Are We Part of the Solution or Part of the Problem?

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SFI WORKING PAPER: 2014-11-044

SANTA FE INSTITUTE

ARE WE PART OF THE SOLUTION OR PART OF THE PROBLEM?

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ABSTRACT

This paper takes a distant, holistic look at the various crises that we are currently encountering worldwide, and argues that these are all part of one and the same phenomenon. The difference in dimensionality between our societies' cognitive capacities and the sphere that is affected by their interventions in the environment is such that each and every intervention causes numerous unintended consequences. As known, frequent risks are dealt with, unknown longer-term risks accumulate. Our world is unable to deal with the multiplicity of unintended consequences of its own earlier actions that are currently emerging. To deal with this, we need to invert the 'resource-to-waste' economy that is limited to our current 'value space' by stimulating the development of non-western values, and to change the current sustainability discussions from 'burden sharing' to 'opportunity creation'. The current ICT revolution offers a unique opportunity to do so. But this requires non-equilibrium economic models that enable the modeling of transitions. Maybe infra-marginal economics offers a way forward.

Key words: sustainability, green growth, unintended consequences

INTRODUCTION

Our current world seems to be limping from crisis to crisis. Financial, economic, environmental, governance crises, resource shortages, pandemics, wars ... Some, such as climate change, are all-encompassing and looming at the edge of human temporal awareness. Others are shorter-term and seem to be controllable thus far, such as the succession of financial and economic crises that have succeeded each other faster and faster. Yet others are somewhere between these extremes, such as the looming energy crisis, the drug resistance of our species, etc.

Many people in politics, economics and civil society expect us to overcome these crises by accelerating innovation. But they ignore that two centuries (AD 1800 – AD 2000) of unbridled innovation in the material and technological realms have shaped a socio-economic structure in the West that seems highly robust and advantageous, and that is spreading all across the world, transforming many societies in the image of the West. But at the same time these innovations have generated such a wide range of uncontrollable unintended consequences that the regulatory mechanisms of our societies seem overwhelmed. That sheds doubt on our capacity to solve the current challenges by means of more innovation, and this idea is reinforced by the fact that to date we have not mobilized an effective collective response to these challenges. The first purpose of this paper is to reflect on the question: "Why is this so?" And if we can find an answer to that question, the next will be "How could we surmount the possible barriers that we identify?"

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Approaching these questions first from a historical perspective will allow us on the one hand to (1) argue that such crises have occurred, at different times, in all societies, and (2) propose a hypothesis to explain this phenomenon. On the other hand, we will use the historical examples to argue that (3) such crises are not inevitable, (4) they are not exogenous and (5) they can be dealt with by anticipation and conscious transformation of the societies that face them.

Next, we will look more closely at the present, and show where our global societal dynamics have created important structural tensions that might be qualified as 'social planetary boundaries', equivalent in their own right to the environmental planetary boundaries of the 2009 Rockström et al. paper. These societal planetary boundaries are highly interconnected, and crossing them too far could tip the global socio-environmental complex system out of its current basin of attraction.

Then we will propose an explanation for these tensions. It views socio-environmental dynamics as a dissipative flow structure (Prigogine 1980) that spreads organization to its periphery and accumulates energy and matter in the core. That dynamic is driven by positive feedback between information processing, knowledge acquisition, group expansion and environmental impact. It results in a growing discrepancy in dimensionality between knowledge gained and impact of that knowledge on the environment, which is experienced as 'unintended consequences' of human actions. Their accumulation can lead to crises.

The fourth section is devoted to the effects of globalization, the creation of a global 'extraction-to-waste' economy that concentrates information processing and wealth among the few, mainly in the developed world, and in order to do that extracts human and resource capital from the remainder of the planet. It emphasizes that our current nation-state system has hampered our efforts to consider these issues globally.

The last two sections initiate the identification of actions that may help us get out of the current predicament. Some of these are individual and group actions, mainly directed at reaffirming our individual and collective responsibilities in determining our future. Others have a special significance for science, such as developing an 'ex-ante', emergence-oriented, set of tools for thought as is currently done in terms of Complex Adaptive Systems. This also entails re-thinking the role of scientists in society, and initiating society-wide discussions about future that we actually see as desirable.

The paper ends with a section on on how the ICT revolution is creating a unique opportunity to transform the 'extraction to waste' economy into one that distributes information-processing capacity (and wealth) by decoupling between information flows and energy/matter flows. In so doing, it facilitates the spread of horizontal, non-hierarchical networks. That development will mitigate some of our cognitive asymmetries, and will promote the reconfiguration of our societies around shared interests and values.

CRISES HAVE OCCURRED IN ALL SOCIETIES, AT DIFFERENT TIMES AND IN DIFFERENT WAYS

Most human societies have experienced a ‘crisis’. In small-scale societies, in a wide range of environments, these have manifested themselves as famines or other local disasters. Archaeologists find evidence of these from very early on in the form of so-called 'growth arrest lines' that point to nutritional stress (White 2001). In complex sedentary societies, they may have taken the form of economic depressions, wars, social conflicts or the collapse of complete empires such as the Roman and Chinese Empires (cf. Tainter 1988).

The recurrence of crises, at a wide range of scales and in virtually any environment or domain of human endeavor, raises the question whether they could be inherent in all human socio-environmental dynamics? And if so, would comparative studies of such instances reveal the drivers of such 'crises'? To put these questions in context, we will present a couple of case studies, one of a crisis that led to the end of Roman society, and one where historical events gave European society a new lease of life by triggering fundamental structural changes.

The case of Rome

To illustrate how successive crises led to the demise of a major social formation, we take the case of the Roman Empire (Tainter 1988, van der Leeuw & de Vries 2002, van der Leeuw 2003). Its expansion was enabled by the fact that, for centuries, Greco-Roman culture, spreading northward from the Mediterranean, had structured the societies of Italy, France, Spain and elsewhere, spreading inventions (money, new crops, the plough), building infrastructure (towns, roads, aqueducts), creating administrative institutions, and collecting wealth. Profiting from this situation, the Romans used an ingenious policy of stepwise assimilation and organization of indigenous political entities based in cities, making them subservient to their needs, i.e. to the uninterrupted growth of flows of wealth, raw materials, foodstuffs and slaves from the conquered territories to Rome (Meyer 1961). This flow linked societies across the Empire for as long as there were pre-organized societies to be conquered and wealth to be gathered (Tainter 1988).

During this whole period, a feedback loop between innovation, wealth creation and institutional change drove Roman society towards increasing its size both demographically and geographically, but at the same time increasing wealth differentials, both locally and between Rome and the periphery. But once the armies came to the Rhine, the Danube and the Sahara, the inflow of accumulated wealth came to an end. Rome became dependent on the wealth generated annually by solar energy (in the form of agricultural products).

In the 2nd century AD this led to major internal investment in the infrastructure (highways, *villae*, industries) of the conquered territories, resulting in a precursor of what we would currently call 'agroindustry', with large-scale production of foodstuffs such as cereals, olive oil, wine etc. Circa AD 250 the problem-solving (innovation) system at the core became less efficient at dealing with the many it had to face as a result of its earlier actions. The wealth gradient between the center and the periphery leveled out as the living standard in the periphery rose. This increased the relative cost of maintaining a military and an administrative establishment to ensure the inward flows of resources (Tainter 2000, Tainter & Crumley 2007). The emperors first devalued their money to deal with their immediate needs, and, several centuries later, split the Empire into four parts to reduce the administrative overhead. Subsequently the coherence of the western Empire decreased to such an extent that it ceased to exist. People increasingly focused on their local environment rather than on the central system. Smaller structures emerged at the edges of the Empire, from which the process of extending a core began anew, based on different ways of information processing. In other words, the alignment between different parts of the overall system broke down, and new alignments emerged that were only relevant locally. The same happened to some extent in the Eastern half of the Empire, but a reorganization driven by the Byzantine Emperors anticipated, and to some extent controlled, that process, so that in the Eastern Mediterranean, the Empire survived a further eight centuries.

The emergence of modern Europe

Comparing this case with that of Europe between c. 1000 and c. 1950 AD, we see how the falling apart of European society was, at different times, avoided by three different 'events': (1) the black death of the 14th century, (2) the discovery and trade-based colonization of new continents, and (3) the invention of ways to use fossil energy.

After the collapse of the Western Roman Empire in the 5th-8th C. AD followed several centuries of cultural, institutional and technological 'decay', which led to a restructuring of European society from the ground up in the period AD 1000-1200. Small principalities warred (Duby 1971), eventually some conquered others, and larger entities emerged. This led to an increase in courtly wealth (cf. the '12th C. Renaissance'), as well as innovation in crafts, arts and (mainly warfare) technology. The wealth discrepancy between the courts and the rest of the population increased and, had this process continued unchecked, we might have seen social upheaval. But the Black Death intervened in the 14th C. AD, killing in three waves a large proportion of the European urban (wealthier) population and enabling the marginal rural population to move into the cities and gain in wealth. Thus, the cycle could reboot.

By the end of the 15th C., in Portugal, Italy, Spain, the Netherlands, and (somewhat later) Britain, population pressure and growing wealth differentials pushed adventurers to discover new riches on other continents, thus inaugurating a new dynamic, driven by intercontinental trade in commodities (spices, precious metals, etc.), not unlike the expansion of the Roman Empire into the Mediterranean. This phase, called by Wallerstein (1974) *'The Rise of the Modern World System'* generated enough new wealth to maintain the coherence of European society until the second half of the 18th C. AD.

After AD 1750, Europe again came to a point where wealth differentials were so important that social unrest was rife, as evidenced by the French Revolution (1789) and unrest in Germany (1848 - 1876). It is our contention that European Society was again given a new lease of life was fossil energy. As the energy constraint was relaxed, *the last two centuries have seen a shift from 'demand-driven' to 'supply-driven' innovation,* in which information processing has replaced energy as the main constraint on innovation, and marketing has enabled innovators to create (very accurate!!) demand for their products. As a result, we are currently engaged in a 'Red Queen' innovation race, needing to keep accelerating innovation and value creation if to keep our western societies together (van der Leeuw 2012).

This process has fundamentally transformed the economics of Europe again, fostering the emergence of education as a fundamental societal need, causing the exponential growth of (and our dependency on) fossil energy, leading to globalization driven and controlled by multinationals, increasing the wealth differentials between core and periphery, bringing the current extreme form of unbridled capitalism and its corrosive effects on trust between social strata that we witness today.

Two important lessons emerge from these stories. First, that wealth discrepancy may well be a societal counterpart to the environmental 'planetary boundaries' of Rockström et al. (2009). Second, that the 'progression' from the agricultural Middle Ages to the Trading Empires of the Early Modern World, and the Industrial and Post-Industrial economies of the last century may seem 'inevitable' in hindsight, but like any (hi)story, is in effect a post-facto narrative that reduces the dimensionality and complexity of what happened.

From the ex-ante perspective that is ours, at each of three transition moments, European societies could potentially have engaged in different trajectories, and this continues to be true for the present. Similarly, Rome could theoretically have followed a different trajectory in the 2nd cen-

tury AD. *History is not inevitable. There are times when processes dominated by strong drivers make change very unlikely, and there are moments when unexpected events or people can indeed change the course of history.* We argue that we are currently living a moment in history that opens a window of opportunity for the world to change. Hence there are choices to be made. Making those choices requires that as individuals and as societies we retake responsibility for our future, instead of leaving it to a small group of people who are currently, knowingly or not, misusing it.

CRISES OF THE 20TH CENTURY

Now let us look, from 30,000 feet, at what our own society during the 100 years. The first major crisis to hit our western society in the 20th century was World War I. A seemingly minor event sparked a release of tensions that had built up between four major social configurations, the Austro-Hungarian, French, German and British Empires. The huge destruction it wrought reduced these tensions for a while. The next crisis, however, occurred soon thereafter, in 1929, due to the fact that very few people controlled the financial markets. It triggered a major destruction of financial capital, increased social tensions in the countries involved, and coincided in the US with major environmental destruction (the 'dust bowl'). The financial capital was not rebuilt until the run-up to World War II, which revived some of the social tensions that had caused WWI, particularly in Germany.

After the war, a major restructuration of the western world created a new financial structure (Bretton Woods, IMF, World Bank), a new attempt at a global political structure (the UN), a new military structure (NATO and the Warsaw Pact), the opening up of trade flows worldwide (leading to the GATT, the WTO), the European Union and similar but less integrated regional pacts, and less visibly a shift towards a material wealth model that used human and resource capital in the periphery to accumulate wealth in core of the system, exported societal tensions from the West to the rest of the Earth. These developments ultimately led to our current consumer society, and heavily involved technological innovation.

After about 20 years of rebuilding, in the '70's and '80s, unintended consequences of the new order, including the dismantling of the colonial empires, began to surface again. In the financial domain, dealing with rapid growth led to the abolition of the gold standard (1976), followed by the 'big bang' (1986) removing (national) policy constraints that had regulated the financial markets, in particular in the US and Britain. The Reagan-Thatcher regime contributed to the collapse of the USSR and the change of regime in Russia (1989) and freed countries in the periphery of the Russian 'Empire'. In a number of ex-colonies a 'revolution of rising expectations' led to profound regime changes (e.g. Indonesia, India/Pakistan, Zimbabwe and many others; much later South Africa) to the advantage of small groups of inhabitants.

Surfacing particularly from the 1980's on, globalization is a major component of the process, increasing trade and the wealth of the core as well subsuming regional risks under global ones, thus leading to more interdependencies between different parts of the world, and increasing the chances that minor local events could have major consequences for the whole world system (the 'butterfly' effect) (cf. Helbing 2012).

SOME OF THE CURRENT CRISIS' MANIFESTATIONS

The possibility of a major environmental crisis was first raised in the 1960's to 1980's in a range of domains including chemistry (Carson, 1962), atmospheric sciences (Broecker 1975) and biology (Dasmann 1968). A major international research effort has subsequently uncovered a number of indicators of anthropogenic action on the global Earth system (CO_2 densities in the atmosphere, loss of biodiversity, ocean acidification, waste production, changes in the phosphorus and nitrogen cycles, etc.). These investigations have made us aware that human actions threaten the relative stability of the Earth System for the first time. Over the last century, many indicators of the expansion of the socio-economic system, both globally and locally, have gone exponential, and so have indicators of its impact on the environment (fig. 1). In the last thirty years, moreover, numerous signs have emerged that we are currently close to hitting, or have actually hit, a series of planetary environmental 'risk barriers' (Rockström et al, 2009) (fig. 2).

Figure 1: The global socio-environmental system is going exponential since AD 1900

Figure 2: Some of the planetary boundaries have already been crossed

Might these signs also indicate that we are approaching a set of societal planetary boundaries? Awareness is growing that we are in effect dealing with a societal challenge. After all, society defines its environment, identifies environmental challenges and proposes solutions for them. Societal action is therefore the only kind of action that can have caused, and may change, the current trend. That leads us to think that we may have been looking under the streetlights to find the key that we have lost somewhere in the dark, beyond those streetlights.

First we will briefly enumerate some of the dimensions in which our societies are threatening our planetary 'safe operating space'. Most of these are known, but because of the disciplinary fragmentation of our sciences, they have insufficiently been linked together in a holistic perspective to see what they imply for our future. Others have not been discussed because they derive from the 'sacred cows' in our culture.

Global demography and health

First, global demography. Fig. 3 shows one of the recent UN predictions of worldwide demographic tendencies. Notwithstanding the fact that it is very difficult to predict these over a whole century, this is one of the most 'solid' forecasts of all. It does take increasing life expectancy into account in proportions related to wealth and healthcare, and also the fact that as populations grow wealthier, they reduce their birthrates. But it does not take into account any potential non-linearities in healthcare, such as the healing of cancers, the potential of stem-cell therapy, etc.

Figure 3: Projected global population AD 2000-2100

Health, as represented by life expectancy at birth, is very unevenly distributed across the globe (Figure 4a), and its distribution appears to be similar to that of wealth. Hence it is not surprising that crude birth rates (fig. 4b) show the opposite pattern - they are highest where life expectancy is lower.

Figure 4a: Global life expectancy at birth

Figure 4b: historical and predicted crude birth rates

It is expected that with growing wealth in the developing world, the crude birth rate will go down as life expectancy increases. The crucial question is whether growth in wealth and decrease in birth rate will occur at more or less the same rates. No one knows, but it is clear that the industrial economy has created important demographic discrepancies that could be qualified as a social planetary boundary.

Food (in)security

Now compare these figures with the evolution of our resource footprint as a global population (Figure 5a). One unintended consequence of major innovations in healthcare has been that we are, as Flannery (2002) put it, "eating our future". We are facing a potential crisis in the global provision of water and food that could trigger major conflicts, for example in Africa where the major economic powers are buying up agricultural land (Fig 5b). Recent increases in food prices are early warning signs that food security is becoming a worldwide concern (Fig. 5c).

Figure 5a: We are already exceeding the Earth's bio-capacity ...

Figure 5b: Distribution of food insecurity

Figure 5c: Food prices have recently spiked

Fossil energy

Energy has been a constraint on human social evolution for most of the species history, until the harnessing of fossil energy around 1800. Since then, energy use has exploded (Figure 6a). Yet the total quantity of fossil energy on earth is limited. This has, already in the 1970's, led to the conclusion that oil as a resource might be exhausted in the near future. Though there is coal for many more years, burning it is highly unadvisable from a global warming perspective. This will force us to reduce its use (figure 6b). In recent years, by taking the rapidly decreasing rate of return on energy extraction investment (ROI) into account, we see that the price of energy oil continue to rise, limiting economic expansion and creating social tensions (figure 6c). Moreover, the decrease in ROI risks leaving a substantial proportion of the theoretically available (identified) resources in the ground, creating a major liability for the financial backers of the oil industry (the so-called 'stranded assets' problem). This poses a very real threat to the stability of our current global financial system.

Figure 6a: Since the beginning of the industrial revolution, energy use has exploded

Figure 6b: The 'optimist' scenario for greenhouse gas emissions will drive global tem pera-ture change way beyond the 2º C. average that seems acceptable.

Figure 6c: We are already at the point where oil production can no longer keep up with oil use.

Finally, if we take into account the energy needed to provide a comfortable life for the whole global population (without the excesses of the current West), we will clearly exceed all acceptable levels of fossil energy use, whether from an atmospheric pollution or an availability perspective. Only renewable energies can avoid this.

Finance

In recent years a very important, and growing, proportion of total financial capital is entirely devoted to speculation. Figure 8a shows how the proportion of capital subject to capital gains tax has been increasing since the late 1940's and has recently in some years constituted close to 40% of total financial capital. Figure 8b shows the evolution of loans to the productive economy and to finance respectively. The fact that speculative capital is much more mobile than capital invested in the production of goods and services, coupled with the fact that these huge financial means are controlled by fewer and fewer people and institutions (some of which are now considered "Too Big to Fail") has contributed to the rapid succession of financial crises that we have seen in the last sixty years (*The Economist* (April 12-18, 2014) runs the headline "*The History of Finance in Five Crises*").

Figure 7a: Fraction of total income (in the USA) that is invested in production (without capital gains tax) and speculation (with capital gains tax).

Figure 7b: Loans to the productive economy and to finance

Recently, Summers (2014) raised the possibility that the global economy could no longer rely on normal market mechanisms to assure full employment and strong growth, so that sustained unconventional policy support is becoming necessary. Whereas his drivers are fundamentally economic and financial, we will argue below that there may be others in play.

Wealth differentials

The historical perspective that we outlined in the first section is that the economies over time create material wealth differentials by concentrating most such material wealth in the hands of a relatively small, if growing, proportion of the population, to the detriment of everyone else. Currently, that wealth is almost entirely in the 'developed' countries (Figure 9a, b). But recently, we observe two seemingly contradictory trends in this dynamic: a leveling off of wealth disparities between 'developed' and 'developing' nations combines with a steepening of the wealth disparities within countries. This is the statistical effect of the rich becoming richer in the developing countries (especially BRICS), while within these countries – as well as in the developed world – the contrast between rich and poor becomes starker.

Figure 8a: Average wealth per capita across the world

Figure 8b: Intra-country wealth distributions across the world

Recent publications (e.g. Piketty 2014[2]) have drawn attention to this phenomenon, which some see as an early warning sign of major social upheavals - in the developed nations as a protest against the squeeze of the middle classes, and in developing nations as a 'revolution of rising expectations' triggered by the fact that a few people are getting (very) rich.

Urbanization

Until recently, the trend towards urbanization was one of the most stable trends known in the social sciences. But in the last half century, the urban proportion of the world population has grown from 33% to over 50%, and it is expected to grow to c. 80% by 2050 (Fig. 10). Bettencourt et al. (2013) observe that energy flows scale sub-linearly with cities, but research and innovation scale super-linearly. Population and services, scale, of course, linearly (Table 1). They argue on this basis that while energy is a constraint in the growth of urbanization, information processing, and innovation in particular, is the driver of urbanization (cf. also Florida 2014). That would explain why the explosion of urbanization and that of material innovations have gone hand in hand to drive our consumption society to where it is now.

Figure 9: Urbanization is proceeding extremely rapidly since 1960

Table 1: The allometric scaling relationship between city size, information processing, population and energy flow

For some, this may imply that urbanization is at the core of the tensions our world is seeing. But we argue that it is merely one of the many manifestations of the fact that our current mode of life (in the developed countries in particular) is butting up against planetary social as well as environmental boundaries.

Innovation and societal coherence

Work done by Strumsky and her colleagues on the 9,000,000-odd patents in the USPTO database shows in the last twenty years (1) a shift from major 'breakthrough' innovations to innovations that recombine existing technologies, or even simply modify existing technologies in minor ways (fig. 10a), (2) a decline in the ROI on innovations, indicating that their impact on the economy (in terms of wealth) is slowing down (Strumsky et al. submitted, cf. Fig 10b), (3) a decline in the number of patents per innovator, and growth in the size of the teams involved innovations (Fig. 10c), indicating that innovation is more and more difficult and involves more and more domains. Concomitantly, we see an overall decrease in return on invested capital in the US (Fig. 7d), as well as a decline of entrepreneurship (Fig. 7e) that might be linked to an overall decline in the frequency of major innovations.

This dataset is far from ideal, and has many biases. But it seems the best we have for the time being. There are many proximate causes that one could point to in order to explain these phenomena. For one, the explosion of patents over the last 50 years may have made it more and more difficult to come up with something that is so new that it sets an innovation cascade in motion within our current technologies. Another contributing factor could be that the shift towards

[2] Though there are a considerable number of critiques of his work, and in particular of his policy conclusions, it seems to us that the main phenomenon illustrated by him - increasing wealth differentials - is indeed real

short-termism in many industries makes it more difficult to develop innovations with long loss leaders. From yet another perspective, this may be the result of a change in the law governing US patents that allowed patenting for designs, etc.

But we would like to put forth a more fundamental reason for the current lack of innovation: Could it be that our *'value space'* (the total set of dimensions to which we accord economic value) reached a limit?

Figure 10a: The last thirty years have seen a shift in patenting away from originations (innovations creating a new technology) towards recombinations and elaborations (of existing technologies)

Figure 10b: Over the same period, the return on investment in innovation has declined.

Figure 10c: The evolution of innovation over the last thirty years. The number of patents per inventor decreased as the size of the teams involved grew, indicating that innovation became more difficult.

Figure 10d: Recent decades have seen an important decrease in return on invested capital in the US

Figure 10e: At the same time, there has been an important decline in entrepreneurship

Summary

A number of indicators point to the fact that some of the natural and human resources on which our current economy is based, are no longer amply available, threatening to cause stresses in the planetary social system. Are we moving towards a tipping point that will force us to introduce major structural changes of a scale and scope that we have not seen for centuries? We have only mentioned a few of the phenomena that point in that direction. As in the case of the environmental planetary boundaries, the inherent major risk is that these societal planetary boundaries (and others) will ultimately come to interact in such a way that they will destabilize the current global order.

In the last 10,000 years, there have been at least two other moments where such very fundamental transitions have occurred before: the emergence of sedentary, cultivating societies around 9,000 BP, and the emergence of urban societies around 5,000 BP. In principle, therefore, humans are able to collectively make such major structural changes in their social organization. However, in both cases a threat of such a global scale as current global warming was absent, and in both cases the changes took considerable time (centuries, if not a millennium). Will the acceleration of innovation triggered by the exploitation of fossil energy and the ICT revolution enable us to reduce the time needed for such structural societal change so drastically that we avoid disaster?

WHAT DRIVES THE CURRENT CRISIS?

The study of crises has led to many descriptive publications, case studies and doomsday hypotheses, from Gibbon (1776-1788) and Spengler (1918) to Diamond (2005), but recently that elements of a *scientific* theory of socio-environmental dynamics, including 'societal crises', are emerging, combining insights from four research domains. The natural sciences have contributed to the set of ideas that is sometimes called 'the science (or theory) of complex systems' (*e.g.* Prigogine 1978, Kauffmann 1993, Bak 1996, Levin 1999, Mitchell 2009). Social anthropology has

contributed 'Cultural Theory' (Thompson *et al.* 1989), and the sciences of organization have contributed to our understanding of the dynamics of social institutions (*e.g.* Pattee 1974, Simon 1969, Huberman *et al.* 1988). Some of these ideas have been taken up and adapted by ecologists (*e.g.* Allen & Starr 1982, O'Neill, De Angelis, Waide and Allen, 1986, Allen & Hoekstra, 1992). Finally, the first attempt at a synthesis of these different ideas comes from a collaborative effort of ecologists and social scientists (Gunderson & Holling, 2001, Holling 2001; Walker & Salt 2006). Here, we will propose a 'meta-description' of such societal crises.

Humans differ from most other species in that they can learn how to learn (Bateson 1972), categorize, make abstractions and hierarchically organize them, and communicate symbols between them. Human learning involves the recognition of patterns, whether temporal, spatial, semantic, syntactic or yet other. By identifying these, we infuse the world around us with structure and meaning, and enable interaction with it. In the process, humans transform their natural and material environment in many different ways, and at many spatial and temporal scales, creating niches in their environment that are closely suited to their needs. Our relations with our environment are thus part of the uninterrupted process of human learning, a positive feedback loop that creates order out of our experiences of the world by isolating and defining patterns in terms of a limited number of dimensions, and storing these as 'knowledge'. The more cognitive dimensions exist, the more problems can be tackled, and the more quickly knowledge is accumulated according to the following feedback loop (van der Leeuw 2006):

> Problem-solving structures knowledge —> more knowledge increases the information processing capacity —> that in turn allows the cognition of new problems —> creates new knowledge —> knowledge creation involves more and more people in processing information —> increases the size of the group involved and its degree of aggregation –> creates more problems —> increases need for problem-solving —> problem-solving structures more knowledge … etc.

The result of this process is the continued accumulation of information-processing capacity, enabling a concomitant increase in matter, energy and information flows through the society, and thus enabling the society to grow. That information-processing capacity includes the sum total of the understanding, know-how and skills of the people involved, including their technical and organizational means of solving problems, their means to maintain group cohesion, etc.

This process has driven transitions from small mobile bands to modern continental societies, as well as increases in settlement from small villages to huge metropolitan areas. The need to mobilize larger and larger groups to deal with bigger and bigger challenges has caused people to increase communication efficiency by making them settle down and live closer together. That capacity to mobilize many minds, and thus to consider many points of view, increased the innovative capacity of aggregated populations - and thus explains the correlation Bettencourt et al. (2003) observe between creativity and city size.

There is an asymmetry, however, in the cognitive process responsible for human knowledge acquisition. Humans only perceive a very small number of the dimensions of the very complex world 'out there' (Read & van der Leeuw 2009), and thus, when they act upon their ideas, they affect many more dimensions of the environmental dynamics than they are aware of. Inevitably, as they accumulate knowledge, humans therefore generate 'unforeseen consequences' of their actions. The large difference in dimensionality means that the set of unintended consequences

grows faster than their understanding. *In other words, as humans learn about their environment, they change it more rapidly than they accumulate knowledge about it. While we think we know more and more, that knowledge is about the situation before our interventions occurred and we know less and less about the environment that has undergone the changes we have initiated*. The cumulative effect of this process ultimately causes societies to be overwhelmed by the unintended consequences of their own earlier actions, triggering crises.

Moreover, there is a pattern to the way in which people accumulate unintended consequences. Societies will deal regularly with those challenges that are frequent, and which they get to know best. But the unintended consequences of their actions span the whole spectrum of temporal scales, from the frequent to the rare. Therefore, as their interventions accumulate, unknown, infrequent challenges are substituted for known, frequent ones. These infrequent challenges accumulate over time. Over time they collide, creating a 'risk barrier' that is experienced as a 'crisis'. Rather than an exogenous event, a crisis is therefore *a temporary incapacity of the social (information processing) system to deal with the multitude of dynamics that it has to deal with to stay in tune with its environment (social as well as material, technological and natural).* As we have just seen above, that incapacity is of course due to the fact that the society is overwhelmed by the unintended consequences of its own past actions, causing many of the tensions that we have observed in the last section.

GLOBALIZATION

For most of human history, inventions by individuals were only transformed into innovations at the societal level if (a) a need was felt for them and (b) there was enough free energy ('wealth') to implement them. The pace of societal change was limited by the fact that *innovation was 'demand-driven' and 'energy-constrained'*, and so was the value differential between the society's 'insiders' and 'outsiders'. But from 1800 AD, as the use of fossil energy enabled the 'industrial revolution', information processing replaced energy as the main constraint *and innovation shifted from 'demand-driven' to 'supply-driven'*[3]. This shifted the control over innovation from the users to the producers and increased the information, value and wealth differentials between the core and the periphery of the system (Piketty 2014) thereby reducing the chances that outsiders became insiders, and creating the *extraction-to-waste economy* (in terms of natural and human capital) that is now close to reaching its limits.

Because of the territorial limitations of governance by nation-states, this system's spread around the globe has enabled, and been driven by, the growth of the multi-national corporations. Their impact has, over the last century or so, incorporated regions that were culturally and socially fundamentally different into that extraction-to-waste economy and made it truly global - driving individuals, groups and countries to gradually adopt mindsets, activities and institutions that are compatible with its underpinning, urban logic. The last 30 years this process has accelerated, and it is now reaching the conurbations of China, Indonesia and India. If left unchecked, it will accelerate global warming, resource shortage and in general the material basis of our world system. But as different sectors interconnect, this may lead to hyper-connectivity so that the world system will become unduly sensitive to minor disturbances in one place or one sector or another (Helbing 2013). Moreover, globalization will increasingly undermine the diversity in thought

[3] This had many implications, from fostering the emergence of the press and education as fundamental societal needs, and of marketing as an important tool in the spread of innovations, to the exponential growth of cities and ultimately the current globalization driven by the consumption society.

and action that has, until now, characterized the different cultures on Earth, and thereby acted as a buffer against said hyper-connectivity. And finally, it will limit, if not render impossible, the expansion of the value space that we will discuss in the next section.

IS OUR 'VALUE SPACE' A CONSTRAINT?

An economy is driven by, and serves to, create value. For it to function effectively, society must accord value to the things and services that it produces. An expansive economy, therefore, goes hand in hand with an expansion of the total set of values accorded by society to the things and services it produces (here referred to as the *'value space'*). Innovation normally goes hand in hand with that expansion. But if, for one reason or other, that expansion slows down, so does the overall capacity for innovation of society.

We contend that the Western value space has been transformed, over the past sixty years, to the point that its expansion is slowing down, and that that may be affecting the rate of innovation in Western society. In industry, this could lead to a reduction in the rate of return on investment in innovation. In finance, it could explain that more and more available funds are being diverted from the productive to the speculative sector. In macro-economic terms it might explain the leveling off of the growth of our economies that has argued by Summers (2013).

In asserting this, we have to remember that, following our model of human problem-solving and learning, the observed growth of interactive populations worldwide (caused by rapid increases in demography, health care and communication) both causes and requires a rapid increase in the rate of innovation if our societies are to remain intact. We are therefore not arguing for an absolute decrease in the rate of innovation, but for a decrease relative to the need to keep our quickly expanding society more or less stable.

What kind of phenomena do we observe that might tentatively corroborate this assertion? Is there a slow but certain transformation of our societies from externally focused, looking towards the future and taking risks, towards inwardly focused, avoiding innovation and risk under the impact of the unanticipated consequences of its own actions? In other words does our existing knowledge, weigh increasingly heavily upon our actions, blocking the ways to finding 'out of the box' solutions to our challenges?

Clearly, as a result of the difference in dimensionality between the known and the unknown our society is increasingly disconnected from the dynamics of the environment with which it is supposed to connect us, hence the looming environmental crisis. Another manifestation of the closure of our value space is the shift in business from long-term strategic thinking to short-term tactical thinking that is a consequence of the fact that speculative now dominates over productive financial investment. We see this as one consequence of the accumulation of unintended consequences, which has more widely shifted the focus of our collective efforts to the immediate and thus causes us to be caught in a kind of historical myopia that biases our understanding of the processes that have driven our societies to this point. Thus we are looking for solutions within our current given structure, rather than stepping out of that structure and thinking outside the box. That hampers any attempt to find an exit from the current crisis.

This is also strikingly evident in the international negotiations about global environmental change, which are still predominantly framed in terms of burden sharing ('Who pays for the global cleanup?'), aiming at maintaining our societies' ways of life by mitigating its negative effects, rather than in terms of opportunity creation and the explicit promotion of change. Burden

sharing does not really inspire anyone, and has caused the deadlock between the developed and developing nations about funding GHG mitigation. Reformulating the debate in terms of opportunity-sharing, creating the conditions to develop innovations (material, procedural, institutional and social) that do the job and will therefore become desirable to others, would seem to be the correct starting point for more successful negotiations.

Another important manifestation is the fact that in economics – with policy the most important lever through which one may currently attempt to change our societal dynamics – there is a similar emphasis on continuity rather than change. Much of the macroeconomics community lacks a conceptual and mathematical tool to conceive of discontinuous change. As became disconcertingly clear at the beginning of the current financial crisis, the dynamic equilibrium models that link supply and demand are formulated in terms of differential equations and thus focus on marginal changes of aggregate measures. They cannot help us in anticipating 'tipping points' or in thinking about structural changes in our current socio-economic system. One potential way to remedy this is to develop the mathematics of discontinuous change, in which supply and demand are not balanced, and the market does not always work best. This would open the way for a less 'productivity' and 'efficiency'-based perspective on economics that could include value dimensions other than cost and price.

But we also see this transformation in the process of innovation itself. We have argued above that, while originating innovations keep occurring, their occurrence does not speed up over time (as it should if the expansion of our value space kept pace with the expansion of our economy). From the perspective of innovators, one could translate this into the fact that the very dense network of inventions in many domains of our economy actually makes it much costlier and laborious to be innovative in those domains, and that there are not enough original inventions to open up new 'innovation spaces'.

IS THERE A WAY OUT?

If the reader has come thus far without throwing in the towel, we expect that he or she might be interested in our suggestions on how to go about dealing with the current conundrum. A first step, in our opinion, is to acknowledge that there are cognitive dynamics that have brought us to this point because they are fundamental to human behavior, and therefore unchangeable[4]. Instead of trying to change those, we must *focus them in different directions*. Instead of changing mindsets, worldviews and behaviors, we need to focus on changing behavior. The change in mindset will, we expect, follow.

How do we change behavior? Well, first of all it seems that as we find ourselves into a huge hole, we have to stop digging. In a literal sense, this effectively means finding ways to slow down, and ultimately reverse, globalization in time for us to retain at least part of the cultural diversity built up over many millennia, which thus far has limited the growth of the waste-to-extraction economy. That does not imply abolishing the market system, but it does imply a redefinition of the balance between governments and markets, to re-enable governments to put in place checks and balances to contain the markets and the large multinational corporations.

Currently, that battle seems engaged, in part - and with limited success – directly between governments and the financial system (elimination of tax havens; changes in tax codes; better information about financial fluxes; investigation into microsecond trading, etc). But more im-

[4] We have not dwelt on these in this paper, but see van der Leeuw 2006, 2012

portantly, it also is engaged between governments and citizens on the one hand and the large energy companies that control much of the world's economies. It pitches the hydrocarbon industries against those that promote the use of renewables. It occurs at a time that the energy companies have been weakened due to their decreasing ROI and the limitations this places upon the future volume of hydrocarbons they can deliver (Leggett, 2014). Moreover, the financial and energy battles are linked because of the 'stranded assets' (see above) that are curtailing projects in the Arctic, but also some of the 'pre-salt' projects in front of the Brazilian coast.[5] Of course the largest part of the necessary regulatory structure in these domains still needs to be established, and it will demand the utmost from all of those who see the need to do so, to achieve this.

Here we must distinguish between the structures of the three major economic blocs (the US, Europe and China) and those of the emerging economics (Mexico, Brazil, India, Indonesia, South Africa, Nigeria, Turkey, etc.). Among the three major blocs, China may have the best opportunity to do create the regulations needed, as government has not relinquished as much control over business and industry as the West has. Europe and the US both have at the moment deep governance challenges, but it seems to us that the Euro area at least may have more control over its industries than the US, because of the way the EU was effectively built around the regulation of industry. A challenge of a completely different order of magnitude is no doubt shaping the structure of the emerging economies, which currently have relatively weak executive and judiciary branches, high levels of corruption and cultures that are in a sense halfway between their autochthonous past and the modern *extraction-to-waste economy*.

How could ordinary citizens direct their efforts? It seems to us that they need to re-engage their own responsibility in the political process, at all levels. In the West we have effectively delegated the responsibility for the wellbeing of our societies (and ourselves) to a small minority, and have lost control over what is happening. Fortunately, political engagement is visibly growing, particularly at the level of cities, citizens' organizations, NGO's and regions. For it to reach the higher levels of government will take time, except where populations have reached a tipping point. But there an absence of sufficiently thoughtful leadership or a 'revolution of rising expectations' often hampers efforts to move forward.

Regaining the initiative by taking up our responsibilities as citizens is not enough. We have to plan our future differently, and to do so we must ask the question 'What kind of future do we actually want?' Then we could design a roadmap that may get us there. This needs - again – to be done locally, regionally and nationally, as well as internationally. Calling for 'innovation' is not enough if we do not first consider where such innovation should lead us. After all, the last 250 years of unbridled innovation have led to our supply-driven consumerist innovation culture and our sustainability challenges. If we want to do better, we must learn to focus innovation.

We know quite a bit about the conditions under which inventions and innovations flourish, and the ways they affect the economy, but have much less scientific, procedural knowledge that could help us focus or steer invention and innovation effectively. Both have to do with the *emergence* of novelty, and emergence is hardly studied in our predominantly reductionist, ex-post scientific approach that focuses ('ex post') on explaining currently observed phenomena by linking them with their past by means of a cause-and-effect narratives. If we are to plan our future, we must therefore adopt an *'ex ante'* perspective, linking learning from the past to learning about the present *and to learning for the future. We should more directly on the emergence of phenomena rather than on explaining existing ones.* One way to promote this is by developing the academic

[5] The investigation of sales pitches and techniques in the pharmaceutical industry is another sign on the wall.

discipline of 'futuring'. Currently, the development of models, scenarios and forecasts is – presumably for reasons of expense – principally in the hands of major corporations, governments or supra-governmental institutions. There is thus no independent community that can critically look at the results of such exercises and help develop such efforts.

Another major barrier to asking 'What kind of future do we want?' seems to be that we view the present as the result of a quasi-inevitable 'evolution' towards the present. That is an ancient tradition in our western culture, but it is a distorting simplification of reality. As we have seen earlier, in our history there have been moments in which our societies' trajectory was determined by either choice (in the sense of 'systemic choice') or the actions of an individual or small group of individuals. Major structural changes resulted from these events, which gave European society a new lease of life. That said, things could have gone a different way, and European societies could have disintegrated. Choice is important, whether systemic, local or individual! The lesson is that if we are facing a tipping point, we must not succumb to an incremental (or even a passive) perspective, but actively stimulate collective, conscious choice.

What about our role as scientists? Over the past century or so, in some of our western societies science has to some extent lost the most precious gift of all, its trust, to its unchecked instrumentation by industry and government. Science was a willing partner in this process, being dependent on both for funding. In certain regions and certain domains, therefore, scientists are either seen as too distant from the concerns of civil society, or too much under the influence of government and industry. The loss of trust in science shows in some countries (such as the US and, to a lesser degree, the UK and European countries) as a reduction in funding for science and/or acceptance of scientific ideas. Hence we must transform the relationship between science and society into a more open and transparent one, more realistic in the expectations we raise and more aware of the potential unintended consequences of our actions. We must listen more, think more broadly in terms of alternatives rather than narrow causal explanations, and rebuild that trust to influence the political debate.

GREEN GROWTH

Why choose the label 'Green Growth' for our vision of the future? The GHG (Climate Change) debate has *ab initio* been presented as a threat to be dealt with, potentially limiting growth or even leading to regression. 'Green Growth', instead, emphasizes that we need to see this as an opportunity for positive transformation, rather than burden sharing, regression or danger. Like 'sustainability' and 'resilience', 'Green Growth' was adopted by different communities, from different perspectives, and is ill defined. For us, it is much more encompassing than the 'green economy'. It implies a fundamental restructuration of society affecting all our institutions and customs, just like earlier structural changes (e.g. sedentism, urbanization and the industrial revolution) have done. The ongoing ICT revolution offers a unique occasion to achieve such a transformation. The ability to process information quasi-independently from any substrate is fundamentally transforming humanity's social, economic and environmental organization anyhow. We should use the occasion to transform our society into a 'Green Growth' based one.

The ICT revolution is leveling the wealth differentials of the 'resource-to-waste' economy. It does so by creating horizontal information-processing networks alongside the vertical ones that dominated our society for so long. Rather than accumulation, spreading of information is becoming an important tool to create wealth. The reason for the relatively high valuations of the social networks is that they have discovered a novel way to profit from existing information differen-

tials - by decreasing rather than increasing them. This does indeed favor an *inversion from the current, predominantly extraction-to-waste economy* (in terms of natural and human capital) *into an economy of opportunity creation and spreading wealth*. And that could substantively enlarge the global 'value space'.

However important the occasion may be - and we think it is unique - we need to grasp that opportunity and not let it slip by uncontrolled. We need to collectively take a hold of the way in which the ICT revolution transforms our society, rather than leave that to corporations that steer society in ways profitable to them. The global value space will not expand if the technology will be used to spread the current productivity and consumption-focused western value system across the Earth. Indeed, we must do the inverse - develop the many non-western values of other societies by actively stimulating them to create novelty based upon *their* value systems. Without stimulating cultural diversity to grow our value system, we will not be able to find ways to live peacefully with 9 billion people on Earth.

In practice, this implies democratically strengthening the constraints imposed on the ICT industry, as well as individually and collectively focusing on our goals. This requires gaining insight into foreseeable effects of ICT development, which is now coming into its revolutionary stage as costs bottom out and computing power achieves such complex tasks as self-driving cars, speech recognition, drones, robotic manufacture of complex objects and automation in the service industries (″The Third Great Wave" The *Economist,* 2014 "Special Report on The World Economy", *The Economist,* October 4, 2014). ICT is expected to further increase transaction efficiencies, trigger more structural changes in the division of labor, further increase specialization of individuals, groups and institutions, change the configuration of firms and markets, as well as their roles and shapes. And as fewer resources are spent on maintaining current institutions, there will be more for innovation. Though there are no limits in sight to what ICT may change, its effects will differ profoundly between developed and developing nations.

In the developed world ICT favors capital over labor, shifting jobs from (automating, capital intensive) industry to (intellectually complex and labor intensive) services. But it has not (yet) achieved substantive increases in productivity or wealth. It accentuates wealth inequalities in favor of those involved in complicated tasks so that, if left unchecked, wealth and power will be ever more concentrated among a very small minority. On the other hand, employment and wages are expected to increase for non-automated menial tasks, while mid-level routine jobs will lose out.

ICT will enable developing economies to leapfrog industrial development. The reorganization of industry into dedicated global supply chains overcomes the need for integrated local industrial production. Any stage of a supply chain may be located anywhere in the world. In many places, this will reduce the opportunity to employ large numbers of people at the base of the wage ladder. Developing countries must find other solutions to lift wealth. ICT can enable this by delocalizing production (3-D printing etc.) and dematerializing products (services in education, health care, etc.), so that they can be produced (almost) without marginal cost.

In both sets of countries, the hope is that global connectivity will facilitate the growth of local craft-based entrepreneurs and increase the value of objects (including immaterial ones such as games) and services, which until now could only be sold in local markets. Examples abound in health services and online education. Mobile apps and networks are also democratizing capital ownership by moving us towards a sharing economy, crowd-funding and peer-to-peer lending. Finally, the ICT revolution is changing intellectual property rights.

Further in the future, the ICT revolution will of course impact our society in ways that one can only glimpse now (BBVA 2013). For one, ICT offers the opportunity to mitigate some of humanity's cognitive limitations. First, it will improve the integration between human and electronic information processing, drastically improving the information processing capacity of our societies. This process is ongoing, exploiting the creation of global horizontal information processing networks. Second, the 'Big Data' revolution will enable us to deal with the bias of human decision-making towards successful past responses inherent in the fact that our ideas are underdetermined by our observations (Atlan 1992), even though the techniques to do so are currently still insufficient. Third, upending Occam's razor by assuming that the world is complex and that we must embrace that complexity rather than simplify it, ICT could help us think about the future by harnessing it to generate high-dimensional problem- and opportunity spaces from a limited number of observed dimensions, and then test those for feasibility. The first small steps in this direction are set by people such as Belnap (e.g. 1975, 2001) and Fontana (2012).

In the practical domain, only by increasing information-processing capacity, education and wealth among the underprivileged can our societies continue to enjoy the high standard of living they currently have. At present, we can distinguish two main kinds of uses of the information-processing links between the developed and the developing worlds. The first aims for direct information transfer from the developed to the developing world, getting the latter to adopt ideas from the former. It does not directly contribute to the expansion of our global value space, even though the confrontation between the ideas spread and local knowledge may generate innovation and new values. The second approach, on the other hand, stimulates the development of local non-western knowledge and the expansion of local wealth creation, and their transfer to the developed world

Examples of the first are the facilitation of distant access to information from many different sources that was initiated by the search engines (Yahoo, Google, etc.), and then led to the development of specialized online encyclopedias such as Wikipedia that not only assemble but also synthesize information. It is now entering a different stage with the emergence of the Massive Open Online Courses (MOOCs). These enable anyone to study free of charge anywhere in the world. They are currently experimental, but likely to spread if ways are found to return to the educating institution a small percentage of the proceeds ultimately generated by the people thus educated. They are part of the 'online revolution', which in the next thirty years will fundamentally transform the worldwide education landscape at all levels. In addition there are many e-based tools that, though they do not deliberately aim to educate, have important educational functions. These range from blogs to social networks to ('serious') games that promote certain learning skills. In this domain, we may expect many more innovations that contribute to the transformation of learning.

Examples of the second kind are very numerous, They have been spreading for fifty years led by NGO's that saw that providing local populations in poor countries with western knowledge or infrastructure was not effective in helping local populations develop their existing talents and gain independence. Stimulating local recycling economies in the developing world is a good example. These are a fundamental part of the local economy, providing jobs, spreading or accumulating knowledge, and reducing waste. Giving them access to world markets has been one way to promote them, as in the case of the South African production of decorative baskets from telephone wire. Another example of this kind of promotion of local developments has been the spread of cellphone banking and microcredit to provide for the initial investments needed for local enterprises that are doing things that are not done in the west. This has been so successful that

more recently microcredit lending has spread to poor areas in the developed world, such as parts of New York City.

REFRAMING OUR EFFORTS

But this is not enough! In this section we will conclude our argument by insisting on the need to fundamentally reframe the current discussions on the future of our planet, changing our perspective from identifying a threat that we must remove to that of seeing an opportunity that we must develop. In the process, the debate at the international political level must be shifted from burden-sharing to opportunity-sharing, and from a "Not In My Back Yard" reaction or attempts to become a free rider profiting from the (financial and other) efforts of others, to a strong drive to move first and farthest, setting a competition in motion that moves the whole of the global economic, social and environmental system in a new direction. We will discuss this at both the level of the individual and at that of a group or society.

At the ***individual level***, macro-economics has for a long time invoked the assumption of 'rational' choice, but has recently extensively studied the domain of individual preference, both based on literature in cognitive studies, psychology and sociology (overview in Ng 2003) and on its own experiments in behavioral economics (e.g. Bowles & Gintis 2011).

Two assumptions of this paper seem to be relevant to that discussion. On the one hand, we emphasize the difference in dimensionality between the human short-term working memory and the wider world in which humans operate. Preferences and choices depend on that short-term working memory and can therefore only take a very limited number of dimensions into account, even though the contexts in which the decisions are made actually impact on people's well-being in many more dimensions (and vice-versa). Hence, choices and preferences are at best only partly commensurate with individuals' longer-term wellbeing, as that depends on many dimensions not taken into account.

Moreover, people's sense of wellbeing is not only based on their aspirations and their evaluation of their own position relative to that of others, but also on a comparison between their own past and their present. Hence people's perception of wellbeing is relative to their perception of others and to their own trajectory. Finally, their comparisons are framed by the cultural and societal dynamics that constitute the complex adaptive system in which people function. There is thus a potential discrepancy between people's short-term choices and their longer-term wellbeing. Current macroeconomics does not capture these complexities.

Reducing the dimensionality of the value space in which decision-making is assumed to happen inevitably distorts the perception of the consequences of that decision-making. In the short term, this may escape our attention, but in the longer term it contributes to the unintended consequences of our actions. Through its assumption of economic rationality, our current macroeconomic science has substantively contributed to recent crises, and will continue to do so unless we profoundly change course.

It is one of the tenets of the resilience community (Gunderson & Holling 2001) that longer-term developments like that of the last sixty years, in which a limited set of values progressively invaded our global world view to the exclusion of novelty based on different values, behaviors and institutions, ultimately leads to hyper-coherence of a society's dynamic structure and rapidly increases its vulnerability to shocks. Once such shocks cause cracks to appear, novel values and ideas that could not express themselves so far, emerge. That is in effect what may be causing our

world to fragment from a bipolar into a multipolar one at all levels as people everywhere begin to assume an increased responsibility for their own actions. As this spreads, it will involve an increasingly wider set of values, and deviate from the kind of 'rational decisions' that reduce long-term wellbeing to growing GDP. Current developments seem to favor the growth of the global value space that we have been arguing for. Over the long term such a move towards an *economy* of perceived improvements in wellbeing is not only desirable but inevitable. To facilitate the transition, an *economics* of wellbeing and diversity such as proposed by Ng must be developed, so that we may satisfy the huge needs of global society. Our social and natural environment is ultimately poisoned by the narrowness of our ideas and of the resource spectrum that we exploit.

At the ***level of societies***, the traditional macro-economic calculus, as proposed by Stern (2006) and others to calculate the effects of different pathways to mitigate climate change "... excludes the possibility that mitigation might drive the economy into a more competitive structure characterized by lower carbon emissions, [yet] with a utility level even higher than the 'utility without climate change' scenario" (Zhang & Shi, 2013). This is because the current economic toolkit only calculates incremental change emerging from the current dynamic equilibrium, and does not enable us to calculate the effects of a deviation from the current trajectory that could shape a different organization. Such a new trajectory would not obey the old rules and would call into existence new feedback loops and new interactions with the environment that cannot taken into account in the calculations. As a result, "... mitigation has become a kind of action undertaken to avoid damage, rather than to explore new opportunity" (Zhang & Shi, ibid.). Moreover, "... because the predicted benefits of collective actions are primarily global but the cost is local, all countries (regions, groups, etc.) have a strong incentive to be free-riders" (Zhang & Shi, ibid.).

In view of these limitations, we need to investigate whether mitigation may lead to local, measurable, new growth opportunities. And that is where infra-marginal economics comes in, as it enables comparison between structurally different organizations and quantification of the efficiency of institutional innovation. With market expansion and improvements in transaction efficiency through institutional innovation, the market structure in a new sector of the economy may jump to greater division of labor through functional reorganization, and therefore generate higher productivity (see annex 1 for a theoretical example). This is a fundamental to the development of any new organizational structure, and will determine which of several organizational forms (such as technologies) will ultimately win out.

In the context of global competitiveness, this approach suggests that economies that take tough emission reduction measures and establish sound rule systems to achieve them will be forerunners in transforming to a more competitive economy (Jaeger et al. 2011; Shi and Zhang 2012). By looking at emergent diversity at the individual and group level, as suggested in the earlier part of this section, and developing the toolkit to compare different organizations from an efficiency perspective, we might get much closer to focusing our societies' innovative capacities and thus enhance the chances that our investments in innovation will actually help us meet the sustainability challenges we are facing.

CONCLUSION

We conclude that we have to take the hypothesis seriously that one of the main impacts of the information revolution will be a redistribution of knowledge and information-processing capacity that fundamentally undermines the current structure of our societies, businesses and gov-

ernments because information can no longer be kept from spreading. Our agenda must therefore be "How do we constructively deal with this change in our global Earth systems to enhance the sustainability, not necessarily of our current societies' structures, but of global human society?"

This begins with assuming individual responsibility for our own and society's actions at all levels, looking into alternatives and evaluating them for their unintended (and intended) consequences, participating in the political process, but above all rethinking and restructuring the way we educate and train future generations of global citizens worldwide. Once we have thus collectively set the first (baby) steps towards behavioral changes, many novel tools will be invented to facilitate and grow that change. Some of these will be opened up by the ICT revolution; others will be forced upon us by the economic and material consequences of the "resource-to-waste" economy or the social consequences of growing inequality and the attendant social instability and unrest.

ACKNOWLEDGEMENTS

The authors acknowledge the important impact of the first author's long-time interaction with the Faculty and Staff of the Santa Fe Institute, and ASU's financial support for the second author that enabled us to begin working together.

ANNEX 1: COMPARING THE UTILITIES OF EXISTING VS. ALTERNATIVE CONSUMPTION

A. THE THEORETICAL CASE

Assume there are three types of goods & services:

A: material-based goods & services for subsistence (e.g. food, clothes);
B: material resources-based goods & services for overconsumption (e.g. ice-cream);
C: non-material goods & service (e.g. music).

and assume:

- Utility in a westernized overconsumption pattern: U1=f1 (A1, B1, C1)
- Utility in an alternative green consumption pattern: U2=f2 (A2, B2, C2)

Then, to maintain the same utility, there are different possible combinations for types A, B, and C. For some particular goods, infra-marginal changes of consumption volume could happen, i.e. change from positive to zero consumption:

$$A1=A2,\ B1>B2,\ C1<C2$$

In those combinations, the traditional economic utility of U2 could be greater than U1, with more C and less B, but its environmental impact would be substantially less than U1. Hence, greater consumption and production of C in structure U2 could bring higher utility, and it is therefore a sustainable development. But if structure U2 could in principle be a scenario with higher utility and sustainability, why did human development not shift to path U2?

B. THE CASE OF A MATERIAL RESOURCE BASED ECONOMY

Unfortunately, in the current economic system, it is hard for the scenario of structure U2 to become reality, or to reach equilibrium in terms of economics. This is due to three major obstacles:

First, path-dependency Once a system is on a particular trajectory, then the mutually reinforcing process between expansion of market size and increase of division of labor would accelerate, leading to a high productivity and low price economy. Also, once the trajectory is locked-in, the transition cost from the locked-in scenarios to the alternative scenario would be very high. The current competition between traditional and renewable energy demonstrates some of the difficulties (Leggett, 2013)

Second, ***there is no way to make a profit by providing for many non-material services without government intervention***, even though there is a demand for them:

- Ecosystem services: without government stepping in, upstream and downstream would most likely descend into a lose-lose spiral, since the upstream cannot trade its eco-services with the downstream, and has instead to make short-term revenue by deforestation, overgrazing, etc.
- The carbon cost, ecosystem cost, pollution cost of economic activities, including mining, manufacturing, etc. is externalized and thus not properly included in the price of goods. This gives goods A&B a marginal edge in competing with non-fossil fuel based goods & services.
- Government action on carbon mitigation needs sufficient evidence of improvements due to green growth, while evidence of the success of green growth is conditioned on government action (a 'chicken & egg' relation).

■ The difficulties of managing the provision of global public goods inherent in the differences between national and global interests.

Third, demand is led by marketing, which reinforces the path dependency of the current system, so that enormous green demand is sleeping and not been activated.

This points to the need for a redefinition of the role of government in the management of common pool resources and the regulation of certain aspects of the economy.

B. THE CASE OF AN ECONOMY NOT DEPENDENT ON A MATERIAL RESOURCE BASE

In a new development model based on non-material resources, such as human capital, creation, culture, identity, environment, and renewable energy, conventional resource constraints would no longer exist, and the productivity of such an economy would dramatically increase with the help of ICT. Moreover, resources that do not play a role in a material resource based economy would become valuable in the new development model.

Such a development model has a number of implications.

Environmental implications. Manufactured goods are made from material and labor, while services substantially depend on labor and creation. They have different impacts on the natural environment.

Implications for human wellbeing. On the demand side (consumer), a dematerialized world is feasible. In terms of satisfying consumer utility, material resource-based goods and non-material-based services, to large extent, can be substituted for one another (e.g. ice-cream vs. a game, Internet entertainment)[6].

Implications for productivity. On the supply side, service can be provided with (almost) zero marginal cost and zero natural use. For instance, it is not much different for a teacher to teach 10 students or 50 students in terms of workload. Especially, ICT can dramatically expand this effect. e.g. Massive Online Open Course (MOOC). The potential for increasing returns, which is the source of economic growth, is then dramatically expanded. Nonetheless, the potential is yet to be explored because of some constraints.

Implications for profitability. For a firm, it is not easy to clearly define the property right of some service, so that the efficiency for direct transaction is low, compared to manufactured goods. For the profit-seeking firm, this is problematic. *The solution is to be sought in the innovation of the firm's business.* (For instance, by substituting a trilateral, indirect transaction between the firm, the consumer and the internet advertiser for three bilateral transactions. When Internet first came out, few people expected it could create so many new business opportunities and business models. In particular, this shift seems to point in the direction of replacing linear transactional thinking by circular economic thinking, such as is being experimented by Gunther Pauli, the founder of "The Blue Economy" (http://www.theblueeconomy.org/blue/Home.html) and Dutch contractors "The Delta Development Group" (http://www.deltadevelopment.eu/en/contact/netherlands).

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6 The utility function in economics usually refers to manufactured goods because it is related to supply and transaction. Since marginal cost pricing rules are not, or minimally, applicable to many services, it is not easy to deal with them in a general equilibrium model.

FIGURES

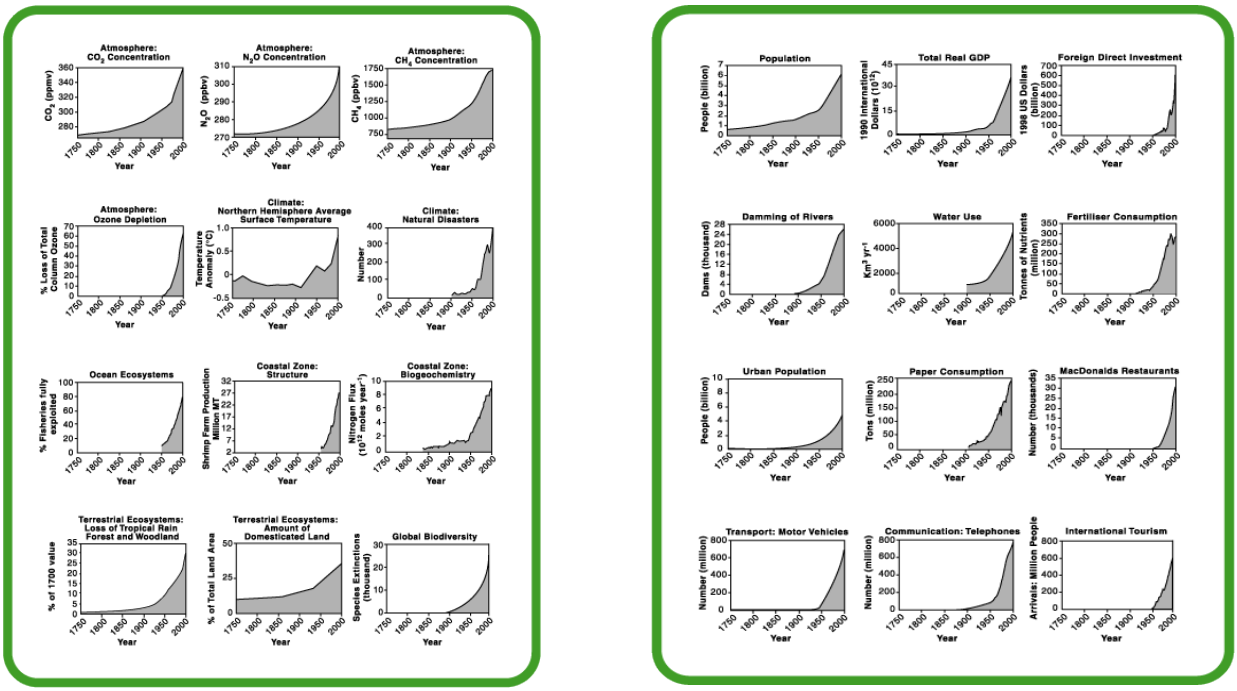

Figure 1: The global socio-environmental system is going exponential since AD 1900

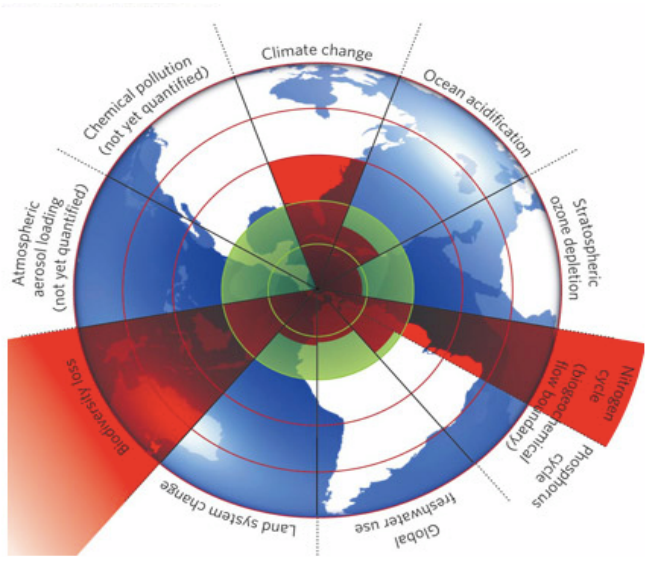

Figure 2: Some of the planetary boundaries have already been crossed

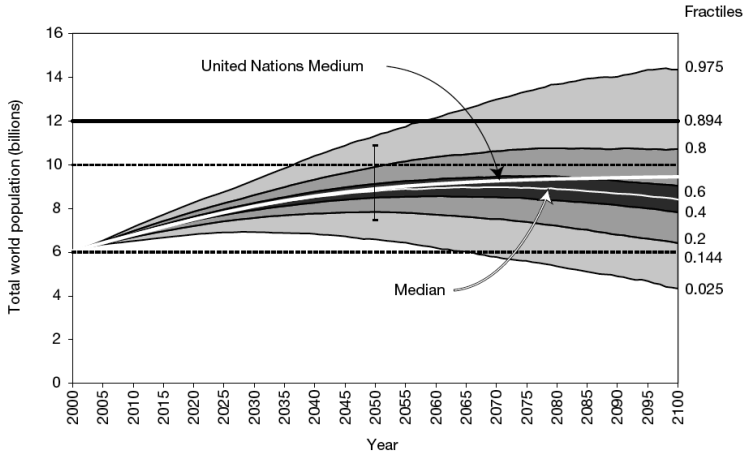

Figure 3: Projected global population AD 2000-2100

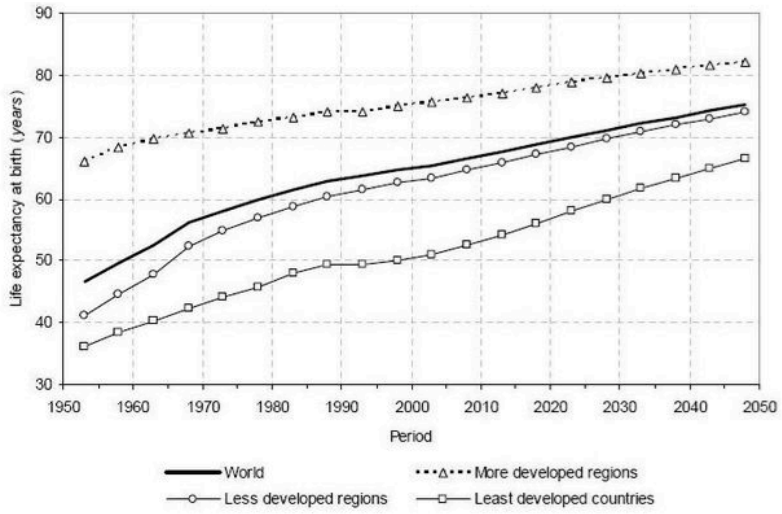

Figure 4a: Global life expectancy predictions

World historical and predicted crude birth rates (1950–2050)
UN, medium variant, 2008 rev.[7]

Years	CBR	Years	CBR
1950–1955	37.2	2000–2005	21.2
1955–1960	35.3	2005–2010	20.3
1960–1965	34.9	2010–2015	19.4
1965–1970	33.4	2015–2020	18.2
1970–1975	30.8	2020–2025	16.9
1975–1980	28.4	2025–2030	15.8
1980–1985	27.9	2030–2035	15.0
1985–1990	27.3	2035–2040	14.5
1990–1995	24.7	2040–2045	14.0
1995–2000	22.5	2045–2050	13.4

Figure 4b: Historical and predicted crude birth rates

Figure 5a: We are already exceeding the Earth's biocapacity ...

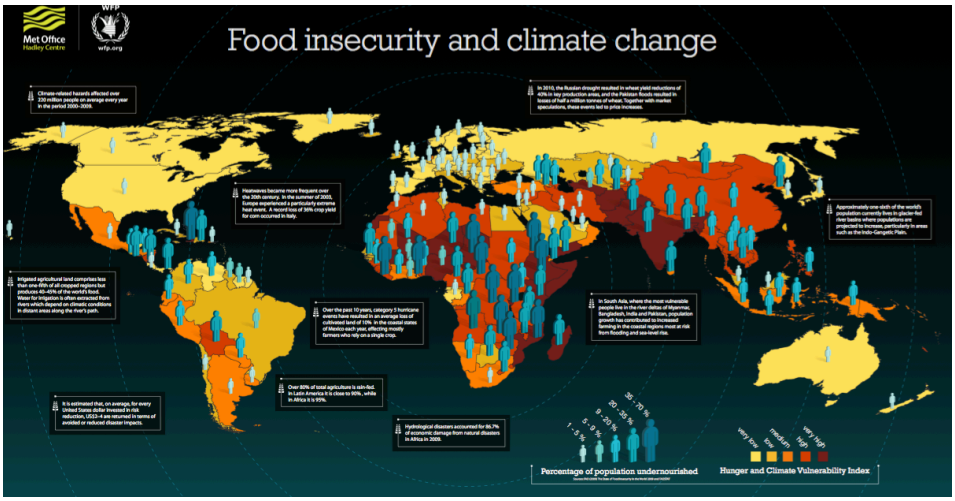

Figure 5b: Food insecurity is unequally spread across the world, and with increasing wealth in developing areas is likely to grow

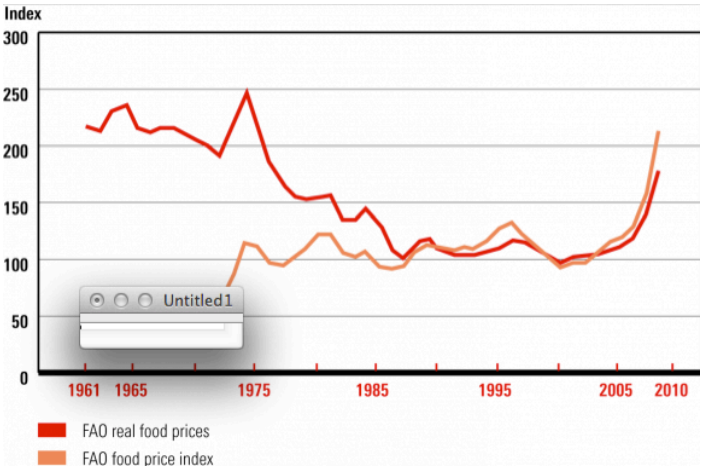

Figure 5c: changes in food prices show a recent spike

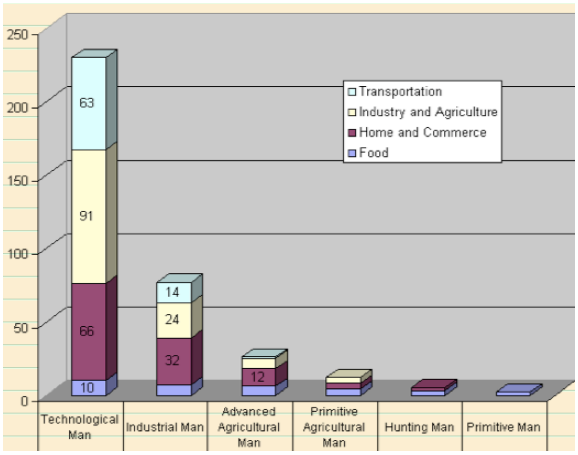

Figure 6a: Since the beginning of the industrial revolution, energy use has exploded

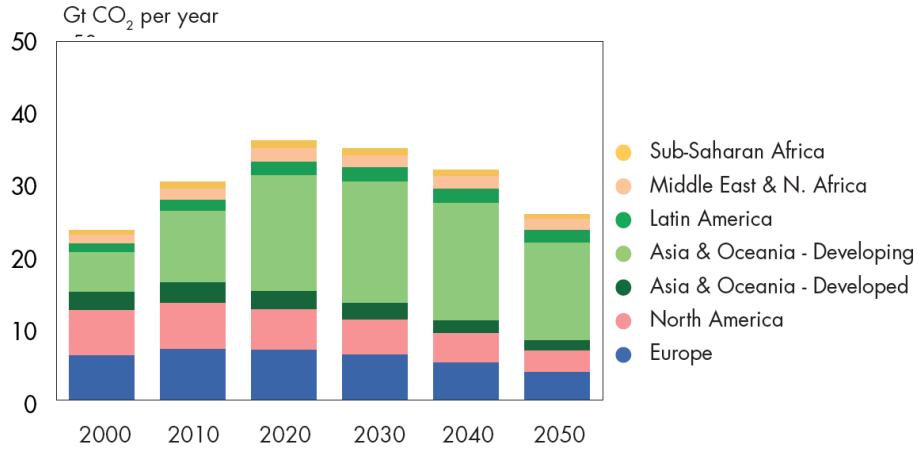

Figure 6b: The 'optimist' scenario for greenhouse gas emissions will drive global temperature change way beyond the 2º average that seems acceptable

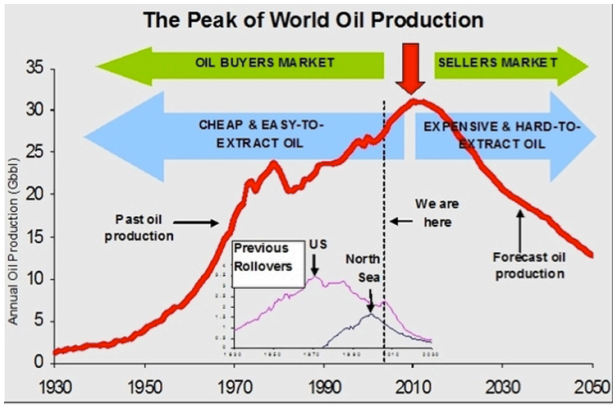

Figure 6c: We are already at the point where oil production can no longer keep up with oil use

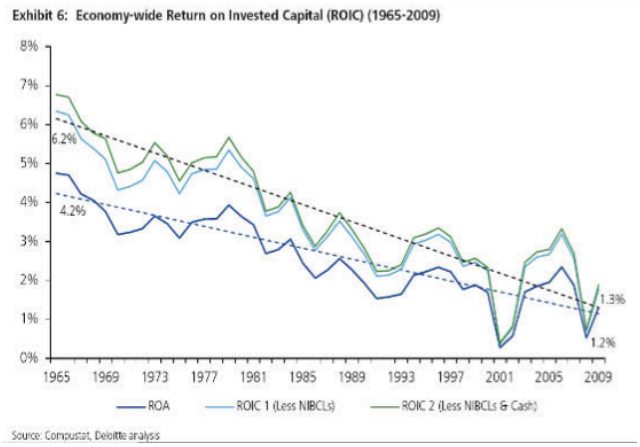

Figure 7a: Evolution of in return on invested capital in the US

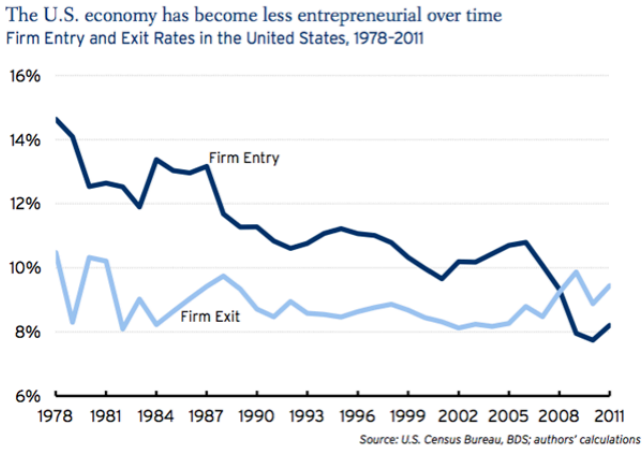

Figure 7b: At the same time, there has been an important decline in entrepreneurship

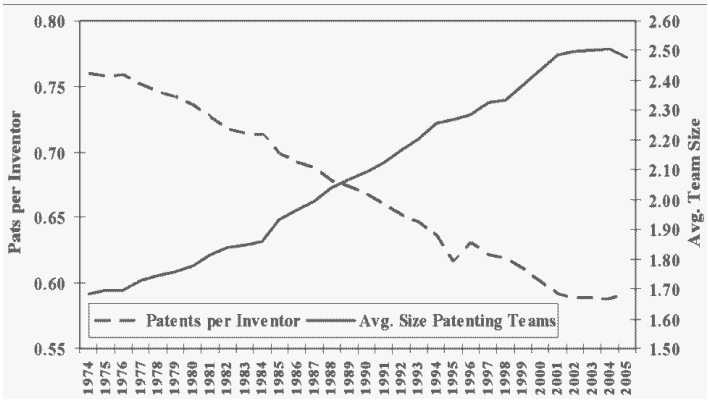

Figure 7c: Over the last thirty years, the number of patents per inventor decreased and the size of the teams involved grew, as innovation became more and more difficult.

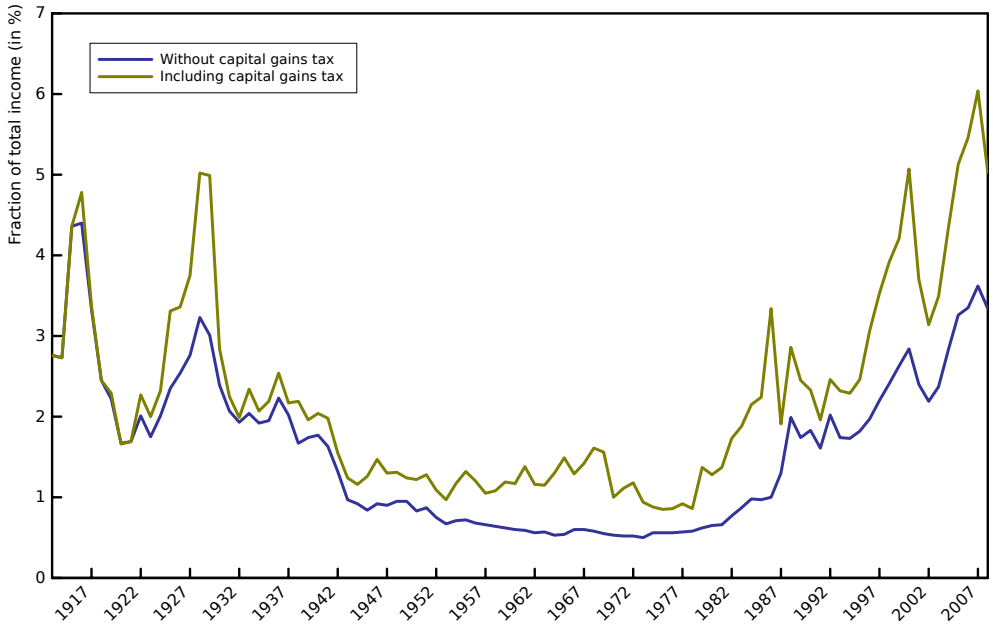

Figure 8a: Fraction of total income (in the USA) that is invested in production (without capital gains tax) and speculation (with capital gains tax)

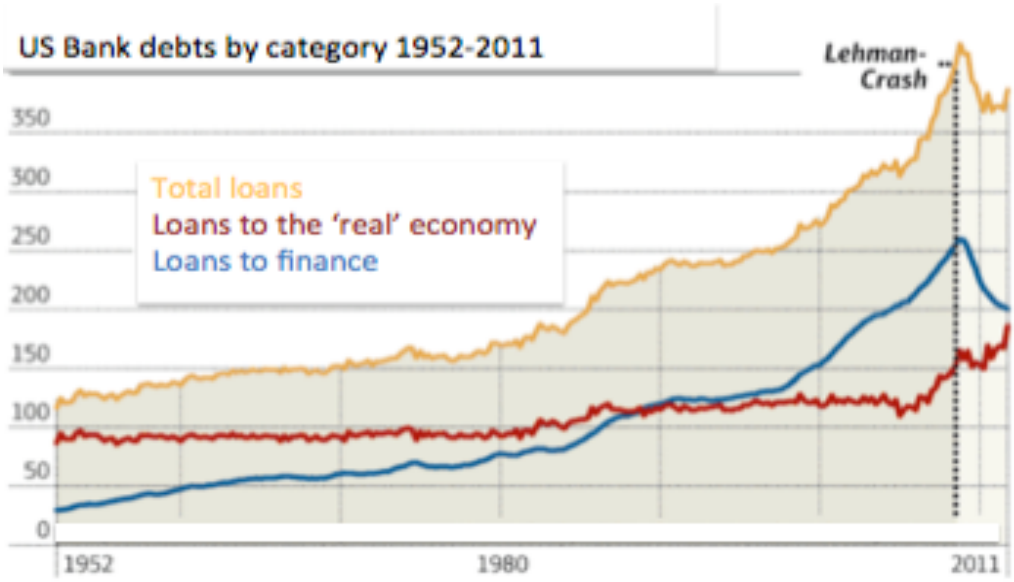

Figure 8b: Destination of loans in the USA.

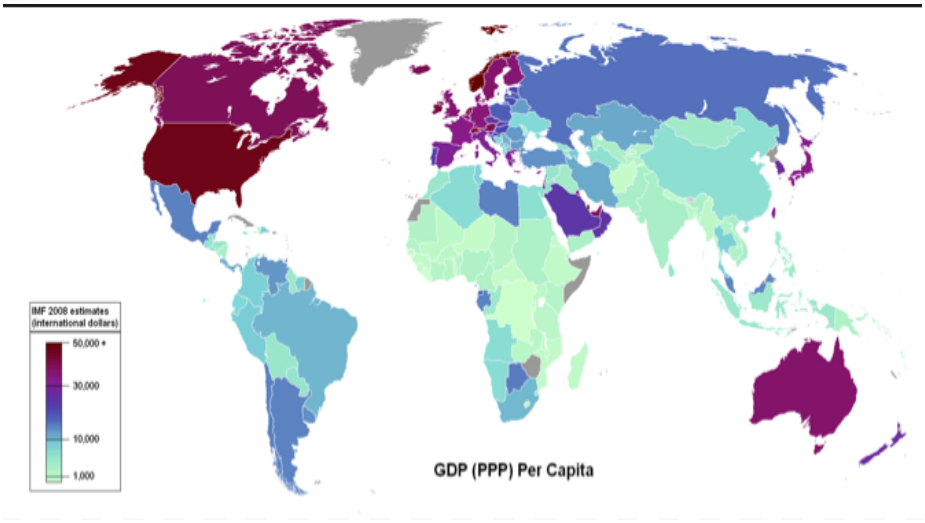

Figure 9a: Average wealth per capita across the world

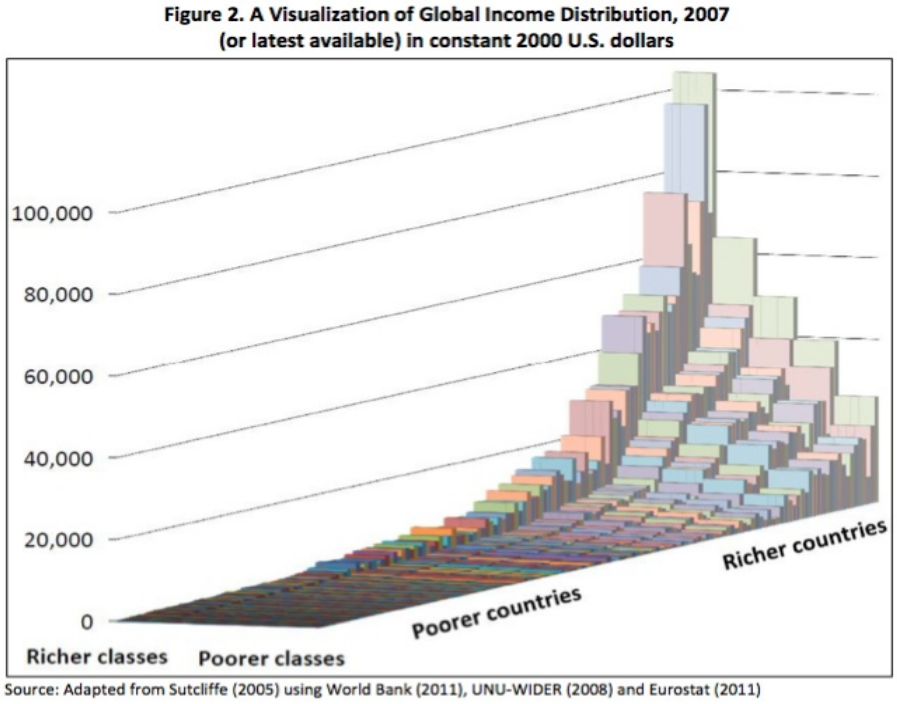

Figure 9b: Intra-country wealth distributions across the world

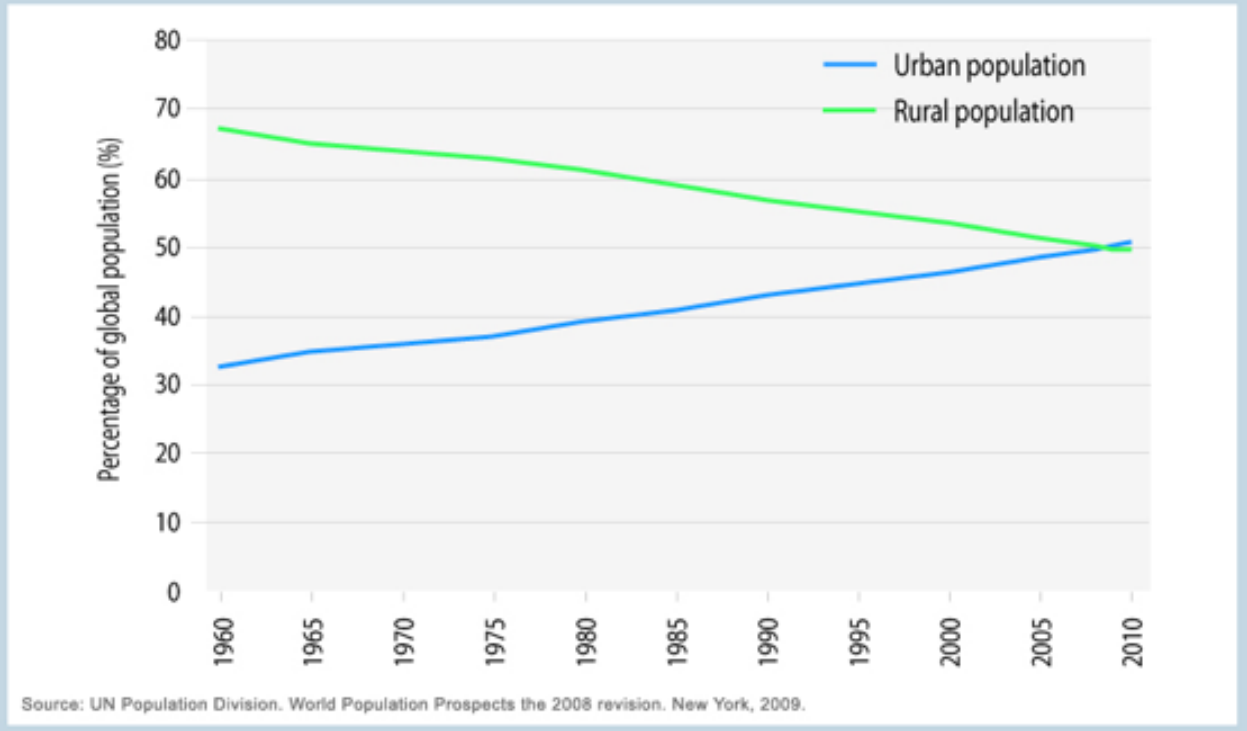

Figure 10a: Evolution of the proportion of people living in cities

Y	β	95% CI	Adj-R^2	Observations	Country-Year
new patents	1.27	[1.25,1.29]	0.72	331	USA 2001
inventors	1.25	[1.22,1.27]	0.76	331	USA 2001
private R&D employment	1.34	[1.29,1.39]	0.92	266	USA 2002
"supercreative" employment	1.15	[1.11,1.18]	0.89	287	USA 2003
R&D establishments	1.19	[1.14,1.22]	0.77	287	USA 1997
R&D employment	1.26	[1.18,1.43]	0.93	295	China 2002
total wages	1.12	[1.09,1.13]	0.96	361	USA 2002
total bank deposits	1.08	[1.03,1.11]	0.91	267	USA 1996
GDP	1.15	[1.06,1.23]	0.96	295	China 2002
GDP	1.26	[1.09,1.46]	0.64	196	EU 1999-2003
GDP	1.13	[1.03,1.23]	0.94	37	Germany 2003
total electrical consumption	1.07	[1.03,1.11]	0.88	392	Germany 2002
new AIDS cases	1.23	[1.18,1.29]	0.76	93	USA 2002-2003
total housing	1.00	[0.99,1.01]	0.99	316	USA 1990
total employment	1.01	[0.99,1.02]	0.98	331	USA 2001
household electrical consumption	1.00	[0.94,1.06]	0.88	377	Germany 2002
household electrical consumption	1.05	[0.89,1.22]	0.91	295	China 2002
household water consumption	1.01	[0.89,1.11]	0.96	295	China 2002
gasoline stations	0.77	[0.74,0.81]	0.93	318	USA 2001
gasoline sales	0.79	[0.73,0.80]	0.94	318	USA 2001
length of electrical cables	0.87	[0.82,0.92]	0.75	380	Germany 2002
road surface	0.83	[0.74,0.92]	0.87	29	Germany 2002

Table 1: Allometric scaling relationship between city size (population), energy use and information processing

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