth century did not fundamentally alter the socio-economic complexity of the time[3]. A dead producer represented a dead consumer. The same small number of social functions (farmer, mason, and cleric) remained before and after, there were just fewer people doing each role. This reflects low levels of complexity and interdependence within and across functions in society. However, in modelling of pandemic influenza in modern societies, it was found that once more than about 10% of people are randomly removed from the workforce, the risks of large-scale societal dislocation increases significantly. This is because at this level of removal it is likely that key people with specialised knowledge will disappear from the workforce, meaning that key teams or functions cannot operate, which further cascades through other co-dependent functions throughout social and economic networks.

What is needed is a general complexity measure that might provide at least a rough guide for such a complex system collapse. Using simple thermodynamic argument, Eric Chassion has defined rising *free energy rate density Φ* (measured in ergs/s/g or W/kg), where free energy is the energy available for doing work, as a quantitative metric for rising

[3] The Black Death did change the feudal system and raised the living conditions of peasants, but it made little difference to the types of skills in use, or kinds of production (though quantity obviously dropped significantly).

complexity[34]. It is universal as it charts in time increasing complexity across the history of the universe from the Milky Way to the Sun, Earth, plants, animals, and society.

With great caution, as we are only considering a very general argument, we might identify Φ with (Energy flow/ GWP) (per annum) for the globalised economy. We can look at this on the scale of the globalised economy, as in figure:1 , or at the cutting edge of complexity within the economy. One analysis shows that the evolution of key manufacturing processes over the last century saw a six order of magnitude increase in the energy and resource intensiveness per unit mass of processed materials[35]. This should be quite intuitive - as we put more and more elements and functionality onto a micro-chip, the energy and resource requirements rise. Notice also, the increasing speed of economic processes naturally correlates with rising complexity as the measure, Φ, is per unit time.

So let us imagine the state of the globalised economy goes from $(E^{o}/GWP^{o}) \rightarrow (E^{*}/GWP^{*})$. What defines a collapse? One could have a case where $(E^{o}/GWP^{o}) = (E^{*}/GWP^{*})$. In this case, a big drop in economic activity is not necessarily associated with collapse. Here economic activity may have fallen by the same factor as energy flow, thus though the economy may be much smaller, the same level of complexity remains.

We can associate collapse with $(E^{o}/GWP^{o}) \gg (E^{*}/GWP^{*})$. Ignoring physically improbable arrangements, collapse would be associated with energy flows falling by a greater factor than GWP loss. This would represent a major fall in the economy's ability to purposefully use energy relative to GWP.

A systemic collapse in the globalised economy implies there is connectedness and integration. It also requires contagion mechanisms; these have been framed within the trophic web model. (In our framework we are not considering global pandemics, nuclear war or asteroid impacts, for example). It should be born in mind that a collapse could have intermediate states, characterised by partial breakdown and semi-stable states. However, here we are just outlining broad features.

The two other considerations are how big a fall has to be for it to be considered a collapse and over what time period. A global systemic collapse as framed here is different from much of the word's common usage in relation to the current crisis - a relatively sudden fall in income, a significant rise in unemployment, and a forced shift in a societies' previously held expectations of what the near-to-medium term holds. However, the operational fabric continues to operate as before, supermarkets are re-supplied, money works, and a diversity of complex goods and services can operate.

Rather, drawing upon section III.1, it can be argued that collapse happens when a system crosses a tipping point and is driven by negative feedbacks into a new and structurally and qualitatively different state, one with a different arrangement between parts and a fall in complexity. The operational fabric could cease to operate and the systems that are adaptive to maintaining our welfare could cease or be severely degraded. As a society, we would have to do other things in other ways to establish our welfare. Functions and specialities, a diversity of goods and services, and complex interdependencies would be lost.

The speed of collapse would be set by the speed of the fastest and most responsive systems coming out of their equilibrium, causing cascading failure across other systems. In particular we will consider that the monetary and financial keystone hub would spread contagion to the keystone hub of production flows, which would feed back into the financial and monetary system and other keystone hubs. The speed of contagion would be set by the operational speeds of these hubs. As the operational speeds have increased along with the growth of the globalised economy, and the functioning of more complex societies have become evermore dependent upon their moment-by-moment, day-by-day operation, the potential speed of collapse has risen.

The collapse of complexity is associated with the release of stored energy. This energy is turned into heat and the temporary animation of high-speed fragmentation. This intermediate collapsing stage would be characterised by high levels of uncertainty, unpredictability and non-linearity.

IV. Converging Crises in the Financial, Banking & Monetary System

In this section the context in which an unprecedented and catastrophic shock could occur sometime within this decade is presented.

The first sub-section considers the implications of massive credit expansion and global imbalances over decades. At the heart of this is too much debt relative to GDP. This is particularly acute as credit, monetary systems and bank solvency are highly co-dependent and support the functionality of the globalised economy. Since 2007/8 when the crisis first broke, systemic risk has increased. Continued ‘kicking the can’ and reduced buffers and confidence in the global financial system have increased the risk of a catastrophic financial shock.

There is a growing risk that oil and food constraints will increasingly bear down on global economic growth in the near-to-medium term. If the amount of affordable oil available to the global economy declines in real-time, and cannot be substituted in real-time, then economic contraction becomes inevitable. Economic contraction feeds back into further economic contraction. Sustained economic contraction is totally incompatible with the credit backing of the globalised economy as expressed through monetary systems, fractional reserve banking, fiat money, financial intermediation and all financial assets. The market ‘discovery’ of such an incompatibility could also be catastrophic.

However, we may not ‘see’ much of the effect of oil constraints because the effects of a breakdown of the financial system arising from the already present implications of credit expansion has already caused cascading failure through keystone-hubs, collapsing the globalised economy and energy demand. Or we may see oil (and food) constraints merely nudge that already increasingly unstable system tipping it into a collapsed state.

IV. 1 Credit over-expansion and imbalances

The response to the financial crisis in 2007/8 staved off a full banking crisis and avoided tipping the economy into a new great depression. It did not solve the massive disparity between debt and income; it displaced immediate risks onto sovereigns via bank guarantees and unsustainable deficits. We responded to too much debt with more debt, yet our ability to service that debt is even more questionable than four years ago. In many cases, through direct and indirect means, we are borrowing additional principal to service existing debt-the very definition of Ponzi borrowing. This situation was always untenable. But the displacement of immediate risk has further increased the potential for catastrophic systemic failure by removing potential buffers in the financial system and undermining further the confidence in the institutional and political actors that would be required to manage a crisis.

The level of debt to GDP across much of the developed world still remains far above the levels that initiated the Great Depression. The epicenter of the crisis was and remains financial debt, which remains in many ways the most obscure. However, the Bank of International Settlements point out that the core issue is not just financial debt; government, corporate (non-financial) and household is far above levels that undermine growth in many of the most advanced economies[36]. They concluded that if government debt is greater than 100% of national income growth is undermined, if household debt is above 85% of national income growth is undermined, and if corporate debt is above 90% growth is undermined.

	Government	Corporate	Household	Total non-financial
US	97	76	95	268
Japan	213	161	82	456
Germany	77	100	64	241
UK	89	126	106	321
France	97	155	69	321
Italy	129	128	53	310
Canada	113	107	94	314
Austria	82	99	57	238
Belgium	115	185	56	356
Finland	57	145	67	269
Greece	132	65	65	262
Netherlands	76	121	130	327
Portugal	107	153	106	366
Spain	72	193	91	356
Ireland	137	210	147	494
Critical level	100	90	85	

Table:1 *Debt as a percentage of GDP for non-financial sectors (2010). Eurozone countries in blue. Figures above critical level in red. Today, 2012, there would be even more red. (Data: BIS and Mathews[37])*

We are also reminded that in the Eurozone just prior to the crisis, even Germany and the Netherlands had levels of *Total External Debt-to-Exports*, and *Total External Debt-to-GDP* that exceed Reinhart and Rogoff's criteria for countries tipped as likely to default[38]. Out-side of the Eurozone, the United Kingdom has total debt (government +financial + non-financial +household) of over 900% of GDP, while Japan's is over 600%[39]. While the United States continue to benefit from their dollar reserve status, grave questions remain, even with the best global outlook, as to whether they will be forced to inflate their currency or default in the medium term. There is a debt crisis over much of the developed world, and if the spot-light is not on some countries' debt situation it is only because their neighbors are so much worse.

What these debt figures do not take into account are contingent liabilities. They do not include state guaranteed bonds, bank guaranteed bonds, or the guarantees behind the complex 'rescue' mechanisms within the Eurozone. Mark Grant uses the example of Belgium, which at the end of 2011 had an official government Debt-to-GDP ratio of 98%[40]. What are not included in the calculation are the guarantees for banks such as BNP Paribas and Fortis bank, as well as standing behind loans to the financial sector. It is also accountable for part of the balance sheets of the ECB, the Stabilization funds, and the Macro Financial Assistance Fund. So Belgium's total debt and contingent liabilities-to-GDP are 203%.

There are also large liabilities distributed throughout the Eurozones's internal payments settlement system (TARGET2). For example, Hans-Werner Sinn of the Bundesbank estimates German contingent liabilities of over half a trillion Euros could be revealed were the Eurozone to break-up[41].

The concern about such contingent liabilities, which exist throughout the Eurozone, is that provided there is no deepening of the financial crisis, or especially if there is no major shock, one can pretend them away. But if a shock occurs and the country is called to pay guarantees it immediately imperils its own solvency. Further, as such a shock it likely to be part of a global banking crisis and a multi-country sovereign crisis in the Eurozone, there would be little credit available to cover liabilities in the market, even if it was affordable. Sovereigns and banks are hot-wired for rapid contagion in the event of a shock. This is part of what we have referred to as a loss of system diversity (putting the banking system and sovereigns on the same platform), that can increase the speed and scale of any major crisis.

The negative effects outlined in the BIS study are only one element of how over-indebtedness damages economic growth. The primary driver of economic recession and depression is debt deflation (see also section: III.3.2) which rests upon the deeply intertwined relationship between the banking system and the monetary system[42]. Banks create deposits when they create loans. Their pumping of credit-money is what makes the world go around. When there is no further capacity for borrowing in an already over borrowed economy, and de-leveraging destroys money as loans are extinguished, the money-credit supply drops relative to the goods and services produced in the economy. Less credit-money in the economy means less for economic activity, resulting in business closures, defaults, falling asset prices, and rising unemployment. As the economic outlook worsens, people and businesses reduce spending due to fear of unemployment, say, and in anticipation of falling prices. This reduces the velocity of money, further reducing the effective money flowing through the economy. This further reduces economic activity in a reinforcing spiral. In all of this, assets and collateral are eaten away.

In this debt deflation process, the real cost of debt rises as GDP contracts faster than total debt. That is, real interest rates climb even as nominal rates fall. The debt burden is increasing. Austerity policies by governments cannot reverse this process - they exacerbate it. Hypothetically new money could enter the economy from foreign trade reversing the deflationary forces. But with much of the world's biggest importers suffering from too much debt, where is this growth to come from? Canada, Australia and China seem to be on the edge of a collapsing property bubble and therefore contain vulnerable banking systems.

In such a context, sovereign risk can only increase. Eurobonds, further leverage of the European Financial Stability Facility (EFSF), and waves of European Central Bank liquidity add debt but do not address insolvency. Indeed, new waves of central bank liquidity seem to be suffering from declining marginal returns, and worse, as we shall soon see.

Interrelated with sovereign debt is the instability of much of the global banking system. Our financial system is especially vulnerable to severe instability because of its intrinsic structure. The first reason is that in a fractional reserve banking system, core capital and shareholder equity is only a tiny fraction, 2%-9%, of assets. Thus leverage of 26 times core capital in the Eurozone banking system could mean an asset loss of just 4% would wipe out the banks. This would leave the banks unable to cover their liabilities to the public, businesses, and other financial institutions.

In reality, leverage throughout the shadow financial system is far higher via complex securitization, and off-balance sheet liabilities. Financial assets are the leveraged collateral for further financial assets which have been further collateralized and leveraged. The use of repos, collateral re-hypothetication and an array of derivatives are the shadow banking system's equivalent of fractional reserve credit expansion, but without the transparency that the 'normal' banking system is expected to pay some heed to. Because of this huge leverage, once a 'run' on such financial assets occurs, it can vaporize massive levels of virtual wealth. Because of the complexity and opacity of how and where such assets are held, in a crisis banks would be unsure whether counter-party banks or even their own balance sheet is safe from one moment to the next.

The Bank of International Settlements shows that over-the-counter derivatives outstanding rose by $100 Trillion to some $700 Trillion between 2010 and 2011, over ten times global GDP[43]. While these values are regarded as 'notional', they represent a web of obligations that may not be redeemable. For example, US treasury secretary Timothy Geithner's refusal to support a 'hair-cut' of Irish bondholders was in the context of US banks holding Credit Default Swaps on Eurozone debt [44]. The implication being that US banks may not be able to pay out if called upon to cover a 'credit event', with cascading implications. Yes, the haircut on Greek debt did not cause a CDS crisis as some feared it would, however, the coverage was small, the parties had time to prepare, and general confidence remained.

A further intrinsic vulnerability is reliance upon short-term funding. Ninety banks in The European Banking Authority's stress tests in mid-2011 have to re-finance €5,400 billion, equivalent to 45% of EU GDP in the following two years[45]. If there is already far too much debt in the financial system and thus on bank balance sheets, and economic contraction due to debt deflation is likely, then the affordability of re-financing such sums would naturally decline further.

Authorities can help systemically important banks 'hide' possible insolvency, but they can only play such games if their bluff is not called. For example, there is concern that the US banking system may be holding huge unacknowledged losses that are being obscured by the suspension of the 'mark to market' rule in 2008[46]. The bluff calling can come from a run on banks, a collapse in bond values, a frozen inter-bank market, a margin call, or a forced asset sale.

It was mentioned that actions by Central Banks and political authorities are adding to systemic risk. This is firstly due to draining confidence. There are only so many meetings of European or G20 finance ministers offering their latest doomed fix, however well intentioned, before their lack of control or remedy becomes an article of faith prompting fear and derision in equal measure. At that point a stampede out of a mountain of financial assets into a molehill of 'suspect' cash and hard assets becomes a growing possibility.

But real decisions designed to shore up an immediate crisis are increasing systemic risk. Ambrose Evans-Pritchard points to one salient example[47]. In early 2012, the inter-bank market was moving closer to a credit crunch that would have dwarfed the post-Lehman one. In response the ECB introduced its 1€ Trillion Long-Term Refinancing Operation (LTRO). Spanish and Italian banks parked this very cheap money in sovereign debt, where they potentially could make significant returns and the ECB could support heavily indebted countries by proxy. The money was 'parked' until it was needed to roll-over existing debt. Those banks are among those European banks that have to re-finance €600 billion over the rest of the year.

But by April, Spanish and Italian bond yields had risen significantly, meaning a large loss on the capital value of the bonds. Were they to rise much further, and all the evidence heretofore suggests this is possible, the losses could trigger a margin call on collateral. So, already weak banks are being pushed deeper into the mire with a risk that they will be forced to sell assets into an increasingly fearful market. That's not all. Because the ECB demands seniority on its bonds, any default pushes other bond holders down the chain increasing their loss ratio if either country defaults, so increasing private sector risk and corresponding risk premium.

Thus the ECB, which alone has an infinite balance sheet (it can print indefinitely at any scale), is by its actions further destabilising the financial system by pushing risk it can absorb onto parts of the system that cannot. It is also making itself indispensable to further refinancing operations as those risks spread and it crowds out private capital.

Of course, the ECB is itself in a bind. The consequences of a disorderly default are huge as we shall see, so it must keep intervening. But endless monetisation brings also brings huge risks, social, economic, and monetary.

The incongruity of national governments with distinct pressures and diverse interests, tied into a single currency; the ECB with one set of tools that cannot serve the diversity of those interests; an array of understandings and misunderstandings as to the nature of the crisis; the innate complexity of the situation; and the growing anger and nationalism of citizens add to the feeling that the mostly likely response to the growing risks or the response to a crisis breaking will be paralysis.

IV. 2 Peak Oil and its Economic Implications

But if the above pessimism turns out to be foolish, if the global economy maintains strong levels of growth, it is likely to hit new constraints, ones that are already being made apparent. The high quality and affordable oil that powered the growth of the globalised economy is being replaced by increasingly low grade and expensive oil. There are already good indications that we cannot maintain production at this level; rather, it will begin to fall. This is an issue of today. Global oil production has been essentially flat since 2005.

Oil contributes to about 40% of global energy production, but well over 90% of all transport fuel. It provides the physical linkages of goods and people across the globalised economy. It also is a raw material in a huge range of production from plastics to pesticides. Peak oil is the point in time when global oil production has reached a maximum and thereafter it enters a period of terminal decline.

The phenomenon of peaking, be it in oil, natural gas, minerals, or even fishing is an expression of the following dynamics. With a finite resource such as oil, we find in general that that which is easiest and cheapest to exploit is used first. As demand for oil increases, and knowledge and technology associated with exploration and exploitation progresses, production can be ramped up. New and cheap oil encourages new oil-based products, markets, and revenues, which in turn provide increasing revenue for investments in production. For a while this is a self-reinforcing process. Countervailing this trend, the energetic, material and financial cost of finding and exploiting new production starts to rise. This is because as time goes on new fields are found in smaller deposits, in deeper water, in more technically demanding geological conditions and require more advanced processing.

The oil produced from individual wells peak and then decline. So must production from fields, countries and the globe. Two-thirds of oil producing countries have already passed their local peak. For example, the United States peaked in 1970 and the United Kingdom in 1999, and decline has continued in both cases. It should be noted that both countries contain the worlds' best universities, most dynamic financial markets, most technologically able exploration and production companies, and stable pro-business political environments. Nevertheless, in neither case has decline been halted.

As large old fields producing cheap oil decline, more and more effort must be made to maintain production with the discovery and production from smaller and more expensive fields. In financial terms, adding each new barrel of production (the marginal barrel) becomes more expensive. Sadad al-Huseini said in 2007 that the technical floor (the basic cost of producing oil) was about $70 per barrel on the margin, and that this would rise by $12 per annum (assuming demand was maintained by economic growth)[48]. This rapid escalation in the marginal cost of producing oil is recent. In early 2002, the marginal barrel was $20.

There are good grounds for arguing that we are at or near the peak of oil production now. The International Energy Agency argued that conventional oil production peaked in 2006[49]. More than 60 countries have already passed their peak. To continue supplying oil commensurate with a growing economy in the light of the prospective decline in conventional production as more old fields deplete, will require huge production increases from unconventional oil such as tar sands, coal-to-liquids, polar and deep water oil. Further, oil producers are using more of their own production to feed their growing economies, meaning there is a declining volume of internationally traded oil.

The question then is can *sufficient* oil be brought on stream *on time, at an affordable price*, and *at a sufficient energy return on energy invested* (EROI). Or can the economy's requirement for additional oil be substituted by efficiency measures, or with other energy sources such as renewable energy and natural gas, say. In the former case, many analysts think this cannot be done, they argue for a near to mid-term net depletion[50,51,52]. Our fixed fleets of cars, planes and ships cannot run on electricity, coal or natural gas. In addition, if we cannot ramp up production of alternative electric cars (and lithium for batteries for example) on time and at scale then we cannot substitute. Further, this requires massive investment from manufacturers and consumers, again, on time and at scale. This requires a strong confident economy, functioning credit markets, and customers who can afford a decline in transport asset resale value. Again there are analysts who argue that substitution and efficiency cannot substitute[53,54].

There are a number of analysts who have studied the implications of a peak in global oil production or warned as to its imminence including industry groups[55,56], the German military[57], other analysts[58,59] and this author who considers economic and systemic implications in some detail[60], [61].

Rather than go into detail about peak oil and its implications, the following points will be made to concentrate on the particular issues relevant to this paper:

- It is a question of risk management, not faith. If there is a 25% probability that those arguing for a near-term peak are correct, and the consequences are half as bad as what some analysts are saying, then it must be risk managed immediately.
- Peak oil is not primarily concerned with reserves, but flow rates. It is a dynamic constraint in a dynamic economy. Promises of energies yet to be accessed, technologies not yet in production (never mind being rolled out at scale) are irrelevant if the constraint is pressing. Using an analogy, it is of little use knowing that there is an oasis a hundred miles away if a stumbling man is dying of thirst now.
- The idea that oil scarcity will lead to rising prices, thus encouraging technological innovation, substitution, and conservation, thereby allowing the continuation of our habituated status quo is conditional. The conditionalities are not met.
- Because the economy is path dependent, it is adaptive to particular forms of energy flows, as revealed in our fixed assets (cars, refineries and pipelines), settlement patterns, trade arbitrage and ultimately many of the structural and social characteristics of the economy. One cannot jump across energy carriers without time, effort and the working operational fabric of the globalised economy.
- Energy is a global systems constraint. In an integrated globalised economy, the health of one country's economy is dependent upon the energy available to other economies. Using a body analogy, a fully resourced heart is pointless if the liver and brain are collapsing due to resource constraints.

In its broadest terms we can look at oil constraints on economic activity from four perspectives. The first is a) thermodynamic-economic, then, b) the economy, then c) food, then d) systemic.

a) Thermodynamic-Economic

To anybody with a basic knowledge of physics it should seem natural and necessary that rising energy flows are required for economic growth. More particularly, it is the amount of that energy that can be converted into useful work. Modern scientifically literate economic analysis confirms this[62,63,64]. The International Monetary Fund in their 2011 World Economic Outlook not only acknowledge the growing risk of oil supply constraints, but model the effects on economic activity: unsurprisingly, they show a strong correlation between declining supply and contracting economic activity[65]. The IMF admit that their modeling does not account for how oil constraints might cause major feedbacks into the economy, that is, their model is adaptive to contingent assumptions based upon historical large-scale stability in the globalised economy.

b) Economic

The thermodynamic constraints are expressed through the changing internal dynamics of the global economy. Rising oil prices affect the economy in two principal ways. Firstly, they squeeze discretionary income. Rising prices have direct effects on the cost of transport, pesticides and so on. More broadly, the indirect effects are upon every element of GWP because energy prices represent a cost of producing GWP. The price of oil is embedded in every good and service produced. Hamilton[66] and Deutsche Bank[67] have argued that when energy share of total consumer expenditure becomes too large, recessions occur. Deutsche Bank say that demand begins to be undermined when consumers are spending more than 6.5% of GDP on oil. This figure is dynamic, falling to lower levels as the economy becomes more fragile. Kopits[68] estimated that when the wholesale cost of oil in the US is greater than 4% recessions become likely. Indeed Hamilton argues that it was oil prices spiking that began the bursting of the credit bubble in the US in 2007.

The second impact of high oil prices is that importers experience a weakening of their balance of payments. More money leaks from a potentially already deflating economy, especially adding to stress on servicing External-Debt-to-GDP. A $20 rise in oil prices adds over $60 billion to the EU's import bill. A country is further impacted if its currency is weakening against the dollar.

High oil prices feed back into the economy through reduced economic activity, increasing pressure on discretionary income and rising defaults. This is an accelerator of debt deflation dynamics. In discussing this we need to be clear about the definitions of inflation and deflation. Often, inflation and deflation are defined in terms of rising and falling prices. These are secondary effects. One can have rising prices in a deflationary environment. In this study, inflation and deflation are a rise or fall in money + credit relative to GDP. Debt deflation, even without rising food and energy prices, leads to reduced discretionary spending as was discussed earlier. Rising food and energy prices, because they are at the heart of non-discretionary expenditure, lead to further squeezes on discretionary spending, credit issuance, and the ability to service debt. Thus economies are caught between vice-grips of debt deflation arising from credit over-expansion, and the rising costs of its primary needs. This reinforces a debt deflationary spiral.

This leads to reduced economic activity and thus a fall in energy demand. The result is an overhang of spare production capacity and a deteriorating investment climate for energy investment. For example, following the oil price collapse in 2008 when oil prices dropped below the marginal cost of production for new developments, projects were cancelled. Credit conditions put further strain on project finance. According to the International

Energy Agency about $170 billion of new projects were cancelled or delayed[69]. The result will be further reductions in available oil in the future when those projects were expected to come on stream.

This situation demonstrates that constrained oil production, even if necessary to the economy does not necessarily lead to ever-rising prices. Economies can only pay so much for oil before their economies become damaged. Damaged economies use less energy and cannot invest in future oil (or other energy) production. This then becomes a harbinger of even deeper economic constraints.

At first glance, one might assume that falling oil (and food) prices might lead to renewed economic activity, initiating an economic recovery until oil production constraints are again felt. But the production constraints would be felt at a lower level of production not only because of the natural decline rates associated with standard peak oil models, but because of the reduced levels of investment.

However, economies would still remain in a debt deflationary environment arising from credit over expansion, so it is doubtful for the reasons discussed in section IV.1, that any growth would be forthcoming. Rather economic contraction would continue, even while oil and all energy prices dropped. If however, by whatever means, a relatively painless debt write-off allowed economic growth to take off, it would soon be hit by rising oil and food prices, again initiating a new debt deflationary cycle, causing further economic contraction and reduced energy investment.

What is missing in this argument is part of what is fundamental to this study. If oil constraints are to continue to contract the global economy, then primary keystone-hubs fail for they are fundamentally incompatible with contraction. At the heart of this incompatibility is the monetary and financial system hub which is growth adaptive. It is the fastest and most responsive system so is likely to be the lead driver of de-stabilisation. But even if we had the 'perfect' monetary and financial system, sustained contraction would still affect the production flow hub, the critical infrastructure hub, the energy and resource infrastructure hub, and the economies of scale hub - all of which are adaptive to growth or economic maintenance of the *status quo*. The de-stabilisation of any of these hubs would be likely to lead to destabilisation of other hubs. The net effect would be to collapse the globalised economy, for it is maintained and dependent upon those hubs. This will be considered after we consider food.

Another issue, one that will only be alluded to, is that global oil and commodity markets may be well supplied with respect to normal demand. More of the oil market may be 'encumbered' by financial contracts[70]. This leads to a 'dark inventory' of oil either as an inflation hedge, or as a form of collateral, that is not entering the market but still raising the oil price higher than would be the case with 'normal' demand[71]. This adds to the risk of a major oil price collapse, and a consequent drop in investment.

c) Food

Global food production has been hitting constraints as rising populations and changing diets hit against flattening productivity, water and fertility constraints, and the likely early effects of climate change.

One of the main effects of the Green Revolution of the 1950's, 60's and 70's was to put food production onto a fossil fuel platform. Modern food production relies on pesticides, fertilisers, machinery, drying systems, long-haul transport, packaging, freezing and so on, all fossil fuel dependent. Modern seed varieties require more water, which requires more complex irrigation and aquifer pumping, again requiring more fossil fuel input, and putting more strain on already stressed water supplies. By various estimates, between six and ten fossil fuel calories are used to produce every calorie of food.

More directly, food is now being converted into fuel, adding further pressure to already strained supplies. Today, 40% of the US corn crop is used to produce biofuels, and globally, biofuels consume 6.5% of grains and 8% of vegetable oil production[72].

The rise and fall in oil prices has been matched by food prices. The Food and Agricultural Organisation (FAO) index and an oil price index is shown in figure:8.

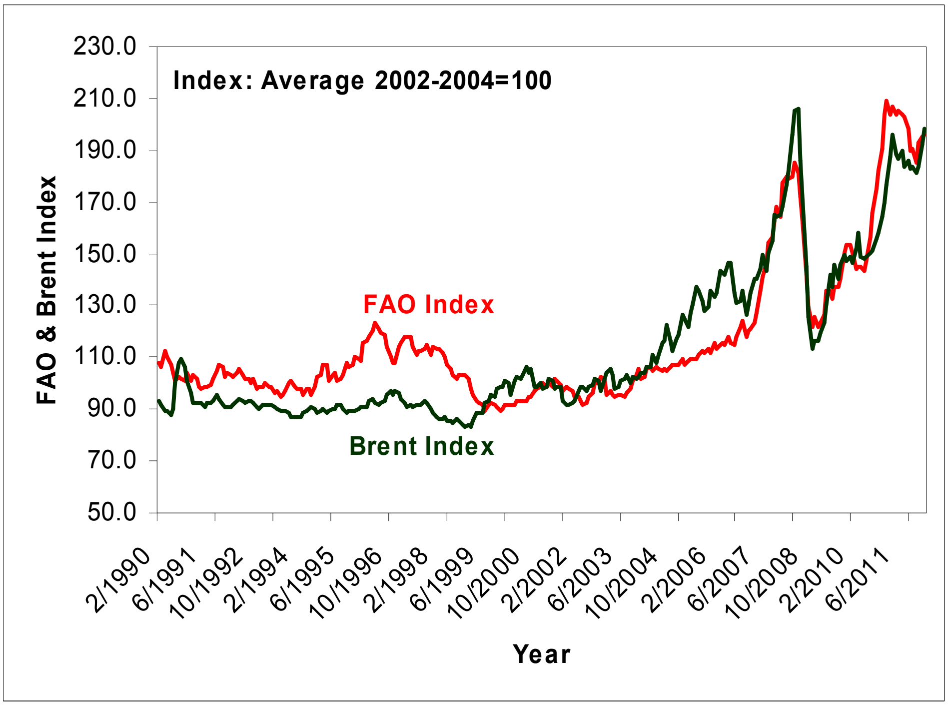

Figure 8: *Beginning about 2005, oil and food prices have risen dramatically. The FOA index represents the cost of a basket of food commodities. Both indexes are scaled so that 100 is the average value between 2002-2004.* (Data: FAO, EIA)

Food is the most inelastic part of consumption. Like oil, rising prices drive out other consumption, which can lead to job losses, unemployment, and defaults. The most developed countries spend about 10% of their disposable income on food, however in many parts of the world it is over 50%.

At this point it is illustrative to look at how the interactions between the financial, oil and food economies can have major unexpected repercussions. When major stresses are transmitted along complex and increasingly vulnerable inter-dependencies, there is a greater risk of system wide contagion and instability.

While food prices remained high, they received a further stimulus and increased volatility via massive quantitative easing in the US. The two rounds of QE were to support battered financial institutions. This injection helped drive a global commodity bubble, affecting an already stressed global food market. Pressure was displaced from the US onto the plates of citizens in the Middle-East and North Africa.

There is general agreement that one of the contributing factors to the rolling revolutions beginning at the end of 2010 was increasing food prices eating into already strained incomes. Food is, and always has been a mainstay of welfare and social peace. Figure:9 shows the recent correlation between the FAO index and outbreaks of political and social unrest.

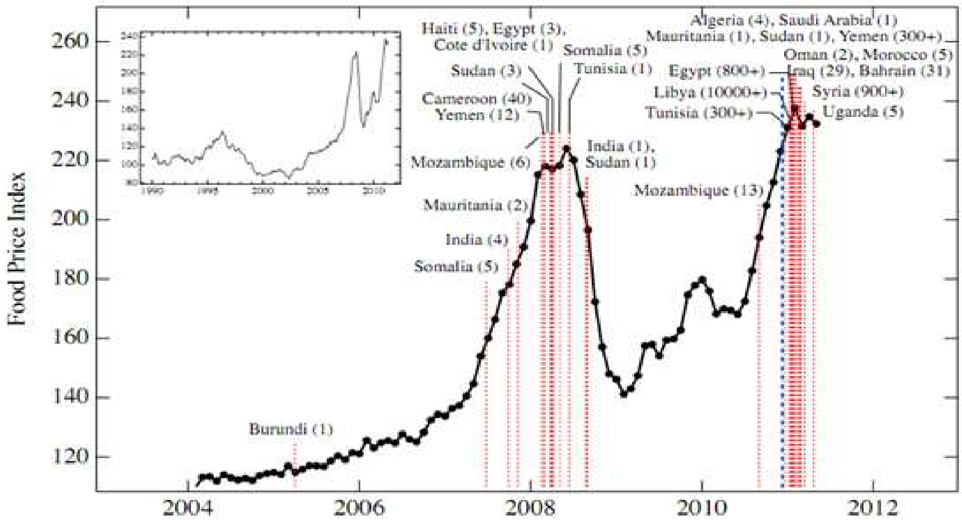

Figure 9: *The FAO food price index and outbreaks of social unrest. (Lagi et. al.*[73])

One outcome was the revolution in Libya, a result of which was the loss of nearly two million barrels of high quality oil a day to the global economy. Thus oil prices remained high, averaging well over $100 even as fears for the global economy increased and growth in many major economies began to stall. From this perspective, QE temporally displaced risk to banks that returned as higher oil and food prices, via the real economy and a distant revolution.

More broadly, food is likely to be a more persistent problem than oil supply. Firstly, this is because we require almost continual replenishment of food to stay alive and avoid severe social and behavioral stress. Secondly, the loss of food in society had a far deeper impact than oil. Finally, the implications of evolving systemic risk means food production, access and affordability would be undermined.

d) Systemic implications of peak oil

If affordable oil production declines, and it raises the price of food, economic activity declines, these are expressions of wider systemic thermodynamic realities. In section III.3 three examples of hubs being forced out of their historical equilibrium by economic contraction were outlined, in the next section, IV.4, the general impact on the financial system will be discussed, and in section V, the implications of a financial collapse on supply-chains. All of these systems potentially undergo a phase transition, crossing a tipping point, and collapsing. That is, they do not have a reverse gear. The fastest acting systems, which lead the impact, are the financial system keystone hub and its impact on supply-chains (production flow hub).

Slow economic contraction would initially lead to a corresponding drop in demand for all types of energy, and then lead to an overhang of spare capacity and reduced investment. However, once the keystone hubs begin to fail, there could be a dramatic collapse in the economy and energy demand and the internal stability of the globalised economy would start to fail; see figure 3. Even the ability to maintain the Energy & Resource Infrastructure keystone hub would be undermined by financial and monetary system failure and the ability to supply the complex inputs required for normal operation. This would undermine food and energy production, processing and distribution. The failure of the financial and monetary hub would undermine access and the affordability of both. All this would feedback into further destruction of economic activity and the collapse of the globalised economy.

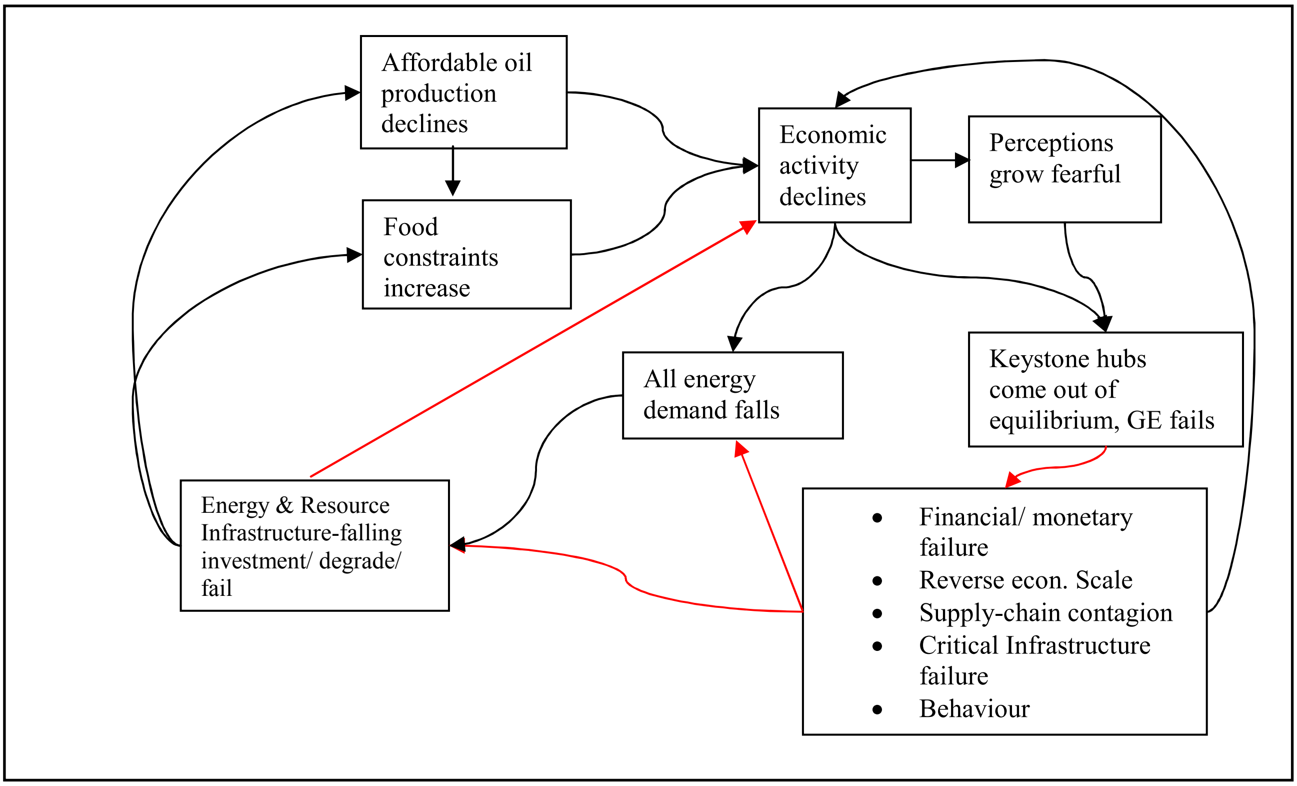

Figure: 10 *The implications of peak oil on the globalised economy. Initially constraints on oil and food squeeze economic activity causing energy demand to fall and investment to drop, squeezing future energy production (black paths). Collapse can occur when the keystone hubs come out of equilibrium (red paths) causing rapid falls in energy demand and a multi-front problem for all energy & resource infrastructure, and a collapsing economy.*

IV.3 Real Wealth, Virtual Wealth & the End of Financial Assets

Much of what is regarded as wealth is only a proxy for real wealth. Consider figure 11 which shows how total financial assets (debt plus equity) for the world has risen as a percentage of global output over the last twenty years. The values may well be a significant underestimate, however what is important is that there are multiples of such assets relative to GWP. In figure12 total financial assets and debt are presented for selected countries and regions, showing that in the most advanced countries financial claims held are over four or more times GDP. This financial wealth is held by pension funds, insurance companies, banks and private investors.

What all financial assets represent are expected claims on future economic growth. Financial assets have a path dependency, in that they are growth adaptive.

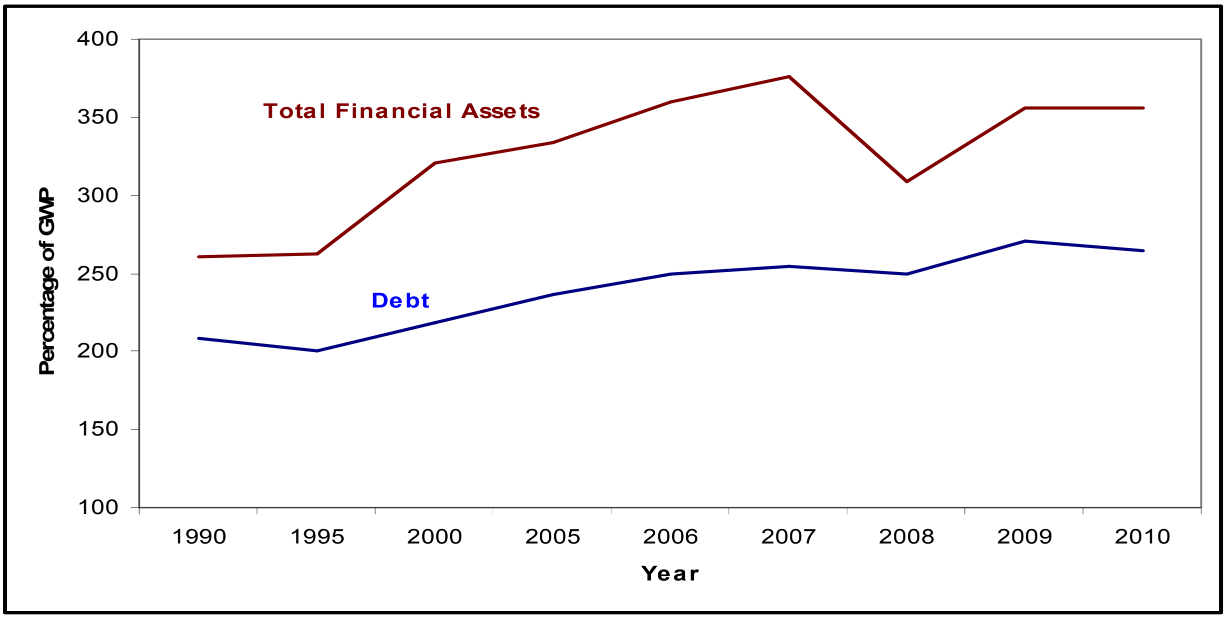

Figure:11 *Global total financial assets (various classes of debt plus equity market valuation) and debt as a percentage of Gross World Product (Data: McKinsey).*

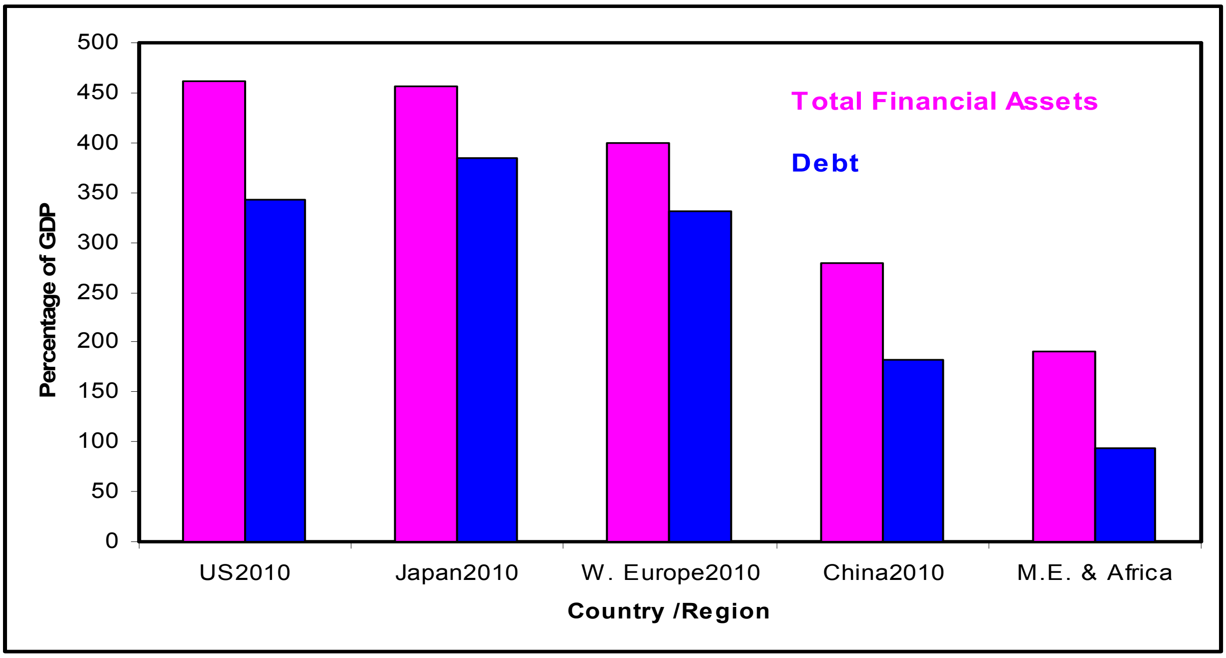

Figure: 12 *Total financial assets and debt, for various countries and regions as a percentage of GDP (Data: McKinsey).*

This financial wealth can be considered as a proxy for real wealth. To buy goods, services or land, one must first convert the financial asset to money, and then use that to obtain the real wealth. Proxy or virtual wealth has a powerful totemic value, as it can confer power and status in the real world. The ultimate value of proxy wealth though is that it can be converted to real things. Proxy wealth can be created at virtually no cost and can expand in a wave of optimism. Real wealth is limited by available land, hard assets and GDP. GDP depends on the operation, stability and functionality of the globalised economy, which requires real energy and resource flows.

There is a popular idea that the purchase of financial assets is investment. However, this 'investment' is primarily about re-allocation within the market. Asset values are maintained by sellers finding buyers, market values are maintained by favourable broad market sentiment. Market participants generally take for granted that virtual-to-real asset conversion can occur at will, which is the ultimate source of value. Only it is not tested as long as there in general faith in the market for proxy wealth.

If debt deflation were to significantly undermine GWP, or if the cascading effects of a financial collapse (arising from our current predicament) or peak oil were to cause a terminal decline or collapse in GDP, then the future prospects for proxy-to-real asset conversion would collapse.

Not only that, a terminally contracting global economy is incompatible with the credit backing of the global financial system, fractional reserve banking, and the monetary system, as we have seen in section III.3.1. This is simply because in an expanding economy credit (principal + interest) can be serviced in real terms; in a contracting economy not even the principal can be returned. So our problem of hyper-credit expansion is that debt expands beyond the GDP's ability to service it, while debt deflation and peak oil causes GDP to contract undermining the ability of the economy to service debt.

The loss of faith, as is the way with markets and human behaviour, will be waves of panic as holders of such proxy assets run for the exit, trying to convert a mountain of financial assets into a molehill of real assets. It would be a sellers-only market.

The conversion of financial to real assets would be further constrained as money is required for intermediation. But in such a crisis, people would cling to any cash they had, banks would be collapsing, there would be fears of currency re-issue, inflation, or even hyper-inflation. Further, as this study will show, such a financial, monetary and banking shock could cause a rapid and terminal collapse in the globalised economy via supply-chain contagion and a large part of our complex society’s productive base would be left to decay or be scavenged.

Global financial markets and the assets they trade are, in their entirety, a Ponzi scheme, and like all Ponzi schemes, they live only as long as confidence is maintained before collapsing under the weight of lost illusions.

V. Financial System-Supply-chain Cross Contagion

Turning and turning in the widening gyre
The falcon cannot hear the falconer;
Things fall apart; the centre cannot hold;
Mere anarchy is loosed upon the world
W. B. Yeats The Second Coming

Something sets off an interrelated Eurozone crisis and banking crisis, a Spanish default say, which spreads panic and fear across other vulnerable Eurozone countries. This sets off a Minsky moment when overleveraged speculators in the banking and shadow banking system are forced to unwind positions into a one-sided (sellers only) market. The financial system contagion passes a tipping point where governments and central banks start to lose control and panic drives a (positive feedback) deepening and widening of the impact globally. In our tropic model of the globalised economy, the banking and monetary system keystone-hub comes out of its equilibrium range, crosses a tipping point, and is driven away by positive feedbacks to some new state.

This directly links to another keystone-hub, production flows. Failing banks, fears of currency re-issue, fears of further default, collapse in Letters of Credit, and growing panic directly quickly shut down trade in the most affected countries. As the week progresses factories close, communications are impaired, social stress and government panic increases. After a week almost all businesses are closed, there is a rising risk to critical infrastructure.

Almost immediately internal trade and imports stops in the most affected countries, and there is impairment in a growing number of other countries. Trade is impaired globally via a credit crunch. This undermines exports from some of the most trade-central countries, with some of the most efficient JIT dependencies in the world. This cuts inputs into the production and trade into countries that were initially weakly affected by direct financial contagion. Globally, the spread of trade contagion depends on complexity, centrality, and inventory times and once a critical threshold is passed spreads exponentially until the effect is damped by a large-scale global production collapse (implying another keystone-hub, economies of scale is driven out of equilibrium).

Trade contagion and its implications feed back into financial system contagion, helping drive further disintegration. The interacting and mutually destabilising effects of keystone-hubs coming out of equilibrium destroy the equilibrium of the globalised economy initiating a systemic collapse.

Growing risk displacement in an increasingly vulnerable system is increasing the risk of system failure. Once the financial system contagion crosses a particular threshold the de-stabilisation of the globalised economy will be exceedingly difficult to arrest; this point may be in as little as ten days. Once a major system collapse occurs, scale, hysteresis, entropy, loss of critical functions, recursion failure, and resource diversion is likely to ensure that the features associated with the previous dynamic state of the globalised economy can never be recovered.

V.1 The Crisis Breaks

We have outlined how the risk of a major shock arising from decades of credit expansion and imbalances is growing. We have also seen that we could expect a similar shock from the effects of peak oil on the economy. What unifies both is a catastrophic collapse arising from a loss of confidence in debt, and the solvency of banks and governments. What would be unique is the scale of the shock and its ability to strike at the heart of the world's financial system. But the implications are not just within the financial and monetary system. They would immediately affect the trade in real goods and services. As our economies have become more complex, de-localised and high speed, the implications on supply-chains could be rapid and devastating.

There are three general points that are worth noting. Together they point to the likelihood that the crisis whenever it comes can be expected to be very large and society unprepared.

The first is *temporal paralysis*:

As financial and monetary systems become more unstable, the risks associated with doing anything significant to change or alter the course increase (see also the discussion of lock-in in the final section). In addition, the diversity of national actors, public opinion, institutional players and perceptions works against a coherent consensus on action. Therefore the temptation is to displace immediate risk by taking the minimal action to avert an imminent crisis. This increases systemic risk. Some steps in the evolving crisis might be handled, for example, a Greek default. However, each new iteration of the crisis is likely to be bigger and more complex than the one before, while the system is becomes ever less resilient.

A second issue is what might be called the *reflexivity trap*:

The actions taken to prevent a crisis, or preparations for dealing with the aftermath of a crisis, may help precipitate the crisis. Therefore to avoid precipitation, the preparation has to be low key and below the radar of the public and markets. This limits the extent and scope of preparation, increasing the risk of a chaotic and slow response.

The final point is about *black swans & brittle systems:*

The growing stress in our very complex globalised economy means it is much less resilient, see the discussion in section 3.1 and figure 2. Thus a small shock or an unpredictable event could set in train a chain of events that could push the globalised economy over a tipping point, and into a process of negative feedback and collapse.

One cannot predict how such a financial and monetary collapse will occur, or when. However, in this section we are considering a scenario, ideally one that in the light of what we know of the economic conditions sketched earlier seems at least reasonable. This scenario should be considered a warning, but also a more general guide to how supply-chain cross contagion might operate in any financial/ monetary collapse.

There has been a growing literature how the Eurozone might break-up and the potential consequences[74,75,76]. What is most striking is the huge range of uncertainties in such a process: legal issues; default processes; re-issue processes; the technicalities of re-issue; what to do with classes of Euro denominated debt; capital, border and trade controls and so on. We are adaptive within a society which has never experienced anything more discordant than a recession since the end of the second world-war. It took ten years to cooperatively plan and introduce the Euro. The likelihood is that there would be a huge divergence between 'on paper' preparations for a default and exit from the Euro and the resultant outcome.

In the scenario, two interacting chains and networks of contagion, sovereign defaults and banking system insolvency are considered. *The Financial Times* has a useful graphic of such a scenario[77]. The driving dynamic is when complacency or optimism is replaced by a cycle of fear. Contagion is a self-re-enforcing process of destabilisation. Because the process of contagion is in the core of the global economy and its banking system, the 'stable surround' is progressively undermined.

Rumours of default cause a run on Country A's banks. The government, without full preparation, defaults and new lending to the government stops. Bills cannot be paid and it becomes immediately clear that the economy will experience a shock. Bond values plummet. The domestic banking system faces a wipe-out. Cash machines close and transactions cannot be processed. Those with access to cash stockpile food and medicines, building a public and political sense of panic.

Money is needed to pay bills and support banks. Will the country a) get new loans and stay in the Euro, or b) restore its national currency and leave the Euro?

Defaults and stays in Euro: The country should in theory be better able to service new loans after defaulting on old ones. The requirements could be enormous, they would need debt to run the state and re-capitalise the banking system rapidly. But if country A receives market support, worried creditors of countries B, C and D are likely to see their bond values plummet, and public debt and banking re-financing costs spiking, and thus spreading systemic risk through the banking system and sovereign debt markets. Thus, financing is unlikely to be forthcoming (we may also be in the grip of a credit crunch), and for the country concerned, having a new national currency would have been a part of the reason they entered a default. Thus it is more probable that a country would default and re-issue.

Defaults and re-issues new currency: How prepared are the government and local central bank authorities, how long will it take to be implemented? Further, how does the complexity of modern financial and monetary architecture within the real economy hinder implementation and what is the chance it will be botched?

One can assume that there would be forced conversion of Euros into the new currency at one or more conversion rates. The banking system would have been made insolvent by a flight of Euros overseas or into cash. The government would intend to re-capitalise the bank in the new currency. There would be a bank holiday over which all deposits and liabilities would be converted into the new national currency. Euro notes would have to be stamped with some sign of its new status. As the government would have been bounced into it, the banks could be shut for a week or more before electronic payments systems were again able to process transactions.

There would be an imposition of capital controls, including trade controls, to prevent an outflow of deposits. Trade controls would be needed to prevent companies falsifying imports in order to get money out. The practicalities in real-time of facilitating trade while at the same time instituting trade controls would be immense.

If it intends to issue a new national currency, it will need to re-denominate all assets and liabilities in the new currency. This will immediately destroy the balance sheets of many companies that had Euro liabilities, but now hold a devalued new currency asset base. This would spread losses directly to companies across the world.

The value of the new currency would fall rapidly against the euro and other currencies. This would lead to an immediate soaring of prices of the most basic goods and the overnight destruction of savings. Let us say the government of an exiting country decides to set an exchange rate with the euro that can be defended with the help of the IMF, say. Ideally, one would want a carefully controlled money supply. However in the growing intensity of the crisis, the temptation would be to print more and more cash to maintain government services and temper major social unrest. The result could be a break-up of the defended exchange rate, major inflation, or even hyper-inflation.

Once one country defaults, it undermines the confidence that the next weakest countries, B, C, and D will not default. Bank runs and asset flights undermine bank balance sheets as television pictures of queues forming outside banks in major European capitals are beamed around the world. How long would it take to introduce capital controls or bank holidays? Would they undermine trade? Bond values plummet, re-financing costs jump across the bond markets causing further contagion. National banks collapse, but cannot be bailed out. The process of default contagion undermines prospects for global economic growth and thus prospects for continued solvency of what were previously though to be 'good' credit risk countries. Trouble comes to countries E, F and G, which may or may not be in the Eurozone. An inverted pyramid of debt is vaporised.

The second interrelated track is what is likely to be rapid contagion across the global banking and shadow banking system. The process of bank contagion, like sovereign default, is a fear driven process of cascading de-stabilisation. As sovereign bonds are defaulted on, national banks shut their doors, and the prospect for whole economies rapidly turn dire, all classes of debt become at risk. The mood turns fearful and pessimistic. France (say) and the Netherlands have to publicly 'stand behind their bank depositors', but in the context of increasing fear and paranoia, rather than re-assuring, this causes panic and bank runs. In many cases state guarantees and national deposit insurance turn out to be, or are perceived to be worthless (see the case of Belgium, discussed earlier).

A Minsky moment occurs when massively overleveraged speculators are forced to unwind their positions to a one-sided (sellers only) market forcing a "discontinuous price discovery". Falling asset values, margin calls, a general flight from risk assets to cash, counter-party risk, forced asset sales to cover obligations (collateral, CDS contracts, capital ratios), discovery of competing claims on collateral, a collapse in credit markets, and collapsing hub banks would re-enforce a rapid and deepening global spread of the crisis. Trade credit and working credit for businesses would vanish. Oil prices would collapse as positions are closed and a flight to liquidity at any price occurs. The global economic outlook would turn awful, raising fears for all credit assets around the world. Raw fear and counter-party risk would paralyse even the banks thought most secure.

There would be a major flight to the dollar, but huge currency volatility would remain as major US banks have to be rescued with unlimited liquidity even though they are clearly insolvent. The outlook for the US economy would turn dire. Its rapidly appreciating currency, the prospective massive drop in GWP, and the prospective massive debt to income levels would mean a deflationary shock with the growing risk of inflation. Investment would stop. US, UK, Japanese, Chinese, and Australian banks would have to be rescued.

V.2 Central Banks & Governments to the Rescue?

Within a day or two we would see global bank runs, bank and credit collapses and food security crises spreading from one default country to prospective defaulters. The banking system would be transmitting profound insolvency across the world. There would be a race between the disintegration process and government and central bank response.

But as the US authorities prevented severe contagion after the fall of Lehman brothers, and bailed out the insurer AIG to protect counter-parties to derivative contracts, why could governments and central banks not do so again? The first reason is that the global financial system is understood to be in a more precarious state now than three years ago, with the cracks apparent not just in Europe and the US, but in China, and elsewhere and with that there is less confidence, and more of its flip-side, fear. Secondly, this would now include a sovereign debt crisis and the break up of the Euro. Third, the tools that officials could wield in 2008 have become worn. Interest rates are already very low, and the crisis is likely to emerge as *a consequence* of a loss of faith in yet more ' big bazooka' patches, and even more ECB liquidity.

The problem for governments and central banks in this context of global dis-integration is not just the escalating scale and breath of the problem, but the reality that it involves various monetary authorities and governments with conflicting perceptions of the crisis and diverse risk-reward decision frameworks. This highlights the issue of trust. There would be a likelihood of a growing divergence between the global and cooperative responses required to help stabilise the process and pressing national demands (and nationalism) to 'protect our own'.

Central banks, the only party capable of responding, would be left with the option of *re-capitalising the world*. That is, all critical insolvent countries and banks-because they would effectively been tied to the same platform. For example, the Fed and ECB would have to guarantee every liability across much of the insolvent global financial system. In the end the only backstop a central bank has is the ability to print infinite money, and if it has to go that far, it has failed because it will have destroyed confidence in the money.

V.3 Financial System Supply-chain Contagion

We can consider three dynamic stages for economies, at a snapshot of a few days into the crisis. Those who have defaulted, in the process of setting up a new currency, and in the most extreme conditions we call Red countries. Those which are being strongly affected by contagion, because their banking system is at (or thought to be at) risk of a major systemic crisis and/ or their government bonds are collapsing and it is thought they might default/ re-issue soon are Amber countries. Finally there are Green countries, all the others, where the contagion so far) is small. There may be bank failures, but no risk of currency re-issue (or they have their own currency), though there may be increased fears about unsupportable debt levels and increasingly pessimistic growth outlooks. Ideally, we should think of a graded scale between dark red and bright green.

Trade Credit & Insurance

The broadest affect on trade is through the issuance of Letters of Credit; this would have world-wide significance even for trade between green countries. Letters of Credit are the method of payment for over 90% of international shipping. They are intermediated by banks over a period between when a buyer-seller agreement is made and when goods are delivered in exchange for a bill of landing. In 2008, following the collapse of Lehman Brothers and the subsequent credit crunch, banks withdrew from such financing. This was held to be responsible for a 93% drop in the Baltic Dry Shipping Index, which measures the cost of bulk dry shipping.

For Letters of Credit to operate, it requires that banks are willing and able to extend credit. Firstly, this requires that banks are solvent. Secondly, even if they are solvent, in a severe credit crunch and financial crisis they are likely to hoard cash on their own balance sheets. This is because they are at risk from closed inter-bank markets; a general collapse in asset values due to forced sales; opaque counter-party risks; and possible bank runs. Of all credit issuance, Letters of Credit are the easiest to pull so as to preserve core liquidity/ solvency.

Further risks for the bank include concern over the issuing bank's solvency; currency re-issue risk; and a possible collapse in the re-sale value of the shipment (due to economic outlook) which is the security for the credit. A lack of trade credit would affect trade between all countries.

A related issue is credit insurance[78]. Most European exports are uninsured, though coverage rises as high as 25% for export focussed Germany. Already *Euler Hermes,* Europe’s biggest trade credit insurer, has suspended cover on shipments to Greece. There are also indications that there is growing caution about coverage of exports to Spain and Italy. During the 2008 crisis, governments stepped in when private sector insurance was pulled. However, in the contagion scenario outlined in this section, many governments could not provide such coverage, or could not afford to risk open-ended contingent liabilities.

a) Red Countries

Almost all trade within the country would stop as banks would be rendered insolvent and be shut down in order to enable re-issue. People and businesses would be left with cash on hand.

Supermarkets, pharmacies, and petrol stations would quickly run out of stock. Re-supply of businesses, factories, and hospitals would become increasingly difficult as inventories vanished. Within days there would be the beginnings of a food security crisis and a lack of medicines. Panic buying could be expected. Initially the most exposed would be those with little cash at hand, low home inventories, mobility restrictions, and weak family and community ties. The number of people affected would increase significantly as the days went on. Communication would be increasingly impaired as mobile phone credit was used up and could not be replaced, petrol became scarce and public transport restricted. This would add to the growing sense of disorientation.

Businesses could not re-stock because they could not pay their suppliers. While it is sometimes mentioned that a currency re-issue could be completed over a weekend, this seems exceedingly optimistic for some of the reasons already mentioned (the uniqueness of the experience, the complexity of financial and monetary systems and infrastructure, the reflexivity trap). It could be days, or even weeks.

Even if the exchange rate of the new currency with the Euro was known, and had the new currency available to businesses and the public, re-pricing would highly problematic. For example, suppose Italian bank accounts underwent a one Euro to one new Lira re-issue. Further, assume there is a defended 50% devaluation of the new Lira against the Euro. One cannot assume that every price along the supply-chain would just be the same nominal value in the new currency. In broad terms, the more import dependent the good or service, the higher the new price would have to be.

This makes re-pricing highly opaque. Firstly because there are so many links in complex supply-chains, and the more links, the greater uncertainty in what the end price might be. Further, because of the dispersed delocalisation of supply-chains, they would be subject to growing volatility across many exchange rates.

This brings us back to another facet of *the stable surround* idea. That is, large-scale stability can support new elements integrating with a system, or help a failed part re-equilibriate. So pricing a new good or service is possible because of the wide stability of prices along the supply-chain, the price stability of essential services, and the pricing of competitors. But if there is a systemic pricing fog (massive volatility) across a whole economy, there is no stable point of reference. This adds to the time over which transactions may not occur, even after a 'successful' re-issue.

The risk of a systemic pricing fog increases for more complex, high speed and delocalised economies. It is such economies we are considering.

But even if the re-issue was successful, speedy, and the effect of the pricing fog was minimal, there would remain many challenges. Many businesses would be bankrupt, having lost Euro assets. People and businesses would hoard any remaining Euros, but even the new currency would be spent guardedly. One would expect a massive and rapid re-orientation away from discretionary consumption towards primary needs-food, essential energy, medicines and communication.

Certain businesses could argue that as 'essential' they should have access to larger currency transfers. Firstly, this may take time (days, weeks?) to organise and institute mechanisms to prevent capital flight. However, the ability of the business to produce is not its own gift, it exists interdependently in a complex society. Because of the number of conditions that are required for production of goods and services in complex societies, the failure of only one element can cause a general output failure- this we have linked with Liebig's Law of the Minimum. Increasing complexity means the company may be unable to spot its vulnerabilities as they depend not just upon the direct but also indirect dependencies. Further, the more extensive the shut-down of wider economic activity the greater the chance that any of their critical inputs might be compromised. For example, remembering the discussion of pandemic planning, key employees, or inputs/ services may not be able to arrive due to lack of transport fuel, so shutting down production. So while some larger companies have been preparing for a break-up of the Eurozone, they can never guarantee production in a crisis.

Red Imports

Red countries' imports would collapse as companies had no access to, or limited access to money and credit. Exporters to red countries would fear they would not get paid, or be paid in a devalued currency.

Even if a red company had money kept in the bank of an Amber or Green country its ability to utilise imports from elsewhere will be increasingly impaired due to other failures in its local supply-chain. Furthermore, it may be tempted to hold onto any deposits elsewhere even at the risk of shutting down its own production if it feared a major economic collapse.

Red companies with long-standing relationships with external suppliers might ask for credit “until the situation improves”, however as the crisis expanded the suppliers' confidence is likely to wear thin.

Barter might work for simple exchanges, but not the diversity of goods and services in a complex economy.

Red imports would collapse.

Red Exports

The value of earning potentially ‘hard’ currency which could be deposited in a green country bank would be immense. However, the ability to export would be undermined by an inability to produce (Liebig’s law of the minimum). Even if a good or service could be produced, the company would have increasing difficulty exporting it. This could be due to transport and shipping problems, getting and paying for insurance, or the availability of customs agents.

If the product could be produced and shipped, there would be no demand from other red countries, and shipping to Amber countries would be a growing risk.

Red exports would collapse.

b) Amber Countries

Amber countries would be increasingly gripped by fears of default and currency re-issue, bank collapses, and bank runs. Currency controls might be introduced. Companies who gave credit to red companies would be facing losses, and may have added trouble accessing their own trade credit or working overdrafts.

Amber Imports

Imports from red countries would be severely affected, and there would be growing problems with imports from other amber countries and green countries.

The recipients of goods from amber countries would increasingly worry if they will get paid in a devalued currency, or not get paid at all if the country's economic situation deteriorates. Therefore they are likely to want upfront payment. This would put increasing strain on amber companies that need credit. In addition some companies will be facing losses from red and amber country trade partners, impairing their own credit worthiness.

Amber Imports would drop significantly.

Amber Exports

Production will be impaired to a growing extent from loss of internal inputs as well as those from red countries and some amber countries. Lack of trade credit could also affect imports from green countries. This will increasingly hamper production within the amber economy as failures in supply-chain linkages propagate more widely through the economy, this would increasingly affect internal production and goods and services available for export.

Exports to red countries would stop, exports to other amber countries would slow to a trickle, and exports to green countries will fall back.

c) Green Countries

Green countries would feel the impact of banking risks and collapses, but governments could be expected to provide liquidity and bailouts. Companies could lose money on investments and credit issued to red countries and would be increasingly worried about losses in amber countries.

Green imports

There would be a severe drop in imports from red countries, and increasing drops from amber countries. Lack of trade credit would also affect imports from other green countries. Imports from amber countries could drop because of production/ supply-chain failures in those countries, fear over getting paid, and exchange rate volatility.

Weak currency green countries would see drops in exports from rapidly appreciating US dollar/ sterling.

Green imports would drop.

Green Exports

Production would begin to be affected by lack of inputs from red and amber countries in particular, but even from some green countries. This could begin to ripple through wider supply-chain networks, affecting local production and goods and services available for export.

Green exports would drop.

V.4 Supply-Chain Contagion

We can make some general conclusions about supply-chain failure based upon our discussions so far.

There are two phases of a supply-chain failure. The first is the direct impact on supply-chains from the primary cause, that is, from the direct effects from the crisis in red, amber and green countries, and from the global collapse in trade credit.

The second phase is the links, via supply-chains, to other nodes that are not affected by the primary cause. That is, the high complexity de-localisation of dependencies means that supply-chain failure in one place can propagate elsewhere on the planet, causing further failures elsewhere. This is *supply-chain contagion*. We shall look at aspects of the second phase in turn.

a) *Impact of the Primary Cause*

The impact on trade credit would be global.

The impact of a financial failure in a weakly connected country, with low centrality, is minimal. In our scenario, the impact is in some of the most high centrality countries in the world (section III.4); the Garas *et. al.* list of most central countries is: China, Russia, Japan, Spain, UK, Netherlands, Italy, Germany, Belgium, Luxembourg, USA, France. We would be expecting at least three of them to be in the red/ amber phase along with a number of other countries such as Greece, Portugal, and Ireland (which probably has high centrality even if not in the top 10). Other Eurozone countries would be at growing risk. Other non-Eurozone countries would also be likely to see plummeting bond markets, bank-runs and bank collapses, and while they could print money in a crisis, exporters to those countries would no doubt fear rapid inflation and thus question real returns, thus hampering imports and exports. In addition, the Minsky moment impact would freeze credit worldwide, and see banks failing across the world. The UK would probably be in the midst of a major banking and shadow banking crisis as the City of London froze.

Secondly, such countries produce some of the most complex and least easily substitutable goods and services in the world. So the loss of such outputs to the world economy would be of very high impact.

Thirdly, these countries would have high levels of vulnerability as they are the most complex with high levels of interdependencies. This would also reflect a long term habituation to normalcy. Those many decades of stability will have embedded increasingly complex, high efficiency JIT logistics.

All of these elements would strike at the heart of global trade within days.

b) *First Impact Stage of Primary Cause*

In a more complex society with more complex production, there are many more critical links for something to be produced and delivered. Some of these are in the company's direct supply-chain, many more are part of the society's operational fabric which is normally taken for granted. Because of Liebig's law of the minimum it only takes one critical failure to stop production and delivery.

Thus, for a trade collapse or a wider system collapse, one does not need everything to fail, only certain things. The impact can then cascade across businesses, economies and society.

c) *Supply-chain contagion*

As examples and studies in section II indicated, a supply-chain crisis becomes non-linear in time. That is, the damage caused by the disruption does not rise in proportion to the length of time the disruption occurs, rather it starts to accelerate.

We can hypothesise that this is firstly because inventories and buffer stocks cushion the early impact of the crisis. If the crisis-causing event is shorter than inventory times, there should be minimal supply-chain problems. As inventories have fallen, tolerance for large-scale and shorter-timed interruptions has fallen.

Secondly, the level and structure of interconnections mean that the more people, businesses, goods, and services (nodes) that are affected, the greater the chance of infecting any remaining unaffected nodes. A simple model can describe this[4], and is shown

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4 Let us imagine at the beginning there are I_o 'infected' supply-chain nodes, where $I_o{}^3I_c$, and I_c represents the minimum infection number for an infection to 'take off', that is it represents a critical transition. There are a total of L globally connected nodes. The rate of change of infected nodes is= (rate of infection spreading) x (number of infected nodes) x (fraction of un-infected nodes relative to total node population). We can associate the rate as being proportional (ß) to the inverse of the average inventory time, Ti. Thus the equation describing this is:

$$\frac{dI}{dt} = \frac{\beta.I}{T_i}.(1 - \frac{I}{L})$$

This has the form of the logistic equation. It has the solution:

in figure:13. The number of infected nodes starts to rise exponentially. Later, the rate of supply-chain failure slows as the pool of unaffected nodes declines. Ultimately, all globally interconnected nodes fail. This is the localisation limit, where the only transactions are gift, barter, or residual trading between closely linked people. The contagion spreads fastest where the inventories are shortest, that is where JIT logistics are most efficient.

In the model we assume there must be a minimum infection number from the initial impact before infection can spread through the whole network, this is the *critical transition point* (I_c). Below this, the supply-chain failure does not spread but can be repaired over time. Above the transition point, failure spreads increasingly rapidly, failure in supply-chains causing cascading failure in a positive feedback. This is the link with phase transitions discussed in section III.

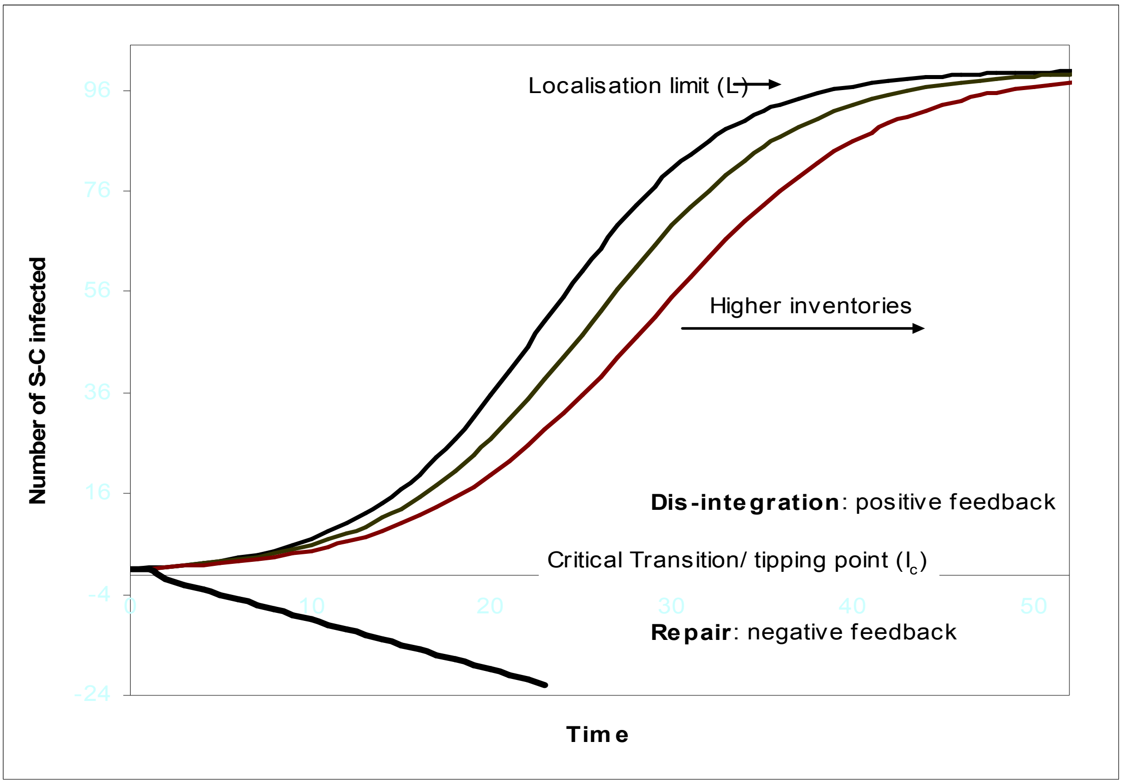

Figure: 13 *A simple model of supply-chain failure cascading through an integrated globalised trade network. A critical transition point marks the boundary between where contagion spreads and where it does not spread, but can be repaired.*

What this model does not consider is centrality. It would be expected that in reality, a transition point would exist but it would be a function of centrality and the number of

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$$I(t) = \frac{L.I_o.e^{\frac{\beta.t}{T_i}}}{L + I_o.(e^{\frac{\beta.t}{T_i}} - 1)}$$

This is valid for $I_o \geq I_c$. For $I_o < I_c$, a linear repair is assumed.

infected supply-chains. As in the scenario being considered there is very high centrality in global terms and initially, a very high number of connections and highly efficient JIT logistics, one could draw the conclusion that supply-chain contagion would be activated globally.

Nor does it account for the residual resilience within the globalised economy which would mean the localisation limit would overestimate the amount of supply-chain failure. We would expect more fragmentation and large drops in production flows, but the impacts would vary over various scales: regions, products and services.

d) *Amplification by Local Hub Failure*

Clearly in the scenario described so far there would be widespread reverberations across all key-stone hubs. Here we consider only critical infrastructure.

If supply-chain failure hit local critical infrastructure, it would have an immediate and wide-ranging impact on a large sway of economic and social life. It is the mundane which needs consideration. The *International Energy Agency* requires its members to have emergency reserves of oil and other fuels, a practice born of experience. Yet what of all the ordinary inputs purchased weekly? An exercise would be to scan all the purchases by a utility over a week, discard the non-critical and see what's left, tens, hundreds even thousands of critical pieces? There are also repairs, which in more complex systems requires specialised equipment and people that might come from across the world.

But the functioning of core elements of critical infrastructure does not occur in a vacuum. Because of interdependencies between elements of critical infrastructure, and because of the general level of complexity (many critical dependencies, consumables, higher levels of low substitutability inputs), there is considerable scope for failure; see figure:14. Thus while a power and grid company might be confident that it has a vast inventory of all the things it needs, it can never be confident that its co-dependents have had such foresight. Water, telecommunications or transport companies might not be so well-prepared, and so pose a contagion risk. The connection between critical infrastructure elements is probably too complex to understand[79].

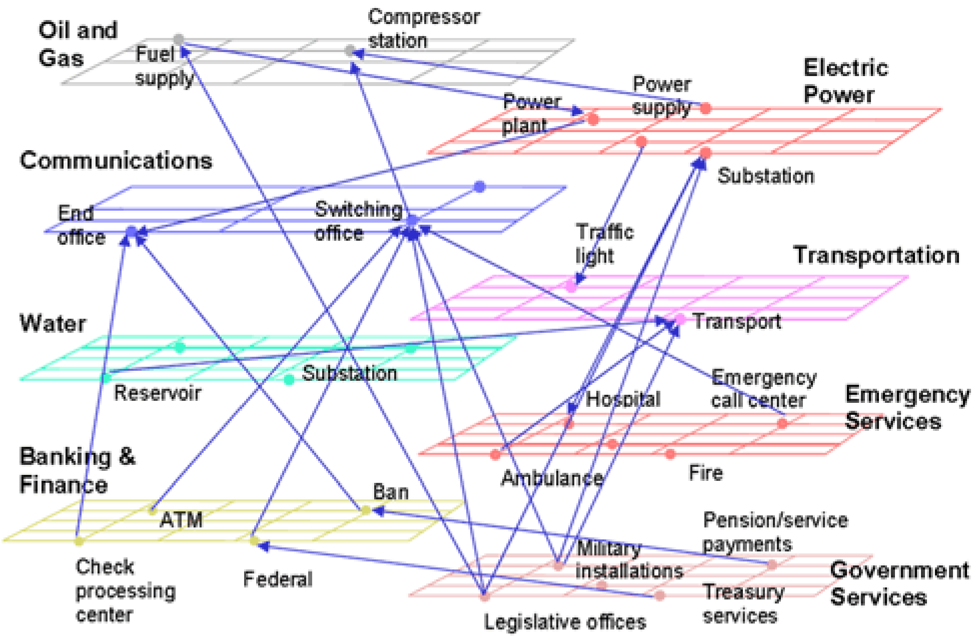

Figure:14 Some of the interdependencies across critical infrastructure. (Source: Dept. Homeland Security[80].

In the financial contagion scenario, a government might ensure that critical infrastructure providers were given special access to guarantees and hard currency, possibly in cooperation with other governments to purchase critical inputs (ideally if they had prepared before-hand, as we are considering a shock evolving over days and weeks). However such goods and services are conditional upon vast, unimaginably complex networks spanning the globe.

V.5 Supply-chain Financial System Feedback

As the global media jumped from food security crises in advanced economies, production failures at home, and panicked markets, populations and political leaders, a dynamic of fear and uncertainty would spread and amplify. The financial system contagion would not just be collapsing because of unsustainable levels of debt–to-income, but because that income would be collapsing as production halted and its future prospects turned dire. This in turn would affect the financial system or attempts to bring it back to its lost equilibrium.

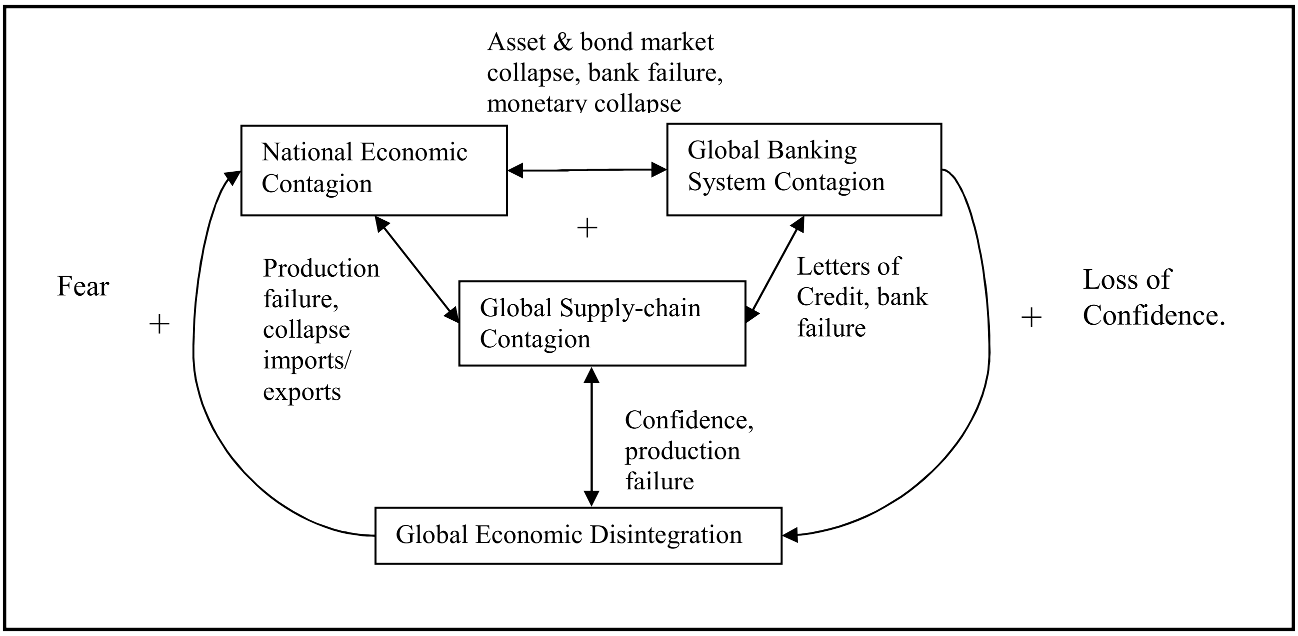

Figure: 15 *A series of positive feedbacks drive a cycle of disintegration.*

Globally, monetary systems would become increasingly opaque. A lack of money, operational banks, currency re-issue, inflation and hyper-inflation expectations would become a reality in many advanced economies in and outside the Eurozone. Debt deflation would in its formal sense start to die-nobody would (even if they could) pay down debt, nor would there be any credit. Production would be increasingly shut down, while complex societies got a rapid lesson on the extent of system dependency.

The perception of continued socio-economic disintegration would alter behavioural responses such as trust radii and social discount rate.

Finally, financial system supply-chain cross-contagion is a re-enforcing negative feedback driving the globalised economy away from its stable state and into a new collapse one.

V.6 Irreversibility & Time

We can imagine the spread of the financial contagion expands, and is then arrested by some action of governments and central banks. Suddenly, all banks are solvent, people and businesses can get their money, and trade and other credit is again available. Can trade pick up where it left off?

In section II.1 the Chatham House report was quoted, in which many businesses said that if the implications of a disruption from the Icelandic ash clouds had gone on just a few days longer, many companies would have taken at least a month to recover. So ending the effect of the primary cause does not end the contagion effects.

By analogy, if a person has a heart-attack there is a finite period in which they can be revived. After that they remain trapped in an alternative state-dead. The extent and length of time in which global trade and production would need to shut down before it becomes un-revivable cannot be clearly defined. However, even if the financial system resumes, the supply-chain contagion could continue evolving. Bearing in mind the discussion in section II.1, it does seem fair to assume the period might be a week or two. Thus, if after two weeks the financial system was 'repaired', supply-chain contagion would continue spreading. It is also noted that the financial system contagion would have had a far more global, deep, and pervasive effect on all economic activity than the examples considered in section II.

Here are some of the reasons it would be so difficult to revive, b) becomes the most significant:

a) Business Failure

Many businesses would have failed in the period, and many others would have been significantly weakened. With the expected outlook that global growth forecasts would be massively downgraded, so trade activity would also be expected to decrease. In such an environment many businesses would still have great difficulty getting working capital. In the light of what had happened, many companies would be reluctant to offer credit terms to trade partners.

b) Recursion Failure

Even solvent companies could not just pick up where they left off, because the companies in their supply-chain could not provide inputs because they could not get inputs into their own production and so on.

But to understand the full impact, it is necessary to see the whole economy as a network. The lack of inputs for one part of the economy, say *A*, can mean another part, *B*, cannot produce. This might mean *C* cannot produce, however, the output of C may be required for *A* or *B* to produce. Thus large parts of the economy could be locked into a loop of non-production. This can be understood as *recursion failure*: *the inability of the economy to resume production and trade because in a complex co-dependent (globalised) economy, production and trade must resume in order for trade and production to resume.*

The more complex the economy is, the greater the barrier is to the resumption of production and trade because the dependent networks are so complex and de-localised. Recursion failure is one of the major barriers to any reversion to the previous dynamical state of the globalised economy.

c) Resource diversion & lost economies of scale

The period of financial and supply-chain crisis would have changed societies. As the financial system resumed operation, many people may not have been paid and confidence would be shattered. Non-discretionary consumption would have fallen dramatically, leading to further economic contraction, rising unemployment, and a growing share of falling national income spent on necessities. Thus large parts of the globalised economy could lose significant productive output.

Spare capacity that existed could be directed to deal with the devastation of the crisis, rather than restarting what existed before.

Further, the operational fabric of countries and regions could be so impaired that complex planning and delivery of reconstruction could be impossible.

d) Entropic decay

One cannot just shut down production lines and infrastructure for an extended period and expect them to work again on demand. Systems rust and decay, valves leak and chemicals go out of date, the longer systems remain idle, the harder they are to resume. This is particularly true for more complex systems. Even with a fully viable operational fabric, a shut-down in a semi-conductor or pharmaceutical plant can take weeks to resume. This represents an added upfront cost, and an increased supply-chain to restart production, and following a crisis, this may be difficult or even impossible.

VI Risk Management, Constraints and a Conclusion.

VI.1 Some thoughts about Risk

The current economic situation is in many ways better than what we have experienced in years. Against that background, we have stuck to the rebalancing scenario. Our central forecast remains indeed quite benign: a soft landing in the United States, a strong and sustained recovery in Europe, a solid trajectory in Japan and buoyant activity in China and India. In line with recent trends, sustained growth in OECD economies would be underpinned by strong job creation and falling unemployment.

OECD Economic Outlook 2007

*GNP growth will average around 3¾% per annum between 2008-2015 — even if there is a downturn and US instability***.**

Paraphrased from ESRI (Ireland) Medium-Term Review No. 11 2008

The consensus view, even if backed by established experts is not, in and of itself, a justification for the consensus view. Consensus views can be embody mythologies and popular prejudices, contingent assumptions viewed as transcendent truth, and habits of looking that obscure what is being regarded. One of our most basic failures is to assume mythologies belong to other ages, and prejudices and delusion to other people.

The widespread failure to identify the process of massive credit expansion and global imbalances, to take action to mitigate the risks, and pre-emptively plan for the consequences of a bursting of the bubble was a thoroughly human failing. Despite ample historical experience of credit bubbles within the economics profession, most professionals supported some level of optimistic continuity.

The assumption of continuity is often a good indicator of the future; it is a central cognitive heuristic. Because the world is not a jumble of random events, we can assume that spring will follow winter, economic growth will return, China's economy will rise, technology will complexify, the supermarkets shelves will be full this evening, tomorrows train will arrive on time(ish), and that if yesterday was ok, chances are tomorrow will be too. The general optimism leading up the first hairline fractures in the globalised economy reflected the herding behaviour common to our species-a re-enforcing euphoria as all the Jones's sprung from the traps chasing house prices, as once they had once chased tulips, South Sea promises, or internet stocks.

We do not like to think of ourselves as potentially irrational herd animals (that will be the Jones's). We seek narrative frameworks that purport to explain our good fortune, ideally in ways that flatter. Reinhardt and Rogoff called it the *This Time It's Different* syndrome as each age sought to deflect warnings by arguing we're smarter now, better organised, or living in a different world. Just as the sellers of an overpriced home will convince themselves that it was their interior decorating skills not an inflating bubble that got them the good deal.

Of course warnings may keep coming, and almost by definition, from the fringes. When assessing risks that challenge consensus, people are more likely to defer to authority, which generally sees itself as the representative of the consensus. Furthermore, as a species with strong attachments to group affirmation, being wrong in a consensus is often a safer option than being right but facing social shaming, or especially if found to be wrong later. Far better to say: “Look, don't blame me, nobody saw this coming, even the experts got it wrong!”

But even if we can appreciate a warning, the inertia of the status quo generally ensures acting on such warnings is difficult. In general we chose the easiest path in the short-term, and the easiest path is the one we are familiar and adaptive with. We would rather put off a hard and high consequence decision now, even if it meant much higher consequences some time in the future. However, if each step on the path of least resistance is a step further from where we ideally should be, the risks associated with doing anything rise as the divergence is so much wider. Eventually one's bluff may be called, but not yet, and hopefully on somebody else’s watch.

The consensus can often be correct and the marginal voices may be deluded. The point for the risk manager is to try and step through cognitive and social blind-spots by first recognising them. This is particularly true if the risks (probability times impact) considered are very high.

Unfortunately, it is very clear that we have learned almost nothing general about risk management as a societal practice arising from the financial crisis. We have merely adopted a new consensus, with a questionable acknowledgement that we will not let *this type* of crisis happen again. However, the argument in this following report is that we are facing growing real-time, severe, civilisation transforming risks without any risk management.

VI.2 Lock-In

There is no *a priori* reason that there should be a satisfactory solution to any problem that we face. Our assumptions of a solution to problems is one that has been framed within the our various local niches, where we often do have some real control, and the facilitation by growing socio-economic complexity enabled by the internal stability of the globalised economy and the energy and resource flows that enable it.

Other ages could point to fate and the capricious gods to give meaning to the inexplicable. We have tended to look at the globalised economy, and assumed it was not just created by us, but the result of our intentions. This is part of our mythology, one that flatters as it deceives.

Our freedom to act is limited by lock-in. Lock-in can be broadly defined as an inability to deal with one problem by changing a sub-system in the economy without negatively modifying others upon which we depend. Further, doing complex surgery on a part of our economy or financial system, because they are so intertwined within the very operation of the globalised economy, can have unexpected and intrinsically unpredictable consequences.

The point here is that we are locked into a vast and unimaginably complex fabric of conditions that we barely understand. But our habituation to constraints, and our propensity to see the parts not the whole, has fostered the illusion that we, or any person or institution, could change significantly the conditions upon which we depend and control the outcome while maintaining our welfare. Furthermore, we live in a culture that often assumes that being able to conceptualise major change, means such change is possible-if only vested interests could be tamed, or politicians were as wise and virtuous as their critics.

For example, it has been acknowledged for many years that the credit backing of our monetary system is fundamentally dangerous for many reasons. Thus, it has been argued that debt free money is a 'solution'. However, the real practical and intellectual challenge is not in the elegance of the solutions, but how it might be introduced in real-time and in a manner that would not unravel the global financial and monetary system that we depend upon for trade, food and medicines, also in real-time. The form of the monetary system is not a merely a 'thing' controlled by 'them'. It is not like replacing some components in a machine (a complex system), but like pulling out a key organ of the living fabric of the globalised economy (a complex adaptive system). But we know far less about the economy's dispersed connectedness then we do of the body's. However, we should be able to intuit that as our dependencies have become ever more complex, high speed and interdependent, our vulnerability to such potential tinkering has increased.

Likewise, we might acknowledge that our JIT, high complexity food systems are increasingly vulnerable. But changing that system at scale would increase food prices just as discretionary income is contracting, food poverty is increasing, and our ability to service debt is being undermined by debt deflation.

Collectively, it is like we are passengers travelling in an unimaginably complex plane locked onto a perilous course. Our understanding of the engine and guidance system is partial, nor do we know many of the connections between them. We may want to change course by retooling the guidance system, but there's a meaningful risk it will stall the engine, and we'll plummet to the ground. Good risk management might argue that before repairs are done, we ensure the passengers have parachutes, but time is running out, maybe it already has.

VI. Conclusion

We are locked into an unimaginably complex predicament and a system of dependency whose future seems at growing risk. To avoid catastrophe we must prepare for failure.

We are entering a time of great challenge and uncertainty, when the systems, ideas and stories that framed our lives in one world are torn apart, but before new stories and dependencies have had time to evolve. Our challenge is to let go, and go forth.

Our immediate concern is crisis and shock planning. It should now be clear that this is far more extensive than merely focussing on the financial system. It includes how we might move forward if a reversion to current conditions proves impossible. That is we also need transition planning and preparation. Even while subject to lock-in and the reflexivity trap, this will be most effective if it works from bottom-up as well as top-down.

Finally, neither wealth nor geography is a protection. Our evolved co-dependencies mean that we are all in this together.

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