Report

The Emergence of Risks: Contributing Factors

international risk governance council

Abbreviations used in the text:

AIDS	Acquired Immune Deficiency Syndrome
CAS	Complex Adaptive System
CME	Coronal Mass Ejection
CO_2	Carbon Dioxide
GM	Genetically Modified
GPS	Global Positioning System
HIV	Human Immunodeficiency Virus
INUS	Insufficient but Necessary part of an Unnecessary but Sufficient cause
IRGC	International Risk Governance Council
IT	Information Technology
LNG	Liquid Natural Gas
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-Operation and Development
ppm	Parts per million
RDM	Robust Decision-Making
SCADA	Supervisory Control and Data Acquisition
UK	United Kingdom
US	United States

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Preface

The International Risk Governance Council (IRGC) aims to support governments, business and other organisations and to foster public confidence in risk governance and in related decision-making by:

- reflecting different views and practices and providing independent, authoritative information;
- improving the understanding and assessment of important risk issues and any ambiguities involved;
- designing innovative, efficient and balanced governance strategies.

IRGC's mission includes developing concepts of risk governance, anticipating major risk issues, and providing risk governance recommendations for decision-makers who deal with policies and strategies involving risk issues.

At the core of IRGC's work is the concept and practice of **risk governance**, defined as the identification, assessment, management and communication of risks in a broad context. It includes the totality of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated, and how and by whom management decisions are taken and implemented.

Central to IRGC's approach to risk governance is its Risk Governance Framework, intended to help policymakers, regulators and risk managers in industry and elsewhere both understand the concept of risk governance and apply it to their handling of risks. A detailed description of IRGC's Risk Governance Framework was published in IRGC's White Paper "Risk Governance – Towards an Integrative Approach" in 2005 [IRGC, 2005].

More recently, IRGC has endeavoured to identify commonly recurring "deficits" in risk governance. IRGC's report on Risk Governance Deficits [2009] is designed to foster better understanding of their causes and how they can be prevented or mitigated through improved assessment and management. The IRGC project on risk governance deficits was the entry point to this current IRGC project on emerging risks, of which the objective is not to develop a list of emerging risks, but, instead, to focus on their origins.

IRGC is concerned that important opportunities for social and economic development may be foregone through inadequate risk governance of emerging risks, which are often seen as peripheral, disturbing factors rather than issues that should be at the centre of attention. One valid reason for this is that decision-makers often find it very difficult to justify the allocation of scarce resources to an emerging risk when there are other, known risks that require better management – this is especially true when there are uncertainties surrounding the likelihood and consequences of an emerging risk. With this report, IRGC hopes to make this task easier by raising awareness about and improving the understanding of emerging, global risks and the sort of impacts that they can have on human health and safety, the environment, the economy and society at large. The perspective presented in this report builds on an earlier concept note[1] and will form the basis for IRGC's development of guidance for practitioners in business and the public sector, to help them overcome obstacles and improve their own capabilities for understanding, anticipating, and responding to emerging risks.

More information on IRGC's emerging risks project can be obtained by emailing governance@irgc.org

(1) The IRGC concept note on emerging risks describes sources and drivers of risks, and the governance issues arising from how organisations and people deal with them [IRGC, 2010a].

Executive summary

IRGC defines as "emerging" a risk that is new, or a familiar risk that becomes apparent in new or unfamiliar conditions. Of particular interest to IRGC are emerging risks of a systemic nature, which typically span more than one country, more than one economic sector, and may have effects across natural, technological and social systems. These risks may be relatively low in frequency, but they have broad ramifications for human health, safety and security, the environment, economic well-being and the fabric of societies.

With this report, IRGC aims to raise awareness among professionals about the fact that risks emerge from a common "fertile ground" that is cultivated by twelve generic "contributing factors". IRGC defines and illustrates these factors in this report. The illustrations, which are drawn from real-world experience, trace how the contributing factors led new risks to emerge or be amplified at their early stages. For example, rising rates of obesity are offered as an illustration of an emerging risk that results from changing social dynamics and economic forces.

The twelve generic factors are not exclusively relevant to the systemic, emerging risks that are the focus of this report. On the contrary, some of them are relevant for all risks. However, IRGC has identified these factors as especially pertinent to emerging risks and assumes that an understanding of these factors will provide practitioners with insights to help anticipate these risks and better manage them at the early phase of their development.

This report is thus not concerned with identifying or predicting any specific emerging risks, but rather the focus is on the general origins of emerging risks. While IRGC believes it is crucial for practitioners to gather in-depth subject knowledge of each emerging risk they are faced with, there are nevertheless some useful, general lessons about the causes and control of emerging risks that can be drawn from historical experience.

IRGC treats the emergence of risks as a negative phenomenon, but we do not intend to deprecate the importance of benefits, or the necessity of risk taking in society. Indeed, one of the central challenges in responding to emerging risks is how to achieve a wise balance between the opportunity for benefit and the downside possibilities.

The twelve factors presented in this report reflect the collective judgement of a wide range of international experts in risk analysis and management. These experts have drawn upon both the peer-reviewed scientific literature and their extensive professional experience in the field. The generic factors may be seen as contributing to the creation of fertile ground from which new risks can emerge (or be amplified), much in the same way as factors such as nutrients and minerals contribute to creating fertile ground for the germination of a seed (or, vice-versa, factors can attenuate the emergence of risks, just as a lack of nutrients can create unfertile ground). There may (or may not) be a single dominant seed that gives rise to the risk but there are often multiple contributing factors in the growth process.

IRGC's twelve factors are all generic, in the sense that they are applicable across multiple domains, but, importantly for practitioners, under certain circumstances, some of them may be more controllable than others and are therefore ripe targets for risk management measures. While the origins of emerging risks often require a basic understanding of the physical and life sciences, several of the factors identified in this report have a psychological, social or economic dimension. In some cases the social science aspects, instead of affecting the likelihood or severity of an emerging risk, can help explain the neglect of a risk's emergence by seemingly competent managers of organisations.

Before outlining the factors, it is useful to first situate them within the context of systems. In particular, we are interested in complex systems, which often give rise to the emergence of systemic risks. Complex systems may be defined, scientifically, as systems "composed of many parts that interact with and adapt to each other" [OECD, 2009a]; their often surprising behaviour needs to be understood as a whole. IRGC has found that a systems perspective, which examines how a system's components relate to each other as well as to the larger system, sheds light on emerging risks. Multiple interacting system components are commonly involved in risk emergence and even multiple systems can be implicated (changes in one system can have ramifications for another system).

Complexity can encompass, or at least strongly influence, many of the twelve factors presented in this report. The behaviour of complex systems involves chance variation and is therefore often unpredictable and hard to control. Some traits common to complex systems, such as non-linearity or threshold behaviour, have the effect of increasing the unpredictability of the system's future behaviour and, as a result, make risk anticipation difficult. On the other hand, some traits such as adaptability and self-organisation may act to make risk emergence less likely, as they can confer on the system a coping capacity, allowing it to withstand some potentially destabilising perturbations.

The twelve factors described below should be considered with the above context in mind. These factors are not presented in any order of importance or impact (indeed, such an assessment could only be usefully made with a specific situation in mind).

Factor # 1: Scientific unknowns

Dealing with emerging risks inevitably requires dealing with scientific unknowns. These unknowns, whether tractable or intractable, contribute to risks being unanticipated, unnoticed, and over- or under-estimated.

Factor # 2: Loss of safety margins

The level of connectivity in many of today's social and technical systems is greater than in the past and the interconnections are increasing. The pace at which these systems operate is becoming faster and many are operating under higher levels of stress. This can lead to tight-coupling of components within systems and to loss of safety margins – a loss of slack or buffering capacity that leaves systems more vulnerable to disruption and thus increases the likelihood that new risks will emerge

Factor # 3: Positive feedback

Systems exhibiting positive feedback react by amplifying a change or perturbation that affects them. Positive feedback tends to be destabilising and can thus amplify the likelihood or consequences of an emerging risk.

Factor # 4: Varying susceptibilities to risk

The consequences of an emerging risk may be different from one population to another. Geography, genetics, experience and wealth are just some of the possible contextual differences that create varying susceptibilities to risk.

Factor # 5: Conflicts about interests, values and science

Public debates about emerging risks seldom witness a clear separation between science, values, and interests. The conflicts that result have the potential to contribute to fertile ground for risk emergence or amplification. For example, emerging risks may be amplified when efforts to assess them and take early management measures encounter opposition on the grounds of contested science or incompatible values.

Factor # 6: Social dynamics

Social change can lead to potential harm. In other circumstances, it can attenuate potential harm. It is therefore important for risk managers to identify, analyse and understand changing social dynamics.

Factor # 7: Technological advances

Risk may emerge when technological change is not accompanied by appropriate prior scientific investigations or post-release surveillance of the resulting public health, economic, ecological and societal impacts. Risks are further exacerbated when economic, policy or regulatory frameworks (institutions, structures and processes) are insufficient, yet technological innovation may be unduly retarded if such frameworks are overly stringent.

Factor # 8: Temporal complications

A risk may emerge or be amplified if its time course makes detection difficult (e.g., the adverse effects of the risk only become evident after a long period of time) or if the time course does not align with the time horizons of concern to analysts, managers and policymakers.

Factor # 9: Communication

Risks may be complicated or amplified by untimely, incomplete, misleading or absent communication. Effective communication that is open and frank can help to build trust. In many cases, such communication can attenuate, or lead to better anticipation and management of, emerging risks.

Factor # 10: Information asymmetries

Information asymmetries occur when some stakeholders hold key information about a risk that is not available to others. These asymmetries may be created intentionally or accidentally. In some cases, the maintenance of asymmetries can reduce risk, but in others, it can be the source of risk or the amplification of risk by creating mistrust and fostering non-cooperative behaviours.

Factor # 11: Perverse incentives

Perverse incentives are those that induce counterproductive or undesirable behaviours, which lead to negative, unintended consequences. Such incentives may lead to the emergence of risks, either by fostering overly risk-prone behaviours or by discouraging risk prevention efforts.

Factor # 12: Malicious motives and acts

Malicious motives give rise to emerging risks and therefore practitioners need to consider intentional as well as unintentional causes of risk. Malicious motives and acts are not new, but in a globalised world with highly interconnected infrastructures (e.g., trade agreements and information and communication systems) they can have much broader-reaching effects than in the past.

Responding to the challenge of emerging risks is not easy. Heuristics and cognitive biases can affect how some of the contributing factors outlined in this report are perceived or dealt with by decision-makers.

Given the many different kinds of emerging risks and the wide range of potential responses by managers, it is not feasible to identify a creative management strategy that will be optimal – or even satisfactory – in all situations. But for emerging risks that arise from the behaviour of complex systems, there are certain elements of organisational capability that may prove to be particularly effective. Those elements include:

- Enhancing the capabilities for surveillance, data collection, knowledge development, scenario planning and formal uncertainty analysis;
- Developing an understanding of human behaviour and acknowledging that logic and traditional rationality are not the sole basis for human decision-making;
- Regularly and systematically reviewing decision-making and communication processes;
- Allowing for enough organisational flexibility and decentralisation to accommodate adaptation and innovation in response to changing situations and new indications of emerging risk;
- Building robustness, redundancies and, mainly, resilience as a strategy to combat uncertainties.

Establishing the capabilities described above at public and private organisations will not be easy. A strong case will need to be made for the necessary resources, and the strong case will require managers and leaders to acknowledge (often publicly) that their organisations are not prepared for emerging risks. Nor will a one-time change in capabilities create a sustainable solution. A new "risk culture" at organisations is necessary to optimally utilise the new capabilities. In the next phase of IRGC's emerging risks project, which is following completion of this report, IRGC plans to supply guidance as to how private and public organisations can develop a professional risk culture. The ultimate goal is continuous improvement in how organisations anticipate and respond to emerging risks.

I Introduction

Consider the H1N1 flu epidemic, the recent global financial crisis, the concerns throughout Europe when Russia cut off natural gas supplies to Ukraine, the massive damages from hurricane Katrina, the tragic events of 9/11 and the subsequent terrorist attacks in Madrid, London and other parts of the world, the enduring epidemic of AIDS in Africa, and the unexpected rise of obesity in many countries of the world. When they emerged, was each of these problems so novel and distinct that it could only be anticipated and understood with specialised knowledge and experience? Or are there generic insights that can be gleaned from the phenomenon of "emerging risks" that may be useful to all those concerned with better anticipation and early management of such risks?

In this report, IRGC argues that, while it is crucial for risk managers to gather in-depth subject knowledge about each emerging risk, there are some useful, general lessons about the causes and control of emerging risks that can be drawn from historical experience. In particular, IRGC has identified twelve generic factors that contribute to emerging risks. They act not in a monocausal way, but by contributing to an environment ("fertile ground") from which risks are likely to emerge or be amplified. IRGC believes that by adopting a systems perspective, one that fosters awareness of these twelve factors, practitioners – whether they be analysts, managers or policymakers – will be able to improve their understanding of why risks emerge, whether they can be predicted, and how they can be recognised and managed at the earliest stages.

The generic factors presented here are the product of the first phase of IRGC's ongoing project on emerging risks. They reflect the collective judgement of a wide range of international experts in risk analysis, complexity and governance. The process of identifying the generic factors began at an international roundtable of risk practitioners in June 2009, and the set of factors was further refined at a December 2009 workshop of risk analysts and system experts. This report is the outcome of collaborative work by this group of experts and was reviewed during a workshop of the Scientific and Technical Council of IRGC in July 2010. Both the opening roundtable and the December 2009 workshop were held at the Swiss Re Centre for Global Dialogue near Zurich, Switzerland. In preparation for the workshop, we also gained insight from a handful of case studies of emerging risks prepared by the IRGC Secretariat, as well as a series of commissioned papers by workshop participants on the causes of emerging risks in different sectors of society. One purpose of preparing these case studies and papers (available on the IRGC website[2]) was to validate the identified contributing factors by seeing if and how they are relevant to topical emerging risks. Informed by these activities, this report modifies and enriches IRGC's original thinking, which was summarised in a 2009 IRGC Concept Note.[3]

(2) The case studies are: Counterfeit prescription drugs; Severe space weather (solar storms); Obesity; Melamine-tainted milk in China; Megacities; and Sea-level rise. The expert papers address: emerging infectious diseases; ecosystems and climate; financial markets; large-scale engineered systems; and the role of complex systems in creating emerging risks for society and economics. All are available online at http://irgc.org/Phase-1-case-studies-and.html
(3) Concept Note on "Emerging Risks: Sources , Drivers and Governance Issues" [IRGC, 2010a], available online at http://www.irgc.org/IMG/pdf/IRGC_EmergingRisks_CN_final.pdf

II Definitions of terms

This section briefly defines the kind of risks that are the focus of this report. For definitions of other risk-related terms, refer to the glossary on page 53.

From its inception, IRGC has focussed on **"systemic risks"** that, though they may originate locally, can have global ramifications. At a minimum, systemic risks typically span more than one country and more than one sector of the economy. They are not under the control of any one organisation, but affect and must be addressed by many stakeholders at once. They also often span the divides between natural, technological and social systems. Systemic risks may be relatively low in frequency, but they have broad ramifications for human health, safety and security, the environment, economic well-being and the fabric of societies.

A particular mortgage lender declaring bankruptcy, for example, may represent a significant personal risk for its employees but it is not seen as a systemic risk. However, if this bankruptcy is the result of inadequate risk management of a widespread problem in the mortgage-lending market – an interconnected problem involving many other financial institutions – then the ramifications could include cross-sectoral and economy-wide impacts. The financial crisis of 2007-08 is a case in point.

Due to the powerful forces of globalisation, significant risks are rarely confined to a specific country or region of the world. While the distinction between personal and systemic risks is not always made, IRGC has particular interests in those systemic risks that may require action by more than one country, sometimes through international collective action, in order to be controlled effectively.

IRGC defines an **"emerging risk"** as one that is new, or a familiar risk that becomes apparent in new or unfamiliar conditions (e.g., the re-emergence of polio in areas where it had been eradicated). Emerging risks may be issues that are perceived as potentially significant, at least by some stakeholders or decision-makers, but their probabilities and consequences are not widely understood or appreciated.

The dynamic element of emerging risks is critical, as adaptive systems respond (or learn to respond) to perturbations. Some emerging risks lessen over time while others become worse than anticipated. Typically, the future consequences of emerging risks cannot be predicted in physical or monetary terms, at least not with any satisfactory degree of precision. Thus, conventional approaches to projecting the frequency and severity of losses, including expected values of losses, are ineffective, as are efforts to quantify the precise benefits and costs of preventive measures. For this reason, emerging risks are sometimes called threats, rather than risks. Indeed, it is often difficult to establish causality between the source of the emerging risk and its consequences using standard scientific and technical approaches. As scientific understanding of emerging risks is evolving – sometimes quite rapidly – keeping abreast of emerging risks continues to be a challenge.

Regardless of what managers and policymakers choose to do about emerging risks (including nothing), they are subject to potential criticism that they have over- or under-reacted. It is no overstatement to observe that entire organisations have collapsed due to the mismanagement of emerging risks. For example, the corporate decisions that allowed widespread worker exposure to asbestos ultimately triggered a series of events that caused large companies to enter bankruptcy proceedings. More recently, Lehman Brothers Holdings Inc., the United States-based global financial services firm, collapsed in 2008 following its mismanagement of the risks related to the sub-prime mortgage market.

When organisations are confronted with an emerging risk, analysts, on behalf of managers, strive to develop a **"risk profile"**. A profile may refer to one risk or several related risks. In the case of a single risk, a profile captures several dimensions, qualitative and quantitative, that describe the risk in ways useful to a risk manager who is making initial decisions about what should be done. The relevant dimensions include, for example, the frequency and consequences as basic elements of the risk, the possible sources of the risk

Developing a risk profile

In the case of emerging risks, the main elements of a risk profile are:

- Sources of the risk
- What is known and what is unknown/uncertain about the risk
- Direction of change that the risk may produce
- Magnitude of this potential change
- Estimates of likelihood and severity of harm
- Sensitivity of possible outcomes to various perturbations of prior conditions

A typical risk profile produces a story-like description of the risk, or set of risks, that may affect an organisation, society and/or the environment.

(though these sources may be quite uncertain when a risk is emerging), and other considerations that may be relevant in judging the gravity or acceptability of the risk. The term risk profile is not used in all fields and, in some contexts, the term "risk characterisation" is used instead [Fineberg and Stern, 1996].

A commonly used methodology for developing a risk profile is scenario analysis, which involves creating a series of scenarios (possible futures) describing how the natural-technological-human system might develop. For each scenario, analysts try to identify sets of factors that might jointly cause outcomes that some people might regard as risks. This method is a form of sensitivity analysis to explore key unknowns.

Once a risk profile has been completed, it is often recommended that managers define their **"risk tolerance"**, their "readiness to bear the risk after risk treatment" in order to achieve their objectives [ISO, 2009]. This concept is related to, although not exactly the same as, **"risk acceptability"**, which refers to an informed decision to accept the likelihood/impact of a particular risk. This decision is most often made in reference to risk tolerance levels set out in legislation or outlined in policy.[4] The term "risk tolerance" is more commonly used in business than in government, but the general idea is for managers to be explicit about how risk tolerance determinations are made.[5] For example, in the private sector, companies are increasingly expected to state explicitly the level of financial loss that the organisation is willing to accept in its operations [IRGC, 2009a].

In the public sector, it is more common to use the approach of **"risk ranking"** or relative risk assessment, rather than risk tolerance. This is a broadly-based, principle-driven approach that involves comparing risks, scoring and ordering them using multiple criteria – for example, likelihood and severity, plus risk criteria specific to the kind of risk in question. Risk ranking can be used to prioritise risks for more rigorous, quantitative assessments.

Zero risk is an unattainable goal but views vary as to when a risk, as described in a risk profile, is acceptable. Some investors are more risk averse than others, due to differences in tastes for risk taking, wealth position and other factors. In the political sphere, trade-offs are sometimes made quite explicit but in other cases there may be reluctance to acknowledge that any degree of possible harm (e.g., loss of human life from a drinking water contaminant or damage to the habitat of an endangered species) is acceptable.

Insofar as risk tolerance is defined in public decision-making, it is typically based on some consideration of the preferences of different citizens and groups in society. For example, where views about risk tolerance differ in society, a risk manager may seek a solution

(4) Risk acceptance can occur without risk treatment (actions taken to modify the risk), or during the process of risk treatment, and risks that are accepted are nevertheless subject to monitoring and review [ISO, 2009].
(5) Note that risk tolerance does entail a value judgment on behalf of the organisation and, in some situations, ethical or moral judgments may be required. One step toward a risk tolerance determination is an identification and evaluation of the elements or issues that need to be taken into consideration

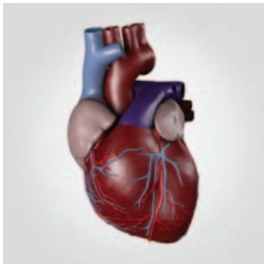
that is tolerable to all of the major stakeholders whose interests are at stake. Yet risk tolerance decisions may sometimes flow from a coherent value system based on concepts such as economic efficiency, justice, equity, security and sustainability. Different value systems may lead to different opinions about risk acceptability.

With these definitions in mind, we turn to a discussion of the causes of emerging risks and how one's overall perspective and thinking with regard to systems and their behaviour can influence one's understanding of how new risks emerge, why they are often unpredictable, and how they can be managed at an early stage.

III The systems perspective

Reductionism proposes that the behaviour of a system can be explained by breaking it down into its component parts, understanding these parts separately, and using this understanding to compose the behaviour of the whole system. For some emerging risks, it may be possible to isolate a cause (or causes) via the use of reductionist thinking, not unlike what has occurred with key advances in physics, chemistry, cell biology and mechanical engineering. Where knowledge is extensive compared to the complexity of the system, this may be highly effective. Drawing on reductionism, a family of problem-solving techniques called "common-cause" or "root-cause" analysis has achieved some success by pinpointing one or more key flaws or dominant factors in the elements of systems that lead to failure or harm. An example of a root cause analysis technique is fault-tree analysis, which is used in all major fields of engineering (including for nuclear power plants) to model and analyse failure processes using graphical representations. For example, an engineer inspecting a detailed technical system may isolate common root causes in hardware or software that contribute to human error or to the improper operation of the system.

As powerful as reductionism has been, it has not been able to fully explain and anticipate some risks that emerge and exhibit systemic character. In contrast, a holistic approach – which proposes that the whole represents more than the sum of its parts and thus that the whole influences how the parts behave – may shed light on these risks, just as holism has fuelled advances in ecology, evolutionary psychology, sociology, economics, and systems engineering. Ecologists observe, for example, that many systems are so complex that it may never be possible to describe all of the relationships between their elements. Moreover, some ecological phenomena cannot be replicated in laboratory conditions and cannot be observed without influencing the larger system under study. Nonetheless, important features of those systems can be examined and may be explained and understood.



In this report, we illustrate that the adoption of a holistic perspective, one that focusses on describing the system as a whole and not as the sum of its parts, can stimulate insights about systemic emerging risks and about how they should be addressed. In a recent safety scandal that damaged one of the most successful companies in the automobile industry, Toyota found that it was not sufficient to test thoroughly the parts of a system that comprise the automobile. As acknowledged by Toyota's chief quality officer at a news conference: the company did not look carefully enough at "how vehicle parts perform as a whole inside the car under different environmental conditions" [Linebaugh et al., 2010].

This **"systems perspective"** refers to a school of thought that is based on the work of systems theorists and may be applied to any type of system, whether biological (the human heart), engineered (the electric power grid), mechanical (transport and logistic systems), ecological (a forest), economic (the stock market), social (a neighbourhood) or geopolitical (the Middle East). When considering parts of a system, system theorists are particularly interested in how the parts relate to each other and their context within the larger system.

(6) Climatic cues are only one of many stresses that are acting simultaneously and in a synergistic manner to disrupt pollination services. Examples of other stresses include: local and regional chemical pollution and invasive species [IRGC, 2009b].

Even more significant is the fact that changes in one system can have ramifications for another system. The science of ecology provides many examples of how a systems perspective is useful in understanding the complexity of interactions between elements of a whole, as well as system-system interactions. For example, climatic cues such as water availability and temperature affect the timing of pollination and the life cycles of pollinators.[6] Climate change could lead to a decline in the frequency and rate of pollination, which, through system-system interactions, could pose environmental risks (loss of plant and animal biodiversity), climate risks (loss of vegetative cover could further influence climate change), and social and economic risks (production of fruit, vegetables, meat and milk could be diminished and many diverse industrial interests harmed, from pharmaceuticals to perfume to bioenergy) [IRGC, 2009b].

In summary, the attribution of cause(s) to the emergence of risks should be informed by both reductionist and holistic inquiries. While a single dominant cause may sometimes explain an emerging risk, multiple interacting factors are quite common and, therefore, professionals responsible for anticipating the emergence of risks can benefit from a systems perspective.

IV Recognising complexity [7]

A systems perspective is especially relevant when considering complex systems, and it is from complex systems that emerging risks (especially systemic ones) often arise.

Complex systems may be defined, scientifically, as systems "composed of many parts that interact with and adapt to each other" [OECD, 2009a]. In most cases, the behaviour of such systems cannot be adequately understood by only studying their component parts. This is because the behaviour of such systems arises through the interactions among those parts. When considering the factors that contribute to the emergence of risks, a discussion of the role of complexity and the traits of complex systems is a useful place to start because complexity can encompass, or at least strongly influence, many of these factors – complexity can be, in many cases, part of the background conditions, or context, within which these factors operate.

The behaviour of complex systems may involve chance-like variation and is therefore often unpredictable and hard to control (in contrast, complicated systems may have numerous components, but these components will always interact in a predictable way, making them much more controllable) [Helbing, 2009]. Complex adaptive systems (CAS) are of particular relevance: they are special cases of complex systems with the capacity to change and learn from experience. When a CAS is perturbed, it tries to adapt. If the system fails to adapt, this may undermine its resilience and sustainability, potentially resulting in collapse (or a flip to a new equilibrium). Examples include ecosystems, ant colonies, the immune system and political parties. Control in a CAS tends to be dispersed rather than centralised, and overall system behaviour is influenced by competition and/or cooperation among agents or system components. Since system responses to perturbations are somewhat unpredictable, the future of a CAS is inherently uncertain. On the other hand, the outlook for complex non-adaptive systems is not particularly promising.

The following traits, common to many complex systems, are relevant to emerging risks. They have the effect of *increasing the unpredictability* of the system's future behaviour and, as a result, risk anticipation becomes more difficult.

- **Emergence:** outcomes that emerge from the system are novel, meaning that they cannot be explained or predicted from the properties of particular system components or what these components do on their own. Flocking behaviour is an emergent property of a group of birds that could not be predicted from complete knowledge about any single bird. The stock market exemplifies emergence on a much larger scale, creating novel market rules, valuations, bubbles and crashes, which are quite unpredictable and not guided or controlled by any one centralised actor, but rather by thousands or millions of self-interested actors.

- **Non-linearity (disproportional causation):** causes and effects are not simply proportional to each other, and can lead to unexpected outcomes (small changes sometimes cause big effects, while big changes sometimes cause little effect whatsoever). Non-linearity is also a reason why the behaviour of complex systems often cannot be predicted based only on an understanding of the behaviours of the system's component parts.
- **Inertia:** Complex systems may exhibit time lags of varying and often indeterminate length between a given perturbation and the system's behavioural response.
- **Threshold behaviour:** Phase transitions occur abruptly as the system crosses a critical threshold ("tipping point") and flips from one state to another. Such flips involve a substantial reorganisation of the system's internal relationships and may involve regime shifts to new equilibria. Examples include the sudden collapse of a fishery, the point where an infectious disease reaches epidemic

(7) Readers with a particular interest in complex systems may wish to consult the paper prepared for IRGC by Prof. Dirk Helbing on systemic risks in society and economics, available online at http://irgc.org/IMG/pdf/Systemic_Risks_in_Society_and_Economics_Helbing.pdf .

proportions, or the transition from free traffic flow to stop-and-go waves or other kinds of congestion. Phase transitions may not be completely unpredictable. Early warning signs for these critical transitions often exist and many different kinds of systems display a phenomenon known as “critical fluctuations” – where they show larger and more frequent perturbations. Furthermore, some systems display a phenomenon called “critical slowing down”, where systems become progressively slower when recovering from perturbations as they approach the critical point [Scheffer et al., 2009].

- **Hysteresis and Path Dependency:** When a system with hysteresis moves to a new state as a result of a stimulus or perturbation, it does not return to its initial state along the same path when the stimulus or perturbation is removed. For example, when a piece of iron is brought into a magnetic field, it retains some magnetization even once the field is removed. The system is thus said to have memory and exhibit path dependency, meaning that its state at any particular time depends on the path the system followed – the order of past events can affect the order of subsequent events and movement along that path is not reversible. A return to a previous state may be impossible. If it is possible, the system is likely to return via a path different from the one it followed previously. Physical, biological and socio-economic systems can all exhibit hysteresis and path dependency. A socio-economic example is the unemployment rate, where a short-term rise tends to persist long after the perturbation (e.g., a recession) has ended.

The above characteristics of complex systems demonstrate why it is difficult for risk managers to anticipate system behaviour or to attempt any control of it. However, IRGC believes that an understanding of these key traits can nevertheless inform and improve risk governance for the better. Furthermore, other traits common to complex systems may act *to make risk emergence less likely*. Adaptability and self-organisation are examples of such traits.

- **Adaptability** means that the independent components that form the complex system can interact and change their behaviour in response to changed external conditions.
- **Self-organisation** means that this adaptation occurs autonomously. This confers on the system a coping capacity, allowing it to withstand some perturbations, which could otherwise be destabilising. Additionally, self-organisation can lead to increased robustness and resource efficiency in the complex system [Helbing, 2008], which can be utilised to reduce the likelihood that risks will emerge.

On the one hand, adaptability and self-organisation can result in the effective absorption by the system of any changes imposed by risk managers, making it more difficult for them to achieve their goals. On the other hand, if risk managers understand how these traits work and recognise their presence, they may be able to use adaptability and self-organisation to their advantage and reach their desired outcomes more naturally and without large degrees of external pressure or concerted actions. This is a matter of suitably designing or influencing the interactions of the system components. For example, instead of specifying exactly what each system element should do, centralised safety regulators may set bounds on actions in the system (“rules of the game”). The flexibility that bounds provide allows for adaptive system behaviours that curtail risk. In the transportation sector, relaxing the reliance on centralised traffic control permits a larger degree of flexible adaptation to local traffic conditions, with large benefits for both drivers and pedestrians [Lämmer and Helbing, 2008].

When faced with the unpredictability of complex systems, risk managers should not rely entirely upon anticipation and prevention. Investments in mitigation and adaptation are also crucial. While it is difficult for businesses and politicians to admit the inevitability of new risks, the admission is necessary to set the stage for coordinated plans of mitigation, recovery adjustment and adaptation. A first step for risk managers is to examine the system closely to determine whether or not it is “complex” (in the scientific sense). If this is the case, then the next step is to determine which of the common traits described above could apply, and therefore, what actions could be most effective.

This background information – this context of systems complexity – should be kept in mind as we move on to examine some of the generic factors that can contribute to risk emergence.

V Why risks emerge: contributing factors to fertile ground

In order to understand why risks emerge, a useful metaphor may be that of a plant emerging from fertile ground. Just as there are a key set of factors that contribute to soil fertility and thus increase the probability that a plant will emerge if a seed is sown (factors such as nutrient and mineral content, pH, soil structure, good drainage and micro-organism content), so too are there key factors that contribute to making "fertile ground" from which risks can emerge. There may (or may not) be a single dominant seed that gives rise to the risk. Instead, there are often multiple contributing factors in the growth process. It is these contributing factors, their attributes and their relevance for risk anticipation, assessment and management that are the focus of this report.

Contributing factors can operate in two directions, either to amplify or to attenuate the likelihood and/or severity of the emerging risk and its consequences.

Some contributing factors work in a linear fashion, either amplifying or attenuating the risk in an additive or subtractive way; others may operate in a non-linear fashion, for example synergistically, where even a small change in a factor may generate a powerful, multiplicative effect on the emerging risk. In a simple example, many drugs can have synergistic effects: consuming a moderate amount of alcohol on its own can have a mild sedative effect, as can consuming a sleeping pill. In most people, neither poses a particular health risk. However, as both drugs are depressants, consuming the two together can have much stronger effects than either alone, to the point that the central nervous system can be slowed enough to cause a loss of consciousness, coma or even death. Such non-linear

A theory of causation

A silo-based approach consisting of tackling specific contributing factors to an emerging risk in isolation is unlikely to provide a workable basis for sound risk governance practices. A particular risk outcome – for instance, the catastrophic failure of the global food system – might emerge along a large number of different pathways, but the sets of factors producing this outcome could be very different along each pathway.[8]

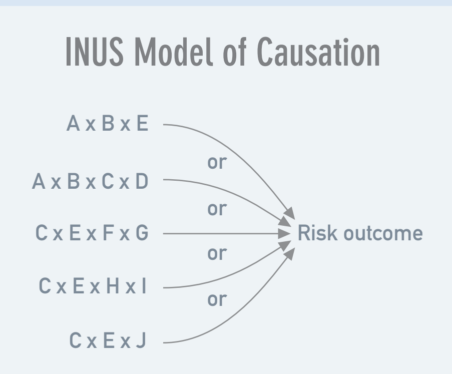


Figure1*

In itself, each set of factors (e.g., AxBxE) would be sufficient to produce a food-system failure, but no one set would be necessary for such an outcome. Yet within each set, the contributing factors (e.g., A, B, C, etc., which could represent factors such as a climate shock, a sharp rise in energy prices, or the outbreak of a devastating pathogen) are each individually necessary but insufficient to produce the food-system failure – each factor within a set is an Insufficient but Necessary part of an Unnecessary but Sufficient (INUS) cause.[9] In other words, within each set, the factors interact multiplicatively, and the absence of one or other factor might prevent the food-system failure from occurring (see Figure 1) [Homer-Dixon, 2009].

* In this diagram, the sign "x" means both that each factor is necessary (the idea of a "logical AND") and that some kind of emergent phenomenon may arise from the interaction of the component factors - in other words, the outcome of the interaction is not the same as simply the sum of the component factors.

(8) When a number of distinct causal routes lead to the same outcome, the outcome (in this example, a food-system failure) can be described as equifinal and the overall system producing the outcome exhibits equifinality.
(9) This is a close interpretation of JL Mackie's account of INUS sets of causes, see JL Mackie, The Cement of the Universe: A Study of Causation, Oxford University Press [1974].

relationships require the use of more sophisticated forecasting algorithms than simple extrapolation in order to predict outcomes, with such predictions being only probabilistic rather than deterministic [OECD, 2009a].

Among the contributing factors, there are two dimensions worth noting, as these can impact upon the actions, or lack of action, taken by decision-makers.

First, there is the **controllability dimension**: some contributing factors may be, under certain circumstances and to varying extents, controllable by risk managers. The phrase “controllable” implies that managers could take steps to influence the contributing factor, even if the factor is not controlled completely by the manager. Faced with a scientific unknown, for example, a manager could increase research activity in the hopes of reducing uncertainties. In contrast, other contributing factors will remain “uncontrollable”; outside the control of the risk manager and thus acting as an external constraint on the impacts of the manager’s actions. The changes in climate as a result of anthropogenic greenhouse gas emissions will occur gradually over a long time-period, due to greenhouse gases already released into the atmosphere. Even a complete halt of future emissions will not prevent some changes in climate over the coming centuries. This may be convenient or inconvenient for policymaking, but risk managers can only acknowledge the fact and adapt policies appropriately (barring some breakthrough in mankind’s ability to remove such gases from the atmosphere in a safe, cost-effective manner). Similarly, risks brought about by demographic change, such as aging of the population, are largely uncontrollable by most actors, but may be influenced (with some degree of controllability), by governments through their social or health policies.

Second, there is the **psychological or cognitive dimension**: decision-makers may underestimate the likelihood of a new risk emerging, leading them to neglect it and be surprised and overwhelmed when

the risk and its consequences become apparent. On the other hand, when the risk is salient, dreadful, and potentially catastrophic in nature, decision-makers may have a tendency to overreact. Errors of human reasoning routinely occur due to the heuristics and cognitive biases that affect our underlying mental processes, and these heuristics and biases can affect how some of the contributing factors outlined in this report are perceived or dealt with by decision-makers. For example, people tend to be bad at estimating probabilities, both of risks and more generally. They fall prey to an inherent over-optimism (optimism bias), are misled by specific details (the conjunction fallacy), by past experiences (the availability bias), or distracted by irrelevant information (the anchoring effect). For risks of large scale or scope and that could affect many people, such as climate change-related risks, people have a tendency not to increase their willingness to act or to pay in a manner proportional to the risk and its consequences (scope neglect), and they feel less pressure and responsibility to act to mitigate the risk because they are part of a large group (bystander apathy). Prior beliefs and interests also affect knowledge gathering and interpretation, as people actively seek evidence that confirms their beliefs, while subjecting disagreeable evidence to greater scrutiny (the confirmation bias).[10] Experts are just as vulnerable to these psychological heuristics and biases as laypeople.

A great deal of literature exists on these heuristics and biases [see for example Kahneman et al., 1982; Slovic, 2000]. While it is not the purview of this report to enter into detail on this subject, it is important to be aware that these behavioural dimensions exist and can contribute to the neglect of emerging risks, or even to the emergence of the risks themselves. For this reason, where heuristics and biases are most relevant, we will draw attention to them in the descriptions of the contributing factors that follow.

(10) For brief explanations of all of the above-mentioned heuristics and biases, see Yudkowsky [2008]

VI Twelve generic contributing factors to fertile ground

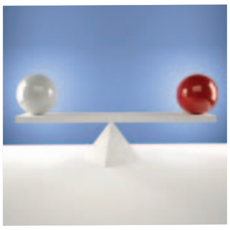
The twelve factors that IRGC discusses below all have the capacity to contribute to creating "fertile ground" from which new risks may emerge. The presence, absence, or direction of influence of these factors thus amplify or attenuate the likelihood and/ or severity of an emerging risk. These factors are generic in the sense that they are prevalent across many domains of nature, science and technology, society and the economy.

The twelve contributing factors

Factor #1: Scientific unknowns
Factor #2: Loss of safety margins
Factor #3: Positive feedback
Factor #4: Varying susceptibilities to risk
Factor #5: Conflicts about interests, values and science
Factor #6: Social dynamics
Factor #7: Technological advances
Factor #8: Temporal complications
Factor #9: Communication
Factor #10: Information asymmetries
Factor #11: Perverse incentives
Factor #12: Malicious motives and acts

All of the factors will not apply to all risks. The relevance of each factor needs to be considered in conjunction with subject-specific knowledge about an emerging risk. For example, complex and interdependent infrastructure networks (i.e., factors #2 and #3) may be less relevant in developing than developed countries while a large disparity between rich and poor (especially the presence of mass poverty) may create more susceptibility to some risks in developing countries (i.e., factor #4).

Additionally, not all of the factors described here are exclusively relevant to emerging risks – some are relevant to all risks, but they may be particularly important in creating conditions conducive to the emergence of the kind of systemic, uncertain or underappreciated risks that are the focus of this report.



Although the report treats the emergence of risks as a negative phenomenon, we do not intend to deprecate the importance of benefits, or the necessity of risk taking in society. Indeed, one of the central challenges in responding to emerging risks is how to achieve a wise balance between the opportunity for benefit and the downside possibilities. Those benefits may be tangible or intangible, reflect economic or ecological progress, be related to physical or mental health, and apply to the welfare of current or future generations. In effect, there is a duality of risk and benefit, with the same phenomenon being a risk or a benefit, depending on the decision context faced by the manager and his or her appetite for risk. Therefore, we note that the factors described here are not necessarily negative, for some of them may also have the capacity to foster the emergence of unforeseen benefits.

Factor #1: Scientific unknowns

Summary: Dealing with emerging risks almost inevitably requires dealing with scientific unknowns. These unknowns (whether tractable or intractable) contribute to risks being unanticipated, unnoticed, and over- or under-estimated.

Some of the first things that a risk manager must try to understand are: What is the risk? What are the probabilities that the risk will occur? How might the risk develop? Unfortunately, when risks arise from complex systems, especially adaptive ones, reliable scientific knowledge is often in short supply, making these questions difficult to answer with acceptable degrees of certainty. Even though vast amounts of information are available about the individual companies and governments that comprise the global economy, errors in predicting the overall performance of the global economy are widespread. What is unknown may seem greater than what is known, and what we think we know may in fact be erroneous or oversimplified!

We use the term "scientific unknowns" here in a broad manner to incorporate both "known unknowns" and "unknown unknowns". The known unknowns are tantamount to uncertainties, where the current state of knowledge does not allow for the precise quantification or description of the likelihood, magnitude or even nature of potential adverse effects. The unknown unknowns are where even less (or no) knowledge is available, making quantification and description of risk impossible. Scientific unknowns can affect the estimation of the likelihood or severity of an emerging risk in a variety of ways: some unknowns will be of much greater importance than others, and thus have greater potential to amplify or attenuate emerging risks.

As risks emerge, a distinction can be drawn between unknowns that are within the control of the risk manager (tractable unknowns) and unknowns that are outside the control of the risk manager (intractable unknowns).[11] Unknowns are tractable when a risk manager, with a high degree of confidence, can expect that targeted research activity (e.g., experiments, data collection, and/or model building) can clarify the unknown or at least bound the possibilities within a useful range. Efforts to decrease tractable unknowns via the gathering of more scientific evidence can certainly aid in the identification and assessment of emerging risks. However, care must be taken to avoid confirmation bias and not to let prior beliefs dominate research efforts. People's instinctive desire to seek out evidence that confirms their prior beliefs or is in accord with their interests could lead to the selective gathering or subjective interpretation of scientific knowledge [Yudkowsky, 2008]. While scientific knowledge and processes are often assumed to be objective and value-free, the fact that science is carried out by human beings means that the potential for cognitive biases can never be completely dismissed.

Another possible difficulty encountered in situations of uncertainty is that the expert opinions and scientific advice gathered will vary. However, there are methods (for example, the Cooke method of expert elicitation [Aspinall, 2010]) that can be used to help decision-makers reconcile the different information they receive from different experts and quantify the key uncertainties. Taking advantage of advances in computer simulation technologies, approaches have also been developed that can aid decision-makers in choosing a risk management strategy in the face of uncertainty. Robust Decision Making (RDM), a tool developed by the non-profit RAND Corporation, is one such approach. RDM entails the use of computer software to generate a large portfolio of possible future scenarios and then, using different realistic initial conditions, test potential risk management strategies against these possible scenarios, to identify strategies that are "robust" – i.e., that perform well across a wide range of possible scenarios. The idea is to combine "the best capabilities of humans and computers to address decision problems under conditions of deep uncertainty" [Lempert et al., 2003].

Intractable unknowns are those that the manager cannot expect to resolve in the time frame that is necessary to inform significant decisions about the emerging risk. For example, it may be impossible to forecast and anticipate the potential catastrophic economic consequences of rapid global climate change [Weitzman, 2009]. An intractable unknown is not necessarily unknowable – though it may be – but it typically requires such a fundamental breakthrough in theory and/or long-term testing that it is, as a practical matter, unknowable for the purposes of making decisions at the early stages of risk emergence. For example, the current state of the science of space weather is plagued by intractable unknowns, which makes estimating the probability of occurrence of solar storms (which may affect satellite communications and electricity grids) largely impossible for the foreseeable future.

Success or failure in the anticipation, assessment and management of emerging risks may hinge on whether risk managers can identify the tractable unknowns, and mobilise scientific resources to resolve them in a timely manner.

(11) Risk analysts sometimes also use the terms aleatory and epistemic uncertainty. Aleatory uncertainty (similar to what we call intractable unknowns) occurs because of natural, unpredictable variation in a system and cannot be decreased through scientific research, while epistemic uncertainty (similar to what we call tractable unknowns) can be reduced through scientific research efforts [IRGC, 2005: 28].

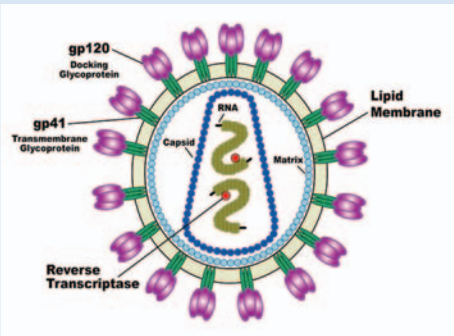
Even if risk managers recognise some unknowns as effectively intractable, they are not helpless, but their thinking about management options may need to shift from anticipation and prevention to mitigation and adaptation – devoting some resources to targeted research is still useful, as this can help to identify prevention and mitigation options. For example, anticipating when and where a solar storm will occur and how large it will be is a practically impossible task because current models are not able to give more than a few hours of warning of a specific solar event [Cole, 2003], and some solar storms may travel so quickly to Earth that virtually no advance warning is possible. Risk management for critical infrastructures at risk of damage from solar storms (especially in vulnerable regions near Earth's magnetic poles) must therefore

HIV/AIDS – A case in which tractable scientific unknowns were rapidly solved

The AIDS pandemic remains an urgent problem for public health, especially in Sub-Saharan Africa. Although it can no longer be considered an "emerging risk", the early stages of the pandemic and the reactions of decision-makers and risk mangers can provide potential lessons relevant to future risks.

When it was first diagnosed in the United States (US) in 1981, there were a whole host of scientific unknowns surrounding the disease that would later come to be known as HIV/AIDS. Most important, it was unknown what was causing the disease and how it was spreading from one person to another. At a time when many people no longer believed that epidemic viruses posed a threat to developed countries and that there were no retroviruses that infected humans, numerous other potential causes were suggested for this novel disease, from fungi to chemicals and even autoimmunity to white blood cells [Gallo and Montagnier, 2003]. Fortunately, some researchers nevertheless believed that the clues suggested a retrovirus as the causal agent of the disease and began to search for such a virus in patients.

In the meantime, from what was known of the most at risk groups in society (injecting drug users, haemophiliacs and homosexual men), the medical and public health communities quickly deduced likely transmission routes and made prevention recommendations to try to slow the spread of the disease – for example, safer sex advice for homosexual men and needle exchange programmes [Kanabus and Fredriksson, 2010]. A key reassuring fact was that acts such as hugging and kissing did not transmit the virus (and thus that more severe responses, such as quarantine, were not necessary).



The structure of HIV

In 1983, doctors at the Pasteur Institute in France announced that they had isolated the retrovirus causing what was now known as Acquired Immune Deficiency Syndrome (AIDS). In 1984, a team of scientists in the US confirmed the discovery of this virus, which came to be called the Human Immunodeficiency Virus 1 (HIV-1). Rapid advances then followed, as scientific unknowns surrounding the disease began to be solved: the genome of HIV-1 was sequenced, its genes and proteins were defined, modes of transmission clarified, and more. The pace of research over the period 1982-85 has been considered the fastest in medical history [Gallo, 2002].

Solving key scientific unknowns allowed for the development and broad use of blood tests for HIV in 1985 (which immediately reduced the risks of transmission via blood transfusions to almost zero in developed countries) as well as anti-HIV drugs and triple-drug therapies, which have prolonged the life-span and improved the quality of life for many patients [Montagnier, 2002].

rely on mitigation strategies, such as building resilience into power grids by coupling systems loosely so as to stop cascading failures (see p.23), or installing devices to block the flow of geo-magnetically induced currents that can destroy electricity transformers.[12]

It is fruitful to draw a distinction between tractable and intractable unknowns, or what some call uncertainty and ignorance. The time boundary between them is not fixed – risk managers may find it difficult to discern, as risks are emerging, which unknowns are tractable and which are not. Under these conditions, it is instructive for risk managers to invest in a portfolio of measures. Some activities may seek to understand, anticipate and prevent the emerging risk while other activities may focus on how to mitigate the adverse consequences of the risk or adapt to the risk.

Climate change is currently being addressed through such a portfolio of measures. One of the key science-policy questions in the United States (US), for example, is how much of the national climate research and development budget – the largest in the world – should be devoted to basic climate science versus how much should be targeted at creative strategies of adaptation to climate change. The international community, especially those concerned for the welfare of people living in coastal regions (including those living in island nations), is devoting increasing attention to the development of adaptation plans for climate change.

This distinction between tractable and intractable unknowns is useful when unknowns have been identified, but what about the “unknown unknowns”? Due to the poorly-understood dynamics of complex systems, there may be significant unknowns of which we are not yet aware. Under such circumstances, risk managers may not even know what questions to ask and may be, in a sense, ignorant of their own ignorance. In this case, early warning systems can play a critical role in the anticipation and identification of emerging risks or of factors that could influence emerging risks.

> When dealing with unknowns, it is important to identify if and how knowledge can actually be usefully developed in the decision-making time frame.

However, risk managers need to appreciate the challenge in garnering insight from any warning system: that of distinguishing a genuine signal from the normal (random) variation in data produced by the system. Good warning systems produce few false negatives and few false positives but risk managers need to have protocols in place for trying to identify both types of errors and for dealing with these unwanted outcomes of useful warning systems [see IRGC, 2009a: 12].

In summary, the risk profile for an emerging risk should include not just what is known, but also the key scientific unknowns, including an assessment of how intractable those unknowns are likely to be.

Scientific unknowns related to sea level rise and its consequences

“There is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate” [IPCC, 2007]. However, there are significant scientific unknowns surrounding the issue of sea level rise, related to both how much and how quickly sea level will rise, as well as what the human and environmental impacts will be. The difficulties these unknowns create for decision-makers could lead to emerging risks being amplified.

The timing and magnitude of future sea level rise have been studied extensively, but the results of studies vary greatly depending on the assumptions made and the variables included in models: published projections for maximum average sea level rise by 2100 range anywhere from 59 centimetres [IPCC, 2007] to five metres [Dasgupta et al., 2007]. Accurate measurements of projected sea level rise rely on factors that, at present, resist

(12) See the case study ‘Severe space weather: Solar storms’, available online at http://irgc.org/Phase-1-case-studies-and.html

precise quantification. For example, the trajectory of global greenhouse gas emissions and associated rates of warming are uncertain and depend on the type (and success) of mitigation action taken. Plus, there are scientific unknowns regarding present-day glacier volume and the processes involved in the discharge from ice sheets.

Given that the consequences for human settlements and ecosystems depend largely on the timing and severity of sea level rise, here, too, the unknowns are many. In terms of societal impacts, some big questions are: how many people will be displaced and where will they go? How will food production be affected? What sort of economic losses will be suffered by affected regions? In terms of physical impacts, it is unknown how ocean circulation will be affected by decreasing salinity (caused by injections of fresh water from melting ice and increased river flows), how much land will be flooded, eroded or permanently submerged, and how much biodiversity will be lost or threatened by changing coastal habitats. Such uncertainties severely complicate the task of risk management, for it is difficult to devise efficient adaptation strategies if, for example, you do not know how high to build a levee or in what time frame coastal populations must be relocated.

Some of these key unknowns are, to a certain extent, intractable – although further research may decrease uncertainties, the complexity of the systems involved means that uncertainties will probably never be eliminated altogether. In addition to making it harder to devise risk management strategies, these unknowns also provide an excuse not to act, or to delay action. In the case of climate change and sea level rise, delaying action has the potential to increase not only the vulnerability of coastal populations, but also the scale of the problem (if warming continues unabated sea level could rise more than if temperatures are stabilised through mitigation). Where decisions are made, it is almost certain that plans will have to be adaptable and be updated as unknowns are reduced over time. Failure to do this could also amplify the consequences of sea level rise.

Factor #2: Loss of safety margins

Summary: The level of connectivity in many of today's social and technical systems is greater than in the past and the interconnections are increasing. The pace at which these systems operate is becoming faster and many are operating under higher levels of stress. This can lead to tight-coupling of components within systems and to loss of safety margins – a loss of slack or buffering capacity that leaves systems more vulnerable to disruption and thus increases the likelihood that new risks will emerge.

Increasing interconnectedness is evident in today's globalised world. Greater (and faster) connectivity are appealing because they can boost communication, economic production and societal innovation. The connectivity of social systems allows people to exchange experiences and knowledge on an international scale, which can act as an important attenuator of risk. However, as systems become more interdependent, faster and more complex, they may also become more tightly-coupled, where the links between the components in the system are very short, meaning that each component can have an almost immediate and major impact on one or more other components in the system [see Perrow, 1999]. This tight coupling is synonymous with a loss of safety margins in a system, which leaves the system more vulnerable to surprises – even a small mechanical failure or accident can have large consequences, perhaps even leading to a system breakdown [Homer-Dixon, 2006].

Tight coupling and corresponding loss of safety margins are features that characterise many emerging risks, whether in the context of financial, environmental, or technological systems. Policy responses to these emerging risks, too, must operate in a context of high and increasing connectivity, creating an environment where the amplification of emerging risks could occur if interventions to mitigate one risk inadvertently

Figure 2: Relationship between system stress and risk, holding system coping capacity constant

exacerbate others in unforeseeable ways by reducing safety margins. For example, one of the aims of promoting biofuel production is to mitigate risks related to energy security by decreasing dependence on imported petroleum products. However, production of first generation biofuels uses feedstocks such as maize and cassava as well as taking up a lot of land previously devoted to agricultural production for food. It is argued that biofuel production thus inadvertently creates new risks to food security by increasing potential food shortages and market price instability.

A system's safety margin can be understood as its buffering capacity or slack. But perhaps the most useful way to grasp the concept is to compare the stress a system is exposed to with its coping capacity. Once increasing stress exceeds the coping capacity, the system has lost its safety margin and enters a state of overload, which can precipitate a breakdown or other kind of non-linear shift in behaviour (see Figure 2).

There are two key situations that can arise in coupled systems, both of which may result in the emergence of systemic risks.

First, there is an increased risk of unanticipated interactions occurring among previously separated system components (or even among previously separated whole systems [see Vespignani, 2010]). Thus, if two or more failures occur independently, affecting different system components, these failures may interact in an unexpected way, resulting in an unforeseeable, undesirable outcome.

> Analysis of what can be done to increase system resilience can lead to improved risk prevention.

Second, there is an increased risk of cascading failures, where a failure of one component in a system can cause failures or other disturbances in other components. The more tightly the components in the system are connected, the faster and further a shock or failure can propagate throughout the system.

Illustrations of cascading effects abound: the failure of one major financial institution can cause others to fail; one malfunction in an electrical system can trigger massive widespread blackouts; or when the leader of a political party suffers a popularity setback, the adverse effects can extend to the entire party. An ecological example is that of the collapse of the Barents Sea capelin fishery in 1986. In this case, a trophic cascade[13] occurred where a failure at one level of the food chain led to failures at other levels and resulted in a collapsed ecosystem – fishing and heavy predation depleted capelin stocks, which themselves were prey for herring, cod, marine mammals and birds [Hamre, 2003; IRGC, 2009a: 70].

Fortunately, risk managers have several options to minimise undesirable outcomes that can result from tight coupling and the loss of safety margins. In some systems, firewalls can be added to limit the spread of damages between components (e.g., they are used to protect electrical systems or to defend computer systems against malicious intrusion). Building system structures with more redundancy and resilience (where each component in the system has not only the ability to draw on other components for support, but also, crucially, a degree of self-sufficiency to fall back on in case of emergency) can limit cascading effects. However, specific incentives are often needed to encourage these measures, which may be costly to put in place and provide no benefit except in case of emergency [Homer-Dixon, 2006]. Making investments such as these can be problematic as it involves resisting pressure from shareholders or tax-payers to reduce what is seen as unnecessary spending – such pressures often lead organisations to reduce their safety margins to dangerously low levels.

(13) "Trophic level" refers to the positions occupied by organisms in the food chain.

Interconnectedness in Megacities

Megacities, defined as urban agglomerations with more than 10 million inhabitants, have emerged as the "urban phenomenon of the 21st century" [Globescan, 2007]. Being extreme products of the ongoing and powerful trend of global urbanisation, megacities are foci for emerging opportunities and emerging risks, with the capacity to display both great resilience and great vulnerability – both traits which relate to the high degree of interconnectedness and interdependencies.

Complexity is created by the sheer number of interactions between demographic, social, political, economic, and ecological processes and systems that are necessary for the day-to-day functioning of the megacity. Infrastructure networks (electricity, water, security, healthcare) are required for the functioning of economic and social systems, and vice-versa [Butsch et al., 2009]. Such a high level of interconnectedness can make megacities (and their surroundings) vulnerable to cascading failures.

Governance structures in megacities need to balance the needs of the city with the needs of the surrounding metropolitan areas. Sheer size may mean that a centralised governance structure will need to adapt to become more decentralised in order to better manage the number and spread of complex system interactions [Globescan, 2007]. The interconnectedness of some systems such as infrastructure and environment can occur on a larger spatial scale (for example, human construction upstream on a river could affect the ecosystems far downstream), i.e. decision-making that goes beyond local interests may be more appropriate to attenuate the likelihood of new risks emerging [Jones, 2000]. Finding a balanced governance approach that can effectively deal with scale, interconnectedness and the resulting complexity of systems in megacities is a formidable challenge.

Factor #3: Positive feedback

Summary: Systems exhibiting positive feedback react by amplifying a change or perturbation that affects them. Positive feedback tends to be destabilising and can thus amplify the likelihood or consequences of an emerging risk.

A system exhibits positive feedback when, in response to a perturbation, the system reacts in such a way that the original perturbation is amplified. A perturbation that is small initially can therefore grow to become so large as to destabilise the whole system. In this context, the term "positive" does not refer to the desirability of the outcome, only to the direction of change (amplification of the perturbation). Because positive feedback tends to be destabilising, it can potentially increase the likelihood or consequences of the emergence of a new, systemic risk. In contrast, negative feedback is fundamentally stabilising as it counteracts the initial change. For example, many systems in the human body use negative feedback to maintain stability in the face of external changes. If external temperatures are very high, the body counteracts the increase in temperature by sweating, which causes heat loss by evaporative cooling in order to maintain a stable, internal body temperature.

Positive feedback occurs in both natural and social systems. With regard to climate change, for example, various positive feedback dynamics within the carbon cycle are well known. The warming of the atmosphere that is occurring due to increased anthropogenic emissions of carbon dioxide and other greenhouse gases is causing (among other things) permafrost melt and tropical forest dieback. Melting permafrost releases

If positive feedback dominates within a system, this may require the implementation of additional safety features to limit amplification effects.

trapped methane, which is a powerful greenhouse gas, and tropical forest dieback reduces the strength of an important carbon sink, which results in less carbon dioxide uptake from the atmosphere – both of these processes further amplify global warming and are thus instances of positive feedback [Frame and Allen, 2008].

A financial panic, or stock market collapse, is a classic example of positive feedback within a social system. In this case, if some market actors become worried and sell stocks, this behaviour makes others more afraid, and they sell, too. As fears are further amplified, panic selling ensues, resulting in plummeting prices and financial losses. Because of the high degree of connectivity in today's financial markets (allowing for fast communication and transactions), positive feedback can cause a crisis to spread quickly, thus greatly amplifying the financial consequences [Homer-Dixon, 2006].

Although, as the previous example demonstrates, the occurrence of positive feedback is related to the level of connectivity in a system – in that a more connected system offers more possibilities for feedback, both positive and negative – powerful positive feedback dynamics can nevertheless occur in relatively simple systems. For this reason, risk managers should specifically look for the presence of feedback, and not simply at connectivity. Sharp flips of system behaviour, or disproportionality of cause and effect more generally, are both strong indicators that positive feedback dynamics may be operating (see 'Recognising complexity', p.14).

The presence of feedback in systems is common and does not necessarily lead to systemic risks or even a negative outcome. On the contrary, both positive and negative feedback can be essential for the proper functioning of systems. It is therefore important for analysts to identify feedback dynamics (both positive and negative) that are occurring in a system, and assess their function and their relative balance (if either positive or negative dominate) in order to better anticipate when risks might emerge or be amplified.

Arctic warming and the importance of ice-albedo feedback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Ice has played a central role in the variation of Earth's climate over many hundreds of millions of years (i.e., transitions from ice ages to glacials and interglacials). This role is explained by the ice-albedo effect. Earth's albedo is a measure of how strongly its surface reflects sunlight back into space. The higher the albedo, the more sunlight is reflected, which has a cooling effect on climate. Because ice is white, it reflects sunlight and contributes to increasing Earth's albedo.

However, with the current global warming trend driven by increasing greenhouse gas concentrations in the atmosphere, Arctic sea-ice cover has been declining: since satellite monitoring began in 1979, it has been observed that the area of the Arctic covered by ice has been shrinking at an average rate of 8.6% per decade, and in 2007 it hit a record low, having lost 43% of its 1979 area [Kerr, 2007]. This melting of ice lowers albedo, which causes more solar energy to be absorbed – the albedo of open water is ~0.07 compared to that of sea ice, which is > 0.60 [Perovich et al., 2007]. This in turn warms the atmosphere and promotes further melting of ice: a positive feedback.

This positive feedback is thought to be one of the major underlying causes for what is known as "Arctic amplification" – the observed rise in Arctic near-surface air temperatures over the last few decades… a rise that is twice as large as the global average [Screen and Simmonds, 2010]. Studies have found evidence to support this theory. For example, over the time period 1979-2005, one study observed a "pervasive increase in the amount of solar energy deposited in the upper Arctic Ocean and surrounding seas, with maximum values of 4% per year" [Perovich et al., 2007]. A 2010 study, using data with a higher spatial resolution and improved model physics, also found evidence that points to the importance of the ice-albedo feedback. The key findings of this analysis were that increased surface temperatures correlate spatially with changes in sea-ice cover, and that Arctic warming was greatest at the surface, suggesting that changes at the surface (decreased sea ice and snow cover) are the main cause of Arctic amplification [Screen and Simmonds, 2010]. These researchers concluded that “the emergence of strong ice-temperature positive feedbacks increases the likelihood of future rapid Arctic warming and sea-ice decline” [Screen and Simmonds, 2010].

Factor #4: Varying susceptibilities to risk

Summary: The consequences of an emerging risk may be different from one population to another. Geography, genetics, experience and wealth are just some of the possible contextual differences that create varying susceptibilities to risk.

Risk does not affect all individuals or populations in an equal manner. Contextual factors such as geographical location, genetic makeup (biological fitness), resource availability or prior experience all affect susceptibility, which in turn impacts the probability, scale and severity of the risk and its consequences. Neglect of varying (or differential) susceptibilities – or of changing susceptibilities over time – can therefore lead to over- or under-estimation of the emergence and possible impacts of an emerging risk, as well as miscalculation of the projected future development of the risk.

Many weather-induced risks – drought, hurricanes, ice storms – affect only limited parts of the world and a minority of the world’s population. The impacts of climate change will be felt all over the world, but the precise impacts will vary: coastal areas affected by rising sea levels will not be affected equally, depending on local factors such as coastal slope, the built infrastructure, the occurrence of storms and surges and the ability of coastal ecosystems to adapt to sea level changes and storm damage.

> Analysts must not only survey existing variance in risk susceptibility, but remain aware of how susceptibilities can change over time.

Indeed, the same phenomenon that places susceptible people at risk of harm may benefit others. Most people view the melting of the Arctic ice sheet as an event with only adverse consequences, but it has already opened up a summer shipping route north of Russia that can shorten some voyages and will offer some commercial benefits.

Evolution is an ongoing process and is, for example, the natural phenomenon behind the emergence of new viruses and bacteria and the ability of bacteria to mutate and develop resistance to antibiotics. Natural selection, a key mechanism of evolution, explains why some human populations are less susceptible to some diseases than others – for example, some populations living in areas endemic to malaria show greater resistance to the parasite [Fortin et al., 2002]. But the genetic variation that is a driving force of evolution can also create gene variants that predispose individuals to disease. For example, specific gene variants are known to contribute to the causation of obesity, some cancers, and other diseases.

When it comes to risks arising from personal behaviour, psychology also plays a central role. Due to what has been called “optimism bias”, people often see themselves as being less susceptible to risks than others, with this “risk denial” being stronger when people feel they have a degree of control over the hazard (e.g., smoking, alcohol [Sjöberg, 2000]). At the personal level, therefore, perceived variability in susceptibility may not match real variability.

Where there is real variability in susceptibility at the personal level, this is frequently a result of people adapting their behaviour in response to risk as they learn from past experiences. For example, the experienced skier or sailor is less at risk than a beginner, particularly in difficult conditions. In Japan, the knowledge of what to do in case of an earthquake is widely spread in the population. In economic policy, governments have learned over time that free-floating exchange rates are less dangerous to their economies than fixed rates. But people and governments differ in their capacities to respond to risks, whether due to differing resources, traditions or other factors. History suggests that for many risks, it is the low-income households and countries that are both more susceptible and less able to respond.

Thus, as susceptibility varies between different individuals, groups or locations, as it increases or decreases over time as a result of physical changes (e.g., to climate or genetic makeup) or behavioural changes (e.g., via learning or changing norms), the consequences of an emerging risk may be amplified or attenuated and its future trajectory may be altered.

Susceptibility to loss of life and property from earthquakes

In only the first four months of 2010 there were three deadly earthquakes (in Haiti, Chile and Yushu, China), which resulted in the deaths of over 233,000 people. Approximately 230,000 of these were killed in the 12 January, 7.0 magnitude earthquake in Haiti alone.

The susceptibility of populations to suffering losses from earthquakes is highly variable and depends on a number of factors including: geography, population density, construction standards and emergency preparedness. Settlements on or close to tectonically active areas (near the boundaries of the tectonic plates) are most at risk, with most of the world's earthquakes occurring in the circum-Pacific seismic belt – a horseshoe shaped belt stretching around the edges of the Pacific Ocean, known as the Pacific Ring of Fire. Of the settlements located in these geologically active zones, those with higher population densities stand to suffer the greatest losses in the case of an earthquake due to the proximity of people, large buildings and infrastructure. Susceptibility can be greatly decreased, however, if there are strict building codes in place requiring that constructions be able to withstand a large earthquake. Such building codes exist, for example, in California, Japan and Chile.

Emergency preparedness, which is strongly linked to good governance (public sector efficacy, degree of corruption), access to resources and past experience, has perhaps the greatest potential to reduce susceptibility. A comparison of the losses suffered in Haiti and Chile in early 2010 demonstrates this. Measuring 8.8 on the Richter scale, the Chilean earthquake of February 27, 2010 was more than ten times as strong as the quake in Haiti and yet the death toll was substantially lower (approximately 520). Adequately enforced building codes, periodically upgraded to take into account previous earthquake experiences, in combination with earthquake training drills, which are an integral part of child and adult education in Chile, limited the death toll. The presence of effective public sector institutions was necessary for such preparedness (although the government's response has nevertheless been heavily criticised for failure to raise the alarm over an impending tsunami and slowness in distributing essential supplies). Following the earthquake, reconstruction efforts will also be helped by Chile's high standard of governance, and by its resilient economy and dynamic private sector [Kaufmann and Tessada, 2010]. Haiti, by contrast, was much poorer and had very bad governance with little control of corruption. This led to poor building construction, a lack of preparedness and an insufficient response, culminating in huge losses of life and property and necessitating a massive international aid effort.

State of the art technology including risk assessment software and tools can certainly play a part in reducing susceptibility to earthquake risks in developing countries such as Haiti. However, improving preparedness requires more than the simple provision of access to information and technology. Such access is useless if the social and institutional context is insufficient to take advantage of it [Sarewitz, 2010].

Factor #5: Conflicts about interests, values and science

Summary: Public debates about emerging risks seldom witness a clear separation between science, values, and interests. The conflicts that result have the potential to contribute to fertile ground for risk emergence or amplification. For example, emerging risks may be amplified when efforts to assess them and take early management measures encounter opposition on the grounds of contested science or incompatible values.

The management of emerging risks often creates winners and losers, and thus making trade-offs among opposing interests – however distasteful that is – is common, even if managers are reluctant to acknowledge it publicly. As risks emerge and interests are threatened (either by the risks themselves or by the steps advocated to address the risks), managers should expect that the science behind the risk determination will be challenged, and that competing values, interests and priorities may be articulated. The conflicts that result have the potential to amplify emerging risks or even contribute to fertile ground for new risks to emerge.

Where the science related to an emerging risk becomes contested, it will be more difficult to develop an "official" risk profile – or at least one that will be widely accepted by stakeholders. Competing risk profiles have the potential to slow down the governance process, potentially amplifying the emerging risk, since it is unlikely that risk tolerance issues will be addressed and risk management measures devised, as long as there is serious debate over the existence of the alleged hazard or the degree of future vulnerability. In 2001, for example, then-US President George W. Bush decided that the US would not seek Senate ratification of the Kyoto Protocol. As one of the reasons for this decision, Bush cited contested science over the causes and consequences of global climate change [Bush, 2001].

As risks emerge, it may not be apparent where the frontier between the scientific debate and the values debate lies, especially when different stakeholders have different understandings of the science as well as different values and interests. Psychological factors create part of this confusion, as people's values influence their view of the science, with subjective ideas of "good" or "bad" affecting perceived risks and leading to systemic biases (this is known as the affect heuristic). Motivated scepticism (or "disconfirmation bias") can also conflate the boundaries between science, values and interests, leading people to stringently question the science that does not align with their values and interests, but more easily accept the science that does.

IRGC recommends clearly differentiating between the assessment of the science and the assessment of the values involved, and later, the evaluation of the risk acceptability. Depending on the forum in which an emerging risk is discussed, people will tend to emphasise either the affective and value-centric angle, or the more evidence-based, scientific angle. In those forums where evidence and logic are highly valued (e.g., administrative hearings), advocates will frame their positions in scientific terms and thus the science of emerging risks will be contested and defended. But in forums where the importance of values and emotions are accentuated (e.g., legislative committee hearings), advocates can be expected to frame their positions by reference to appealing values, ideologies and emotions.

For important yet routine risks, trade-offs can be addressed with technical tools such as risk-benefit analysis and cost-benefit analysis. Values in decision-making are embedded in the inputs to the technical analysis, with some inputs being quantitative and others more qualitative. Even when risks are highly uncertain, modern methods of cost-benefit analysis can shed light on the economic value of acquiring better information (before making a final decision) as well as promising strategies that are robust under a large number of future scenarios in the risk profile.

In some situations, a conflict of values can be illuminated through a form of multi-criteria decision analysis, where the different decision alternatives are analysed according to their impacts on different yet legitimate objectives (criteria). The trade-offs among criteria may be illuminated, or it may be shown that one alternative is dominant, i.e., better on at least one criterion and at least not inferior with respect to the other criteria. Since formal analyses can sometimes be opaque, it is important that communication of such analyses be effective, and that stakeholders have an opportunity to participate in the design of such analyses. It should be noted that there are some circumstances in which not being explicit about the objectives of different parties may facilitate arriving at an agreement or outcome [Raiffa, 1985].

When emerging risks involve conflicts, efforts should be made to clarify the underlying interests and values of involved parties.

When emerging risks are highly controversial, cost-benefit methods are likely to be ineffective at resolving conflict. In some cases, excessive reliance on such methods can even exacerbate conflicts, especially if sponsors of the analysis are seen as hiding ethical assumptions or key intangible considerations in complex mathematical exercises. In these more challenging cases, cost-benefit methods need to be supplemented by strategies of deliberation that involve the participation of key stakeholders and the public. Deliberative strategies range from small, informal meetings of interest group leaders to high-level commissions with representatives from multiple interest groups as well as experts and laypeople [Fineberg and Stern, 1996; Dietz and Stern, 2008].

There are documented cases where reasoned deliberation has prevented (or overcome) efforts to block a technology or industrial facility. The use of Liquid Natural Gas (LNG) is increasingly encouraged in energy policies to mitigate some of the risks related to climate change and energy security. But conflicts about the siting of LNG terminals often arise as individuals and communities are afraid of potential risks. In this case, interests are opposed, and in many regions of the world the siting of LNG terminals has triggered substantial – and sometimes effective – community opposition. In the Netherlands, however, the government was able to obtain community acceptance of a new LNG terminal through creative use of public participation and local discussion [Xianpei et al., 1988].

Public participation is not a panacea. There are well-documented cases where reasoned efforts at deliberation have failed to achieve community consensus about how emerging risks should be managed. In the US, for example, more than two decades of effort – including a wide range of technical and deliberative exercises – have failed to provide a sustainable solution to the need for permanent disposal of high-level nuclear waste. At the time of writing, the US is reconsidering a multi-year effort to build a permanent nuclear waste repository at Yucca Mountain in Nevada [Garber, 2009; Endres, 2009]. In some cases, badly managed public engagement could contribute to the emergence or amplification of risks. On the whole, the success of deliberative strategies has a lot to do with the nature of the conflict – dialogue driven by unquantifiable, subjective value-based concerns will be very different from dialogue driven by quantifiable, objective interest-based concerns. While stakeholders may, through dialogue, change their perspectives on an issue and come to identify new or modified interests, it is less likely that they will compromise where basic values are concerned, as these are more strongly tied to identity than are interests, which are material in nature.

In summary, risks often emerge or are amplified in a context where contested science and values complicate the identification, prevention and mitigation of risk. While science, values and interests may appear to be conceptually separate, they are entangled (perhaps consciously as well as subconsciously) in the minds and behaviours of some people. When risks emerge amidst strong controversy, they should be addressed by various deliberative as well as analytical mechanisms. For example, public participation, involving laypeople as well as experts and elites, is required by law in some countries when environmental planning decisions are made (e.g., countries that are parties to the United Nations Economic Commission for Europe Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, known as the Aarhus Convention [UNECE, 1998]). When trust in governmental authorities is low, the challenge for emerging risk management will be particularly great [Löfstedt, 2005].

Genetically modified crops in India

With continuing population and consumption growth expected over the next 40 years, increasing demand for food will pose significant risks to global food security. Agriculture will have to be transformed in order to increase yields in a sustainable way, without further degrading the environment or exacerbating climate change. Modern genetic techniques offer a potential way to achieve this via the insertion of genes conferring favourable traits (such as pesticide resistance, larger yields or drought tolerance) on crops [Godfray et al., 2010]. However, there are also potential risks, including contamination of non-genetically modified (GM) crops and potential toxicity of crops (due to the introduced genes which produce toxins against pests).

Gaining public acceptance of GM crops has proved challenging in some regions of the world, and the debate over the potential risks has become highly politicised and polarised due to conflicts of interests and values. In India, the debate began with the introduction of GM cotton in 2002 (which is now grown by 90% of Indian cotton farmers). In terms of concrete interests, the biotechnology industry, in this case the US company Monsanto and its Indian partner MAHYCO-Monsanto Biotech India, was keen to create a large and lucrative market in India. They were supported by leading government scientists who saw opportunities to foster innovation and economic progress in India (including poverty alleviation and improved food security). The interests of the Indian Pesticide Industry were directly in conflict with those of the biotech industry, as it stood to see sales and profits decline. It thus lobbied against the approval of GM seeds. As for the farmers themselves, how GM seeds would affect their interests was initially uncertain – some farmers believed it would lead to greater profits and were favourable towards the technology, while others objected to the high price of seeds and the obligation to keep purchasing them. Large numbers of farmer suicides in India have figured prominently in the GM debate, with the anti-GM movement arguing that indebtedness due to purchases of GM seeds and subsequent crop failures are what led these farmers to suicide [Malone, 2008]. For many anti-GM groups, values played a significant role, too, with anti-globalisation sentiment – discourse focussed on retaining the independence of farmers from huge multinational companies – figuring strongly [Birner et al., 2004].

The above conflicts have led to the contested allegations about farmer suicides (a study by the International Food Policy Research Institute found no evidence to support increased suicide rates since the introduction of GM seeds [Gruère et al., 2008]) and contested science regarding the effectiveness of the technology and its potential adverse impacts. In 2010, renewed debate surrounded the introduction of the GM eggplant "Bt Brinjal" which, despite having the advantage of requiring 5-6 times less pesticide than non-GM brinjal and having been cleared by India's Genetic Engineering Approval Committee, has raised a lot of opposition. Even though the Prime Minister declared that "we should pursue all possible leads that biotechnology provides that might increase our food security" [Bagla, 2010], the government of India eventually decided to take the precautionary approach by putting an indefinite moratorium on Bt Brinjal's commercial release. Contested science, including claims that safety data were incomplete or unacceptable because much of it came from MAHYCO, was cited as one of the main reasons for this decision [The Economic Times, 2010; Bagla, 2010].

Factor #6: Social dynamics

Summary: Social change can lead to potential harm. In other circumstances it can attenuate potential harm. It is therefore important for risk managers to identify, analyse and understand changing social dynamics.

When risks emerge, it is tempting to perceive their causes narrowly as relating to specific agents such as technologies, substances, viruses or human behaviours. As important as these agents are, risk managers should also consider the broader social dynamics that may be acting to amplify or attenuate risks.

Obesity, for example, is a familiar condition that is caused by chronic excess of energy intake relative to expenditure of energy from physical activity. But this definition, though accurate, misses the powerful social dynamics that have contributed to the emergence of the epidemic of obesity around the world (see box p.32).

Societies are continually evolving. As complex systems, they may adapt to new or changing technologies, economic forces, political ideologies, cultural norms, value systems, religious beliefs and more. However, they sometimes fail to adapt.

Globalisation is one trend that has significantly changed the risk landscape in many sectors. Rapid growth of international trade has accelerated the spread of any risk related to traded products, whether it is contaminated food, faulty toys or counterfeit drugs. The ease and speed of international travel has exacerbated the spread of infectious diseases. And the interdependencies in the world's financial systems have security implications for individual investors, companies and even entire nations and regions. One major conduit of globalisation, the internet, has also played a significant role both in the emergence of new risks and in facilitating risk management through the growing popularity of social networks. For example, the use of some social networks may create or amplify privacy risks, but the use of other networks may attenuate risks by helping people to become better informed and thus better able to minimise risks to which they may personally be exposed (e.g., Angie's list for doctors).

Even though globalisation has brought with it many opportunities via improved communications, modernisation, greater economic competition and growth, some argue that the benefits have not been equally shared; that poor countries have been largely left out and that social and economic inequality has risen rather than fallen. Levels of development, poverty and inequality are important social factors with the capacity to contribute to fertile grounds for risks to emerge or amplify. Wealth can obviously be used to develop or purchase advanced technologies and to invest in risk prevention or mitigation – for example, the risks related to counterfeit prescription drugs (see p.43) may be lower in wealthy, developed nations because they have the resources to invest in regular quality checks and vigorous law enforcement. However, it is not just a lack of wealth that can make poorer or less developed communities more vulnerable to emerging risks, but also a lack of education, literacy or social capital. The ability to access and understand information is critical to the ability to identify, assess and manage risks.

> While often not directly controllable, social dynamics may sometimes be influenced in a way that allows for the prevention, mitigation or adaption to emerging risks.

Patterns of immigration around the world have also been a source of emerging risks as well as a response of people to unacceptable risks in their countries of origin. Immigrants offer many social and economic benefits to host countries, but they also create costs and risks for schools, social services and law enforcement institutions. In France, for example, immigration from North Africa following the Second World War both fulfilled the need for more workers, thereby allowing the country to maintain high rates of economic growth, and provided the immigrants themselves with new opportunities and the ability to escape economic, educational or other risks that they faced at home [Messina, 2007]. But this changed from the mid-1970s onwards as, due to slowed economic growth, immigrants began to be perceived as a source of risks (predominantly risks to national values and identity) as much as of opportunities [Freedman, 2004]. Resistance to immigration is a persistent source of social and political conflict and, in extreme conditions, can precipitate discrimination, terrorism, border conflicts and military confrontations.

Some decision-makers, such as those in the mass media and government, have a degree of influence over social dynamics as well as the opportunity and capability to support the establishment of new behavioural norms, which may reverse social trends that could lead to risk emergence. Some of the ways in which this may be achieved include: the implementation of education campaigns (e.g., teaching children about healthy diets to counteract the obesity problem or teaching immigrants the local language and culture to help them better integrate into society), advertising campaigns (e.g., communicating the importance of vaccination and personal hygiene during a flu pandemic), or financial incentives (e.g., offering bonus payments or tax breaks as a way to influence birth rates).

One key consideration related to social dynamics is that people make decisions differently in groups than they do as individuals. Thus, when attempting to influence social dynamics in order to attenuate emerging risks, decision-makers should be aware of the potential impacts of psychological and sociological factors. For example, the likelihood that an individual will act when faced with a potential hazard or emergency is decreased when that individual is part of a group – thus it is less likely that an individual will call the police when witnessing a mugging on the street if there are lots of other witnesses around. Each individual hopes that someone else will act and perceives his own responsibility as diluted by the group, leading to a reduction in pressure to act. This phenomenon is known as "bystander apathy" and it can lead people to be complacent about risks that might affect society as whole. Similarly, it has been shown that people are more likely to make more extreme decisions (whether more risk prone or more risk averse) in groups than as individuals, since the group dynamic makes them less reluctant to accept an extreme position [Lloyds, 2010]. "Pluralistic ignorance", a term which describes how people look to others around them for social clues on how to act, can also lead to a greater acceptance of risk or perpetuate problematic social trends or behavioural norms.

Risk managers need to see social dynamics as important factors to consider and as factors over which

The Obesity Epidemic [14]

The prevalence of overweight and obesity has increased significantly in recent decades. The problem is so severe that many developed countries are now facing what has been called an "obesity epidemic", with obesity rates in the US and Mexico exceeding 30% and those in the United Kingdom (UK), Australia and New Zealand (to name just a few) exceeding 20% [OECD, 2009b]. Developing countries, too, have witnessed a three-fold increase in obesity rates over the past twenty years [Hossain et al., 2007].

While, in most cases, obesity is the result of an excess of caloric intake (a biological phenomenon), changing social dynamics have been one of the major drivers of the obesity epidemic. Lifestyle changes over the course of the 20th century – partly induced by technological advances in industrial machinery, information technology and the popularity of new, passive forms of entertainment such as television and video games – have led to greatly reduced physical activity in leisure time and at work. Demographers also point to urbanisation of the globe's population and urban design, which promotes motor-vehicle use and restricts opportunities for physical activity.

In many cultures, the institution of family has become weaker, leading to changes in eating habits (fewer common meals), while the growing rate of participation of women in the labour force has stimulated an explosion of demand for pre-prepared meals and takeaway foods [James Martin Institute, 2008].

Globalisation, the growth of social networks, interconnectedness and trade has resulted in the spread of "fast food" culture around the globe and increased the availability and variety of processed foods in many countries. The processed and fast food industries have become what amount to institutionalised food pushers through the use of aggressive marketing, advertising and increased portion sizes. Research also shows that obesity may spread through large social networks, person-to-person, almost like an infectious disease, via the creation of new social norms [Christakis and Fowler, 2007].

The level of poverty and development of populations is another factor linked to obesity trends. In developed countries, the lower income or minority groups have the highest rates of obesity and obesity-related diseases, such as type-two diabetes. This phenomenon is most often attributed to education levels (less access to knowledge about the risks of obesity and how to maintain a healthy diet and weight) and the relative cost of healthy foods (processed, energy dense foods are often cheaper than fresh fruits and vegetables) [Drenowski and Darmon, 2005].

The social dynamics behind the obesity epidemic have strong momentum, are complex, and are not easy to unravel and reverse.

(14) A longer, more in-depth illustration of how the twelve contributing factors have played a role in the emergence and amplification of the obesity is available online at http://irgc.org/Phase-1-case-studies-and.html

Natural resource stress and social dynamics

The drive for economic and social development has sometimes led communities to overexploit the natural resources at their disposal. This is evident, for example, in the clearing of the Amazon rainforest for agricultural and farm land, or the depletion and collapse of fisheries as a result of sustained overfishing. The dynamics of development are thus one important aspect of social dynamics that can influence the emergence of new risks and have substantial environmental and social consequences – changing social dynamics, in the absence of good governance, have the potential to lead to increased and unsustainable resource depletion, and the natural resource stress that results can in turn affect social dynamics, even to the point of provoking serious conflict.

Detailed research over the last 20 years on how natural resource stress affects political and social behaviour shows that it hardly ever operates in isolation. Rather, it interacts synergistically with other ecological, institutional, economic, and political variables to produce a broad range of effects – some of which might bear directly on interests at the macro-level of the state (e.g., if the state's main income is derived from natural resource exports, as is sometimes the case with oil), but many of which have repercussions that are felt at the level of individual households and may have enormous implications for human well-being [see, for example, Sachs and Warner, 1997; Collier and Hoeffler, 2005; Ross, 2008]

These latter effects can result from various forms of social dislocation caused by natural resource stress – including widening gaps between rich and poor, weakening of governance, and deeper ethnic cleavages – that in turn make sub-national violence in the form of insurgency, ethnic clashes, rebellion, and urban criminality more likely. The long-running conflict in the Niger Delta region of Nigeria (a conflict based on competition over oil, exploitation of minority ethnic groups and unequal distribution of oil-derived wealth), has fuelled violence between ethnic groups, resulted in the militarisation of the region, caused significant political unrest and environmental damage, and affected Nigeria's economy and oil export capacity [Aaron, 2005; Omeje, 2004].

Evidence of natural resource stress is, therefore, a potentially useful indicator that social dynamics may be changing in such a way as to amplify emerging risks. Indeed, in some cases, the natural resource stress itself – especially where non-renewable or essential resources, such as water, are concerned – can constitute a substantial emerging risk.

they can have some influence. Without accounting for social dynamics, many cascading effects will be neglected while opportunities for prevention, mitigation and adaptation measures will be missed.

Factor #7: Technological advances

Summary: Risk may emerge when technological change is not accompanied by appropriate prior scientific investigations or post-release surveillance of the resulting public health, economic, ecological and societal impacts. Risks are further exacerbated when economic, policy or regulatory frameworks (institutions, structures and processes) are insufficient, yet technological innovation may be unduly retarded if such frameworks are overly stringent.

History suggests that technological advances, while a potent source of prosperity and improved quality of life, can produce unwanted risks, especially when rapid diffusion of technology occurs without adequate ex ante risk assessment or ex post monitoring and surveillance of impacts. Businesses and regulatory institutions have key roles to play in the management of emerging risks from technological innovation.

The energy sector of the global economy, for example, is subject to strong regulatory and financial pressures for commercialisation of new technologies. New drilling techniques, such as horizontal drilling and hydraulic fracturing, are capturing unconventional supplies of natural gas and oil, but questions are being raised about safety, geological and environmental impacts. Carbon capture and sequestration systems are desired at large coal-fired power stations, but the regulatory, safety and liability regimes for permanent geological deep sequestration of carbon are not yet established. The production of first-generation, crop-based biofuels is aiming to reduce global demand for petroleum, but the ramifications for the global food system, water supplies, and land use are driving development of more advanced forms of biofuels. Even some second-generation biofuels, though promising, have ramifications for land use that require coordination with environmental planners. Other forms of renewable energy also pose risks. The global expansion of wind power, on land and off-shore, is occurring faster than the impacts on people and the environment can be fully understood. Proper siting of wind turbines can minimise impacts on quality of life and on wildlife, but careful siting takes time, resources, community participation and expertise.

Regulation is one of the principal tools of risk governance for emerging risks. But it is challenging for regulators to regulate technologies in their developmental phase (before all their potential consequences are known), whilst keeping pace with technological advances in order to minimise risks that may occur.

When regulatory agencies lack the leadership, expertise and resources to do their jobs effectively, errors occur. The errors may be forms of over-regulation, under-regulation or simply inadequate regulation and, when they occur, they can create large financial costs and other adverse impacts on society and the environment.

Investments in regulation are often not particularly attractive to politicians and the public, and thus regulatory agencies are often plagued with insufficient resources and staff. As a result, pioneers of new technologies become frustrated when they cannot obtain permits or other regulatory authorisations. When regulations are established under these conditions, they may reflect gross misunderstandings of the industry, technologies, and risks that are being regulated. And when resources are scarce and public concerns about risk are heightened by the media, regulators may be overly risk averse, which can impede technological innovation and economic development. Alternatively, when cost pressures are particularly severe, regulation, enforcement and compliance may diminish, and risks may consequently be amplified.

> Cooperation between actors involved in technological advancement and regulation must be sought.

Public efforts to identify, anticipate, and regulate new technology-related risks are not easy to finance. Given the many urgent demands on public funds, industry often finds it preferable to finance the activities of scientists and regulators through self-imposed fees rather than by competing for allocation of general tax revenues. For example, regulators of pesticides, prescription drugs, industrial chemicals, fuel additives, and nuclear power plants may be funded, at least in part, by fees on industry. Although such arrangements need to be designed and monitored to eliminate conflict of interest, they have proven to be sustainable methods of financing for crucial regulatory activities that address emerging risks.

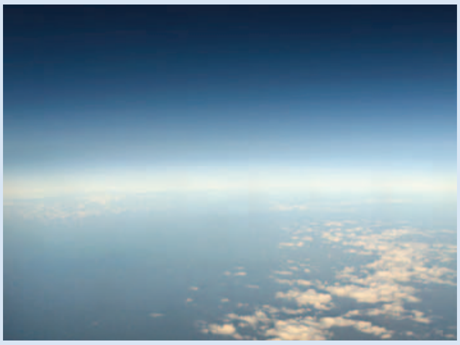
Even when regulators are funded adequately, the quality of their work needs to be scrutinised through peer review and stakeholder participation. When formal assessments of risk, technology and regulatory impacts are conducted, they may be primitive, incomplete, flawed, or biased in one way or another. Common deficiencies include: a lack of early methodological work to set out the appropriate evaluation instruments, incomplete identification of possible risks and scientific uncertainties, over-reliance on models for which the extrapolative validity is unknown, unclear allocations of the burden of proving risk and safety, a failure to consider the welfare of susceptible subpopulations and ecosystems, lack of stakeholder engagement, an ill-considered mix of pre-market assessment and post-market surveillance and a failure to assess the benefits and costs of alternative risk-management measures. The root of these quality problems is often a lack of constructive dialogue and collaboration among regulators, technologists, academic scientists, environmentalists, experts from other agencies and other stakeholders.

Countries around the world differ enormously in the stringency of their requirements to screen for emerging risks through pre-market and post-market safety studies.

As a result, companies often face an inappropriate incentive to "forum shop" by seeking approval of their new technology first in countries with weak regulatory systems and only later, once experience in the initial markets has built confidence, in countries with more stringent regulations. In the long run, however, it may be wiser for risk managers in companies to obtain approval first in those countries with the most globally respected regulatory systems. Approval in these countries helps pave the way for doing business around the world while providing a significant degree of protection against emerging risks.

Regulatory systems for emerging risks related to technological advances are under study. The Organisation for Economic Co-operation and Development (OECD), academic centres, and think tanks around the world have fostered a systematic effort toward better regulation, which includes building more science, economics, flexibility, innovation, and urgency into regulatory structures and processes. Risk managers should be encouraged to learn about the experiences of regulators in other countries, including those who work in different sectors and on different types of emerging risks.

Geo-engineering [15]



Many climate researchers now believe that atmospheric concentrations of carbon dioxide (CO_2) must be stabilised at or below 350 parts per million (ppm) in order to avoid "dangerous climate change" [Monastersky, 2009]. Because concentrations have already surpassed 382 ppm, growing numbers deem it likely that some geo-engineering techniques – defined as "deliberate large-scale intervention in the Earth's climate system in order to moderate global warming" [The Royal Society, 2009] – may be needed to supplement mitigation efforts and keep temperature increases to a minimum. However, the potential use of geo-engineering techniques is controversial both due to fears that (unforeseen) negative side-effects could be significant, and that providing a technical fix could take away the impetus to urgently reduce global emissions.

Geo-engineering methods include techniques for removing CO_2 from the atmosphere and techniques for solar radiation management, which reflect some of the sun's light and heat back into space [The Royal Society, 2009]. As promising as some of these technologies may seem, however, much more research needs to be done in order to establish how well they will work and what unanticipated, secondary risks and consequences may result. Currently, geo-engineering techniques are still in the early stages of development and uncertainties (regarding scientific assessment of environmental and social impacts) abound. For example, injecting sulphate aerosols (small particles that reflect sunlight) into the stratosphere would have a desirable cooling effect. But it is also possible that these aerosols could catalyse chemical reactions that deplete the ozone layer, or that they could suppress rainfall [Morton, 2009]. The risks could outweigh the benefits. Given the large scale on which these technologies are designed to be employed, the fact that their effects may extend beyond national boundaries, plus the fact that they are attempting to exert control on complex, unpredictable systems (see "Recognising complexity", p.14), testing or deployment in the absence of proper regulation could lead to the emergence of new, systemic risks.

Mechanisms to control and regulate the deployment of these new technologies will be necessary not only to govern the eventual deployment of these techniques, but even earlier, to govern their research and development. There is a risk that institutions will be unable to develop systems to govern the scientific uncertainties quickly enough. Given the cross border implications of geo-engineering, this may involve new or amended international treaties and/or institutions, on top of local and national regulation. Moral hazards, ethical and social concerns will also need to be explored in detail during the development of a governance framework [The Royal Society, 2009].

(15) See the IRGC Opinion Piece "Cooling the Earth through Solar Radiation Management: The need for research and an approach to its governance" for more information on the risk governance of geo-engineering. Available online at http://irgc.org/Opinion-Piece.html

Factor #8: Temporal complications

Summary: A risk may emerge or be amplified if its time course makes detection difficult (e.g., the adverse effects of the risk only become evident after a long period of time) or if the time course does not align with the time horizons of concern to analysts, managers and policymakers.

Temporal complications arise during the risk governance process. First, complications can result from the time course – or time path – of the risk itself, which can make it difficult to anticipate and identify the risk in its early stages, or determine how it should be managed. These sorts of temporal complications often arise as a result of limited knowledge of the complexity of the systems involved (see Sections III and IV) or the nature of the risk itself (e.g., elevated rates of diseases from chemical exposures that appear only after a long latency period). Second, complications can result from non-concordance between the time course of the risk and the time horizons of risk managers. While the time course of a risk is usually outside the immediate control of risk managers, the time horizon of the risk assessors and managers is largely within their control and thus can be adjusted to support prevention and mitigation.

Consider first the time course of an emerging risk from a systems perspective. When a complex adaptive system is subject to a perturbation, the response of the system may not be immediate. The time delays between stresses, perturbations, system responses, and impacts on organisms and society are a major source of complication in identifying risks as they emerge.

If a new product or technology produces harm quickly after its introduction, or a system reacts quickly after perturbation, the task of recognising the emerging risk may prove to be manageable. As mobile phone use while driving grew rapidly around the world, the resulting driver distraction was rather quickly identified as a significant factor in traffic crashes. Efforts are now underway in many countries, through education and legal measures, to curtail the use of mobile phones while driving. In this case, the time lag between emergence of the technology and identification of a new risk was relatively short.

> Anticipating how an emerging risk will evolve requires an understanding of its time course and thus the risk profile needs to address temporal issues.

When the harm becomes evident only after a long period of time following exposure, the emerging risk is less likely to be identified before significant harm to human health or the environment has been done. For example, the health dangers of using asbestos in insulation and construction were not even suspected until decades after its use became widespread in the 1870s. This is because disease (asbestosis and lung cancer) only develops after prolonged exposure to asbestos – the latency period for cancer can be 10-50 years after first exposure. It took many more decades for the causal link to become widely accepted, and licensing regulations and exposure limits for asbestos were first introduced in the UK as late as 1984 [Gee and Greenberg, 2002]. Today there is some concern in the promising new field of nanotechnology that some nano-products could also have adverse health effects with long latency periods [IRGC, 2006]. A 2008 study suggested that inhalation of carbon nanotubes could potentially lead to the development of lung cancer in much the same way as inhalation of asbestos fibres [Poland et al., 2008].

For infectious diseases, a key temporal feature is the duration of time that a person can be infectious without experiencing any overt symptoms of disease. For viruses with a quick onset of symptoms, patients may seek health care before they have an opportunity to infect large numbers of people, or alternatively, if the virus does spread, it will at least become apparent very quickly that a new virus has emerged and the extent of the epidemic will be easy to assess. Containment measures can thus be put in place more rapidly. But long periods of infectivity prior to symptoms can be a prescription for disaster. In the case of the HIV virus that is responsible for AIDS, people are frequently infected for years without knowing it and, as a result, they have ample opportunity to infect large numbers of people. The AIDS epidemic was therefore well established before the virus was identified, fully characterised, and understood.

Active surveillance systems are crucial to the early detection of those emerging risks whose time course is such that cause and effect occur with a major time lag. Even with good surveillance systems, these risks will frequently be difficult to identify in their early stages. Nevertheless, recognising the complexity of the systems involved, understanding the relevant traits of complex systems (see section IV) and gathering knowledge about the nature, evolution and trends for the sort of risk in question (e.g., for infectious diseases in general) can provide clues of where to look or what to look for.

In large engineered systems, temporal considerations can play a pivotal role in the operation of crucial safety systems: risks may emerge as the result of time delays (for example, the time required for a backup system to start up and function at full capacity after failure in a primary system occurs), or risk management actions may have to be carefully timed in order to be effective. Following the trip of an electricity line, there is a finite time period within which operators must act to reduce the load on other lines in the system. Failure to act quickly enough will result in multiple line failures and widespread blackouts, as occurred in Italy on September 28, 2003, when more then 56 million people lost power for nine hours. In this case, the overload created by an initial tripped line could only be sustained for 15 minutes, but the operators' response was not sufficiently urgent (taking 20 minutes at least), and cascading failures resulted [UCTE, 2003].

Even if the time course of an emerging risk is fully understood, the time horizon of risk assessors and managers may not be properly aligned. Risk managers do not exist in a societal void where only scientific facts can influence their decisions. Instead, incentives, values and external pressures all play a part, and these can result in a misalignment of the time horizons of decision-makers relative to the time course of the risk.

A pre-occupation with near-term impacts (including a preference for solutions that show immediate results) is common. Business leaders are under intense pressure to attend to concerns about near-term profit and shareholder value. Politicians are geared toward election cycles, which have a shorter time horizon than many of the long-term, emerging risks that threaten the welfare of citizens and ecosystems. And even the leaders of non-governmental organisations (NGOs) dedicated to prevention of emerging risks may find that a short-term orientation is best for enhancing organisational visibility and raising funds for pressing needs. Thus, for emerging risks with long time courses that can be prevented or mitigated only by imposing near-term costs or inconveniences, the short-term orientations of businesses, governments and NGOs are a major barrier to effective action.

Long-term fiscal risks in aging societies

Throughout the world, many countries are facing demographic transitions that are accompanied by serious fiscal risks with long time courses: the problem is that their numbers of senior citizens are rising faster than their numbers of young working people and this population aging is unprecedented and enduring [UN DESA, 2002]. This demographic imbalance results from declining fertility rates and rising life expectancies as societies become more prosperous and better educated. Long-term fiscal risks are projected because the number of taxpayers is not growing fast enough to support the number of senior citizens who will require subsidised pensions and health care. The time course of the risk will vary between different countries, with the pace of population ageing being much faster in developing countries, giving them less time to adapt [UN DESA, 2002].

In China, the dilemma is exacerbated by the one-child policy that was adopted in the country's constitution in 1978 and enforced beginning in 1979. While the policy is strictly enforced only for urban residents and government employees, incentives for smaller families were also put into place in rural areas in order to contain population growth. As a result, the percentage of Chinese residents over the age of 65 is projected to rise rapidly from 5% in 1982 to 7.5% in 2005, 15% in 2025 and 31% in 2050 [Hesketh et al., 2005]. In some cities such as Shanghai, the imbalance has become so severe that larger families are being actively encouraged with aggressive campaigns, despite the formal one-child policy [Cha, 2009].

When a society experiences rapid aging, fiscal risks emerge due to explosive growth in the society's expenditures on medical care and pensions. Yet the solutions to the fiscal consequences of aging are often unpalatable – at least in the near term – to taxpayers, businesses and politicians. In the case of China, it is particularly difficult for national leaders to reverse the one-child policy and, in fact, leaders continue to reaffirm the policy, despite its long-term risks to the well-being of China.

Increasing vulnerability to solar storms [16]

Solar storms occur as a result of coronal mass ejections (CMEs) and flares emitted by the sun. The radiation carried by these events causes disruptive currents in Earth's upper atmosphere (ionosphere) and magnetosphere, which can lead to geo-magnetic storms on Earth. These storms pose important risks to modern society because they have the potential to severely damage or disrupt many of the technologies upon which it relies including satellites, electricity and telecommunication infrastructures, oil and gas pipelines, global positioning system (GPS) navigation signals and radio waves. A 2008 report from the US National Academy of Sciences estimates that the economic costs of a severe geo-magnetic storm affecting the US could be in the realm of US $ 1-2 trillion during the first year alone, with full recovery taking between 4-10 years [NAS, 2008].

Although the frequency and intensity of flares and CMEs peak and trough according to the (on average) eleven year solar cycle, the timing, size and speed of any given event is highly unpredictable [Cole, 2003]. This makes the time course of the risk problematic because it is unknowable both when a large flare or CME will occur and how fast it will travel to Earth and cause damaging effects. Solar storms can be expected to occur more frequently at a solar maximum, but a large solar storm can nevertheless occur during a solar minimum, and while frequent small storms can have little or no impact, very large storms have a low probability of occurrence, but potentially a very high impact.

Temporal complications also affect the task of risk management, which chiefly involves making infrastructure more resilient and resistant to the effects of geo-magnetic storms and putting contingency procedures in place to minimise damage if a storm occurs. Building resilience and redundancies into, for example, the electric grid, can be a very expensive and complicated venture [Jansen et al., 2000]. Risk managers may be reluctant to make the necessary investments because they feel that in the short-to-medium term (indeed, even in the long-term given the low probabilities of severe storms), they will see no returns and so the money could be better invested elsewhere. As far as contingency procedures are concerned, these may prove of little use owing to the time frames involved – current capabilities for early warning of an approaching CME or solar flare are very limited. Several hours warning may be possible in some cases, but on the other hand, a significant number of storms cannot be predicted at all (another example of an intractable unknown, see p.19), and therefore there may be little or no time to enact the contingency procedures [Normile and Stone, 2006; Cole, 2003].

(16) For a more in-depth discussion of risks related to solar storms, see the Emerging Risk case study on this topic, available online at http://irgc.org/Phase-1-case-studies-and.html

Factor #9: Communication

Summary: Risks may be complicated or amplified by untimely, incomplete, misleading or absent communication. Effective communication that is open and frank can help to build trust. In many cases, such communication can attenuate, or lead to better anticipation and management of, emerging risks.

By "communication" IRGC means not just top-down messages (e.g., scientists or regulators to laypeople) but also bottom-up messages from the concerned public to scientists, regulators and politicians.

The evolution of the new scientific discipline of synthetic biology – an engineering approach to biology which involves intentional genetic or other alterations in the form and function of biological organisms – provides a good example of this. There is concern among those working in the field that if risk communication is not well-handled, the public reaction to the new technology could be very negative. Public fear of the potential emerging risks could result in restrictive regulations, impeding further innovation and development of synthetic biology techniques. Thus, there is a great need to understand why some people are concerned and to supply balanced information about the risks and benefits a technology may bring [IRGC, 2010b].

The food sector also provides many examples of how failures in risk communication can result in the amplification of emerging risks and in lost benefits. Most people are very concerned about whether their health can be affected by what they eat and so some countries (such as the US and the countries of the European Union) have developed sophisticated tools for food safety assessment and risk management. Thanks to years of persistent communication, consumers have become more aware of potential food safety risks. However, communication failures can result in some consumers overreacting to true or pseudo scientific information about some products and this can generate new or re-emerging risks. For example, the presence of acrylamide in plastic packaging has been pointed out as possibly harmful if consumers heat the products before taking them out of the packaging. For this reason, some consumers refrain from buying their food in plastic packaging; they don't realise that safe packaging is one of the major ways of reducing risks related to food spoilage and poisoning, which, in proportion, are much more harmful than the presence of acrylamide in food. Communication failures can also have the opposite result – inadequate communication could lead consumers to under-react, and not take action to protect themselves from emerging food safety risks.

Similarly, communication about potential emerging risks related to nanotechnologies in cosmetics requires careful handling: while titanium dioxide particles in sunscreen are effective in protecting against sun burn, some also believe that, as nanoparticles, they may penetrate the skin and have unwanted effects upon entering the body. If the scientific facts are not properly communicated, the public may over react and, in doing so, miss out on the benefits the product has to offer while at the same time increasing their risk of sunburn and skin cancer.

The above examples demonstrate how amplification of emerging risks can result from external communication failures when those outside the formal risk governance processes – often the public – are given information by those responsible for risk governance processes. In some cases, communication failures stem partly from a desire to avoid scaring the public and provoking an extreme reaction (which would be, in itself, a communication failure). Although we must acknowledge that, in some cases, people will not react to an emerging risk unless they are afraid of the potential consequences – for example, some argue that if the public were more scared of the potential catastrophic consequences of climate change, policies, regulations and behaviours could be more easily changed – in most cases, effective risk communication should be able to avoid this outcome. A basic understanding of how common thought processes, heuristics and biases as well as political and media campaigns can affect people's assessments of and reactions to risk is therefore useful when considering how to frame the risk for communication to the public in order to avoid extreme reactions [see Pidgeon et al., 2003; Kasperson et al., 1988].

> Effective risk communication channels can be a valuable tool for gathering information and aiding early anticipation and assessment of emerging risks.

This external dimension of communication is often focussed on by risk professionals and in the literature. However, it is equally important to point out that risk amplification can also result from failures in internal risk communication, where those actors central to risk framing, assessment and management (including policymakers, natural and social scientists) fail to facilitate the exchange of information amongst themselves to ensure that every actor is well informed and is aware of his responsibilities [Renn, 2008].

What people are concerned about may be different than what scientists and regulators suspect. For example, some citizens are concerned that carbon capture and storage at coal-fired power plants could create safety risks or contamination of ground water. But other citizens are simply concerned about economics: the cost of storage, the effect on their electric rates, and the ramifications for their property values. The development of good communication requires a clear understanding of the concerns of the target audience or what these concerns might be in the future.

In an environment where effective risk communication is well established, the two-way dialogue between the public and risk professionals is a valuable process for the anticipation and assessment of emerging risks. Effective communication about emerging risks must emphasise the two-way nature of the communication process, where both the public and the risk professionals engage in a process of learning that is much more bottom-up than the top-down, external dimension of risk communication that was used in the past [Renn, 2008; Leiss, 1996]. Listening to the concerns of the public may alert risk

Trust in Toyota Motor Corporation

As recently as 2007, Toyota was seen as one of the must trusted and successful multinational corporations. Commentators pointed to how Toyota used “lean manufacturing”, defined as reliance on common parts across product lines and a smaller number of suppliers, thereby allowing greater economies of scale, quality control, and cost reduction [Wakabayashi, 2010]. Toyota was also seen as a pioneer of green technologies, most notably through rapidly growing sales of the highly fuel-efficient Toyota Prius. In 2009, Toyota became Japan’s largest company, with US $230 billion in global sales.

In March 2007, Toyota began receiving reports that pedals in the Tundra pick-up truck were slow to return to idle after the driver removed pressure from the pedal. In late 2008, complaints about sticky gas pedals were received in Europe from owners of the small cars Aygo and Yaris (despite the fact that these models were equipped with a new friction lever that is supposed to address the problem experienced in the Tundra). In the fall of 2009, more complaints about Toyota vehicles were voiced in Canada and the US and, in model year 2008, Toyota vehicles accounted for 41% of the sudden acceleration complaints in the entire US car industry [Greimel, 2010].

Critics of Toyota argue that the company failed to take prompt recall actions in the US, only announcing a recall in late 2009, on the heels of a nationwide broadcast of a 911 recording of a fatal accident in which passengers in a Lexus with a reportedly stuck throttle frantically request help before suffering a fatal crash. Critics argue further that Toyota did not communicate openly or honestly about the potential problems, even offering dubious explanations at various points in the time line (e.g., the suggestion that after-market carpets were causing the pedals to stick) rather than acknowledging that they did not know the causes of the reported problems [Linebaugh et al., 2010].

After months of criticism (and virtual silence from Toyota) in the US media, Toyota effectively capitulated. They recalled 9.5 million vehicles between late 2009 and February 1, 2010, a figure that is larger than the 7.8 million vehicles that Toyota sold worldwide in

2009 [Linebaugh, 2010]. They suspended sales of eight new models in the US, including their best sellers, the Camry and the Corolla, until they could address the complaints about their products. In the midst of these actions, the CEO of Toyota Motors was effectively compelled to travel to the US and testify at congressional hearings with the assistance of an interpreter [Maynard, 2010].

Some, perhaps even most, of the damage to Toyota's reputation may have been unjustified, as there is increasing evidence that many of the complaints were related to incidents involving driver error in operating the vehicle.

However, the consequences of Toyota's communication failures have been financially significant: billions of dollars in lawsuits against Toyota have been filed in US courts [Simon, 2010]; shopper "consideration" measures indicate that, in January 2010, Toyota was losing potential customers to Ford, Honda and General Motors; Toyota's market share of new vehicle sales is rapidly falling in the US [Terlep, 2010]; and the resale value of used Toyota products in the US has fallen noticeably [Carpenter, 2010].

These immediate financial effects may be overshadowed in the long-run by the effects of an erosion of trust and subsequent loss of brand reputation. The cascading impacts of Toyota's lack of candidness and poor risk communication (which had the effect of scaring, rather than reassuring, the public [Greimel, 2010]), while significant, are not yet fully understood.

managers to changes they would not otherwise have noticed or prioritised, for example changing attitudes, behaviours or systems that give rise to new risks. It may also aid in conducting concern assessments for emerging risks that have already been identified (i.e., selecting issues, including values, that the public link with the risk in question, their risk perceptions, and the likely socio-economic impacts of the risk) [IRGC, 2005].

Factor #10: Information asymmetries

Summary: Information asymmetries occur when some stakeholders hold key information about a risk that is not available to others. These asymmetries may be created intentionally or accidentally. In some cases, the maintenance of asymmetries can reduce risk, but in others, it can be the source of risk or the amplification of risk by creating mistrust and fostering non-cooperative behaviours.

Even when useful knowledge about emerging risks is available, the information may not be equally available among all of the relevant decision-makers. Such information asymmetries can result from unintentional communication failures or from deliberate attempts at concealment – either way, the distribution of information is, in many cases, largely within the control of decision-makers.

In some circumstances, information asymmetries may be necessary and they may have the potential to attenuate the likelihood or severity of an emerging risk. This is often the case where risks to national security are concerned. For example, government agencies gathering information on suspected terrorists will share their information with the fewest possible stakeholders in order to maintain information asymmetries (between themselves and the terrorists) that could allow them to foil planned attacks. The operating premise is that the more stakeholders learn of counterterrorism plans, the greater the chance that the plans could fall into the wrong hands.

Care must be taken to ensure that this targeted withholding of information is justified by gains in security. If such care is not taken, information asymmetries may act to amplify the likelihood or severity of an emerging risk. The failure to prevent the 9/11 terrorist attacks has been partially blamed on inadequate information sharing between the relevant intelligence and law enforcement agencies in the US [Grewe, 2004].

In other circumstances, information asymmetries may be entirely inappropriate, since denying information to risk managers, professionals or citizens may result in no foreseeable overall benefit, though it could serve particular interests. Indeed, without adequate access to information, risk managers and others may neglect preventive activities or, even worse, take actions that inadvertently exacerbate a risk.

> The identification and evaluation of information asymmetries is important in the governance of emerging risks, and thus should be considered in a risk profile.

In the recent controversy surrounding Toyota Motor's handling of safety issues (see box p.40), at least two types of information asymmetries have been questioned. Inside the company, a hierarchical culture has apparently discouraged lower-level managers at Toyota from disclosing safety problems to their superiors [Kingston, 2010]. And when dealing with US safety regulators, managers at Toyota were not always candid about what they knew and did not know about alleged safety problems. The cumulative effect of these allegations against Toyota has been to damage – at least in the short-run – the reputation of a highly successful corporation.

The assessment of occupational health and safety risks is a persistent source of tension between labour and management. Unequal access to tentative risk information has been a significant source of the tension. Such information often resides – at least initially – in the hands of management. In such cases, executives informed through the work of corporate medical officers, claims managers, and other specialised management staff may refrain from sharing tentative risk information on the grounds that too little is known or that such information is prone to misuse by advocates in collective bargaining, litigation or regulatory processes. These concerns on the part of management foster the creation of information asymmetries.

Ironically, concealment of tentative risk information may undercut the interests of management in the long run, as secrecy (and suspicions of intentional concealment) breeds mistrust and non-cooperative behaviour, as well as legal vulnerabilities. In contrast, under conditions of disclosure, workers and unions are empowered to take actions to protect themselves through personal prevention or mitigation, to advocate active medical surveillance, or to seek compensation, ex ante or ex post, for possible harm. By reducing information asymmetries about workplace risks, managers invite workers to participate in both the development of risk profiles and the risk tolerance decisions that must inevitably occur. In some countries, workplace safety and health regulations are designed to compel the sharing of risk information among all stakeholders in the workplace.

For consumers and suppliers of products and services, emerging risks – and information about those risks – are a highly sensitive matter. In the food sector of the economy, for example, risks can arise anywhere in the complex supply chain from the farm to the grocery store and home kitchen. In a globalised food sector, this means that numerous, dispersed actors around the world – from small farmers and huge agribusinesses to brand-name processors and cooks at restaurants and in homes – contribute to the quality and safety of the final product that people eat.

The financial crisis of 2007-08

In the financial sector, a plausible case has been made that the global financial crisis of 2007-08, and the deep recession that ensued, was rooted to a significant degree in the failure of home mortgage participants, financial regulators, ratings agencies and finance companies to disclose information about risk to investors.

In the home mortgage market, there were information asymmetries between borrowers on the one hand and mortgage providers on the other hand. Many borrowers did not understand key features of their mortgage product, particularly their susceptibility to re-pricing/refinancing risk at mortgage renewal time. Perhaps more importantly, the bundling of mortgages for resale in global financial markets and the evolution of "securitised" products were accomplished with insufficient information about risk. The numerous parties involved included the originators and issuers of securities; the underwriters who structure and package them; rating agencies, which supply opinions as to their risks; intermediaries who sell them; end-investors who buy them to hold in their portfolios; and other financial intermediaries who specialise in trading in and out of them for profit. While these presumably sophisticated actors would seem to be capable of protecting themselves, in fact the significant knowledge gaps about risk (and the extensive variability in access to information among actors) contributed to the global financial crisis.

This crisis occurred in an environment where some large financial entities were subject to lenient or diminished regulatory oversight and credit agencies faced a potential conflict of interest in rating the products of companies that were also clients of the rating agencies. Thus, risks may be particularly likely to emerge and go uncorrected when there is inadequate regulatory oversight.

Recognition that markets, by themselves, do not adequately address information asymmetries is spurring renewed interest in regulatory solutions to emerging risks in this field. A modest objective for intensified regulatory efforts is to achieve an enhanced degree of public trust about the risk profiles that are produced and the risk tolerance decisions that are made by key decision-makers in the global economy.

Counterfeit drugs [17]

The fight against counterfeit prescription drugs has two significant information asymmetries that contribute to risk amplification. In both cases, it is the counterfeiters who have the requisite knowledge and the other stakeholders (the consumers, the public, the authorities, the pharmaceutical companies) who lack crucial information.

First, there are asymmetries of information about the composition of counterfeit drugs; whether they contain the correct ingredients and in the correct quantities and, if not, whether they contain harmless or rather toxic and dangerous substitutes. Unsuspecting consumers expect that the drugs they purchase contain the correct ingredients and may be unaware of the potential risks. Public health and national drug regulatory authorities find it difficult to detect and quantify the effects on patients of counterfeit drugs, which are mostly concealed in broader public health statistics [Cockburn et al., 2005]. Studies use laboratory testing to ascertain the quality of pharmaceutical products and detect substandard drugs, but without detailed knowledge of the place of manufacture and distribution of these products, it is difficult to substantially reduce the public health risks.

This leads to the second important information asymmetry, which relates to the actual size of the market for counterfeit drugs and the extent of their distribution. Accurate knowledge in this regard is hard to obtain because there is no universal definition for "counterfeit drugs" (making it more difficult to identify relevant data), plus bits of knowledge about different aspects of the problem are possessed by many different stakeholders and are not effectively shared (often knowledge is deliberately withheld). Pharmaceutical companies are reluctant to make their data public (data concerning counterfeiting of their branded products) because of potential harm to their profits, reputation and competitive advantage [Cockburn et al., 2005]. Governments are reluctant to report discoveries of counterfeit drugs in their countries (as evidenced by the very few incidence reports by member countries to the World Health Organization), possibly because they don't want to expose corruption or make known the extent of their problem or lack of success in dealing with it [Gibson, 2004]. A lack of public warnings about the problem further exacerbates it, since ignorance of the attributes of counterfeit medicines on the part of patients and health professionals increases vulnerability and lowers detection and reporting rates for counterfeits [IMPACT, 2008].

(17) For an more in-depth discussion of the risk related to counterfeit drugs, see the Emerging Risk case study on this topic, available online at http://irgc.org/Phase-1-case-studies-and.html

This pattern of ignorance, where most stakeholders have imperfect and different fragments of information, allows risks related to counterfeit drugs – risks to individual health, to community health and to innovation in the pharmaceutical sector – to be amplified. The counterfeiters, with their first-hand knowledge of the counterfeit market and trade, seize the advantage and profit from it.

Factor #11: Perverse incentives

Summary: Perverse incentives are those that induce counterproductive or undesirable behaviours, which lead to negative, unintended consequences. Such incentives may lead to the emergence of risks, either by fostering overly risk-prone behaviours or by discouraging risk prevention efforts.

> Since incentives for risk taking are largely within the control of society (public and private sectors), misaligned incentives can be addressed through regulation and other policy measures.

One of the central insights of economic reasoning is that people will take more or less risk depending upon what incentives and disincentives are present for risk taking. For example, remuneration schemes or tax deductions for certain activities should provide incentives to adequately balance opportunities and risks. Ideally, economists argue, the incentives faced by individuals should be arranged so that the overall system produces the type and amount of risk that society desires.

When key decision-makers face tangible and intangible incentives to incur more (or less) risk than best serve the interests of affected individuals or society, it should not be surprising that poor risk tolerance decisions are made. Incentives are "perverse" when there is misalignment between the incentives that market actors face and the amount of risk that society desires – this leads to counterproductive or undesirable behaviours. Thus, even if scientific unknowns and information asymmetries are minimised, the phenomenon of perverse, inappropriate incentives can lead to the creation – and even concealment – of emerging risks.

Perverse incentives may appear when a "checklist mentality" exists within an organisation, with people striving only to meet pre-set indicators, rather than adapting goals to suit changing circumstances and attempting to get the best results possible [World Bank, 2005]. The measurement culture that is common today – where indicators are chosen on the basis of their being easily measured or quantified – also tends to favour the creation of simple incentives, which may not be the most appropriate. Because the creation of incentives is something that is within the control of society, eradicating perverse incentives should be a straightforward way to help attenuate the likelihood or severity of emerging risks.

Unfortunately, leaders in both business and government face perverse incentives with regard to the emergence of risks. Illustrations of such perverse incentives are well-documented in both the history of risk management and contemporary challenges.

The Endangered Species Act in the US – a regulatory program designed to halt biodiversity decline and recover species from the brink of extinction – has not always been successful owing to the perverse incentives it creates. The Act makes it illegal for private landowners to engage in any activity that could harm an endangered species or its habitat without first obtaining a federal permit. This effectively makes the discovery of an endangered species on private land an economic liability for the landowner, whose use of the land becomes restricted – for example, clearing land for farming or the harvesting of timber may no longer be allowed. Studies have shown that landowners pre-emptively destroy or degrade potential habitat on their land in order to avoid becoming subject to the Act's requirements, thus harming the prospects for endangered species' survival [Adler, 2007; Lueck and Michael, 2003].

In the regulation of new prescription drugs, concerns have been raised that pharmaceutical manufacturers and regulators have insufficient incentives to investigate the side effects of therapies that, once approved, are prescribed to millions of patients. For manufacturers, such "post-market" surveillance studies are sometimes perceived as an unnecessary source of market and legal risk, while regulators may perceive them as an unwelcome device to "second guess" the original approval decisions that were made based on limited experimental information. Yet, scientifically, there is no substitute for rigorous, large-scale studies of the actual experience of patients with medications. Without such surveillance, emerging risks – even risks with significant, fatal side effects – may go unnoticed.

Perhaps the most pervasive form of perverse incentive is the encouragement to seek short-term gain – political or financial – at the expense of long-term well-being for the economy, public health, society or environmental quality. When the time course of an emerging risk is measured in decades or centuries rather than weeks or years, it may be particularly difficult to design reward systems that encourage long-term risk management.

In financial markets, contemporary experience points to a variety of perverse incentives that have fostered emerging risks because of stakeholders seeking short-term gain. One might think that managers who originate home mortgages would have clear incentives to investigate the riskiness of borrowers and refrain from authorising loans that entail excessive risk of foreclosure. Yet the compensation schemes for originators of mortgages in the US (prior to the subprime crisis of 2007-08) were often designed to reward the number (or total value) of mortgages originated, without any deduction or penalty for subsequent defaults [Shiller, 2008]. Perhaps a more glaring example of perverse incentives was the generous bonuses that were provided to executives of financial companies that were bailed out by the US Department of Treasury after the 2007-08 meltdown – the bonuses were guaranteed, regardless of risk management performance or profit generated. In effect, the same executives who made horrendous investment choices were rewarded for their (mis)behaviour. The concept of "moral hazard" would suggest that these executives have been encouraged to take even more financial risk in the future [Bebchuck, 2009].

It is easier to pinpoint the pervasive problem of perverse incentives than it is to prescribe solutions that produce more good than harm. The basic principle is to ensure that people making decisions about risk have some stake in the game, both benefit on the upside and cost on the downside. Where possible, the stakes need to be symmetrical, or at least linked to the organisation's or society's preferred risk tolerance posture.

In the environmental field, solutions are gravitating toward arrangements where individuals and companies pay for the right to emit pollutants into the environment, drivers pay for their contribution to congestion, and landowners pay for any destruction of critical habitat for threatened and endangered species. The theme is to align incentives with the quest for sustainability.

Scholars of global climate policy insist that, without a tangible price on the emissions of greenhouse gases, companies and governments are not incentivised to invest in systems of accurate monitoring or control of the gases [Stavins, 2000; Stewart and Wiener, 2003]. Ideally, prices on greenhouse gases would be established in global markets, thereby ensuring that investments in controls occur at those locations and facilities where controls are most cost-effective. Yet the practical obstacles to accomplishing such a global system were vividly demonstrated in the December 2009 Copenhagen meetings on climate change.

Melamine-contaminated milk in China [18]

Following a scandal in 2004 when 13 babies died from malnutrition as a result of drinking infant formula made only from starch and sugar, the Chinese government put in place new regulations imposing strict nutritional requirements for infant formula, including a minimum protein content [Ingelfinger, 2008]. However, these well-intentioned new regulations did not have their desired effect of reducing risks to infant health. Quite the opposite, they were a contributing factor to the addition of melamine – an industrial chemical commonly used in plastics and resins – to infant formula and other dairy products. This practice was uncovered in September 2008 after several infants had died and many thousands had fallen ill [Yang et al., 2009].

(18) For an more in-depth discussion of the case of the melamine-tainted milk in China, see the Emerging Risk case study on this topic, available online at http://www.irgc.org/Phase-1-case-studies-and.html

In the context of the weak regulatory environment that existed in China, the new nutritional regulations had created a perverse incentive for milk manufacturers to seek the cheapest possible way to fulfil the requirements. Melamine was already being routinely used in the animal feed industry in China as a way to feign higher protein content – tests for protein used nitrogen as a proxy, and melamine has high nitrogen content, while being much cheaper than the real thing.

Producers thus saw an opportunity for short-term gain – the addition of melamine saved them money and allowed them to "meet" nutritional standards. Even if producers were not aware of the toxicity of melamine at the time, they were nevertheless aware that their products contained much less than their stated nutritional value and they were therefore knowingly creating a health risk (malnutrition) for consumers of milk products and especially for infants.

Factor #12: Malicious motives and acts

Summary: Malicious motives give rise to emerging risks and therefore practitioners need to consider intentional as well as unintentional causes of risk. Malicious motives and acts are not new, but in a globalised world with highly interconnected infrastructures (e.g., trade agreements and information and communication systems) they can have much broader-reaching effects than in the past.

Huge, highly interdependent systems, whether they are transportation networks, electrical grids or supply chains in the food sector, can be vulnerable to malicious acts by terrorists, warring states, or others. Motives for such acts are rooted in human nature: greed, envy, cheating, pleasure, religious extremism, ideological fervour and hatred based on race or nationality. Both open and authoritarian societies have difficulty controlling these motives.

Assessing where important clashes of interests, ideologies, or values exist (or are likely to develop) is one potential way to anticipate where malicious acts may occur and the types of risks that may emerge as a result of such acts. Where motives for malicious acts are based on clashes of material interests, there may be scope to attenuate the likelihood of these acts via negotiations or bargaining. If motives for malicious acts are based on clashes of fundamental values, religions or ideologies, finding suitable compromises will certainly be less straightforward.

> While a 100% prevention rate is practically unachievable, mitigation and adaptation efforts can nevertheless attenuate negative consequences.

Recent developments – from the proliferation of megacities to more globally interdependent banking networks and trading – are accentuating vulnerabilities to malicious acts. Yet security policies do not appear to be keeping pace with the increasing complexity of systems or the ingenuity of those with malicious intent and weaponry available to them.

Security specialists have ample grounds for concern about various forms of cyber attack. The growing use of networked digital industrial control systems, for example, has made industrial infrastructure more vulnerable to malicious acts. In the past, most supervisory control and data acquisition (SCADA) systems were custom systems and were not accessible via the internet or other external communication links. Thus, they were difficult to attack. Today, such systems contain common information technologies, including off-the-shelf operating systems such as Windows, and some include connections to the web (for example, via billing systems). This makes some of the systems more susceptible to worms, viruses and application-level attacks than in the past [Weiss, 2009; Byres and Lowe, 2005].

Other kinds of cyber attack have also been well-documented in the recent past. Beginning in April 2007, amidst a dispute between Estonia and Russia, one of the largest incidents of cyber warfare was waged against websites of key organisations in Estonia. In 2008, three days prior to Georgia's invasion of South Ossetia, the web sites of OS Radio and other key organisations were hacked. Military and security specialists concerned about state-sponsored cyber warfare are studying these incidents (and others) to gain insight into strategies, damages and potential countermeasures.

The attractiveness of cyber attack as a terrorist threat is subject to some dispute. After the terrorist attacks in New York City (September, 2001), Madrid (March, 2004), and London (July, 2005), disrupted terrorist cells were investigated to determine what further plans were considered or under development. Those plans included use of bio-toxins, chemical weapons, radioactive weapons plus conventional explosives and firearms. Few of the plans incorporated attacks with cyber weapons, though future terrorist groups may behave differently. Given the relatively low cost of learning about cyber attacks, the entry barriers to cyber warfare are considered to be small and thus risks from cyber warfare should be expected to emerge [Knapp and Boulton, 2006].

Concern about cyber spies has grown in the US due to evidence that the US electrical grid may be vulnerable and may even have been penetrated by cyber spies and defence contractors [Markoff and Barboza, 2010; Wang and Rong, 2009]. Much of this activity has been traced to Russia, China and other countries but the extent of state sponsorship is disputed [Gorman, 2009]. These spies have not yet sought to damage the power grid or other key infrastructure, but efforts to do so could occur during a crisis or war.

As risk profiles are developed, it is critical to analyse potential vulnerabilities from the perspective of those with malicious intent. However, as important as it is to prevent malicious attacks against critical infrastructure, prevention efforts will never be 100% effective. Efforts to minimise damages and shorten recovery times after attacks are considered crucial priorities. It is remarkable how quickly operations in New York City, London and Madrid resumed after unexpected terrorist attacks, even though none of the cities were well prepared for the attacks.

In summary, malicious motives can give rise to emerging risks. Risk profiles need to consider intentional as well as unintentional causes of risk. Efforts at prevention are laudable, but especially in open societies – where vulnerable infrastructures cannot be fully protected – investments in mitigation and adaptation (including recovery plans) merit some priority.

Emerging information technology (IT), security and financial risks

When organisations consider the possibility of malicious acts, they usually look to the outside for the source of the risk, and protect themselves accordingly. More often than not, however, the origin of the risk comes from within the organisation itself. In one sample of financial system intrusions analysed by the US Federal Bureau of Investigation, attacks by insiders were found to be twice as likely as those from outsiders, and the cost of an intrusion from the inside was 30 times as great [Wulf and Jones, 2009]. Examples from the banking sector, in particular, are becoming more and more frequent and usually involve a failure to sufficiently restrict or secure electronic data or to monitor electronic data movements. This can put the organisation and its customers at risk of financial or reputational loss.

In early 2010, an unidentified individual offered to sell data stolen from a bank in Switzerland to the German government for the sum of €2.5 million. This data supposedly belongs to 1500 potential German tax evaders. After receiving the legal green light, the German government pledged to buy the data, which they estimate could bring in more than €100 million in back taxes and fines, plus result in many other tax evaders turning themselves in to escape prosecution [Fischer, 2010]. It is not even the first time that the German government has bought stolen data of this kind – it paid nearly €5 million in 2008 for data stolen from a bank in Liechtenstein [Pilarski, 2010]. This type of trading in stolen information is "a gray zone of intelligence" where "the principles are not as strict as in penal law" [Cottier cited in Giles, 2010]. States willing to pay for stolen data provide more incentive for theft and "the risk is that foreign governments won't say where they got the information from, leading to less rather than more transparency" [Cottier cited in Giles, 2010]. When states consider this kind of behaviour to be acceptable (e.g., because it helps them to fight illegal actions such as tax evasion), they take the risk of generating mistrust in their own institutions.

In cases such as these, it is possible that the malicious act is carried out by an employee who just wants to profit financially at the organisation's expense. Alternatively, it is possible that an individual feels "authorised" by some form of moral personal judgement to steal information and thereby harm the security of other citizens. On the other hand, financial institutions should be aware that if they turn a blind eye to illegal practices (in this case tax evasion) they are more vulnerable to these types of attacks The economic welfare of these institutions may, by way of consequence, be threatened.

Vulnerabilities in IT security could thus lead to the emergence of financial risks with severe consequences. Political risks are also foreseeable – it is not farfetched to imagine that governments could find themselves in serious trouble if sold or leaked data were to compromise national security or destroy trust in elected representatives. Given that motives for malicious acts derive from human nature (e.g., greed, hatred, envy) and are thus virtually impossible to eradicate, the focus is largely on technical solutions to ensure data security.

Conclusion and way forward

In this report, IRGC has argued that emerging, systemic risks, even though they originate in different parts of the world and in various sectors of the economy, are not isolated events. To the contrary, such risks emerge from a common "fertile ground" that is cultivated by twelve generic factors.

IRGC has illustrated how these generic factors have been observed in the emergence of risks in the past, with the implication that awareness of these factors can help risk analysts understand how and why risks could emerge in their environment, and how to better anticipate and prepare for them. As important as the twelve factors are, they are not necessarily exhaustive and they certainly are not a substitute for detailed subject knowledge of each emerging risk. Indeed, managers may find it useful to consider the ramifications of detailed subject knowledge by thinking through the twelve generic factors and the illustrations provided here.

In illustrating the contributing factors, IRGC has drawn insights from concepts and applications in systems theory, especially the recent advances in understanding how complex systems give rise to unexpected risks. For readers interested in looking more deeply into the behaviour of complex systems, this report contains a wealth of references to concepts and applications relevant to a wide range of emerging risks.

Ideally, when confronted with emerging risks, managers proceed by: preparing a risk profile for each risk or group of risks; defining (or reaffirming or refining) their general tolerance for risk; and making management decisions based on the findings in the profile and their established vulnerability to and tolerance for risks. What this report illustrates is that the practical application of this ideal approach is difficult in the case of emerging, systemic risks.

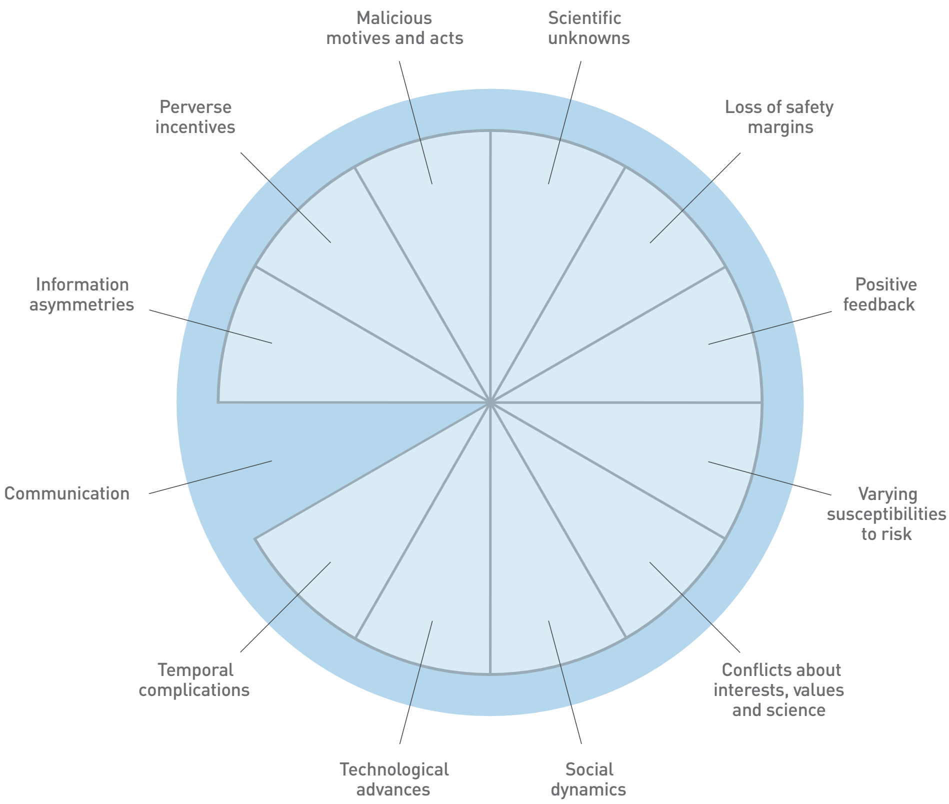


Figure 3: Above is a chart showing the twelve contributing factors, which should be understood not as discrete units, but as complex, interdependent factors. Communication has a particularly key role, as it can influence all of the other factors [c.f. the IRGC Risk Governance Framework, which has communication as its centrepiece, see IRGC, 2005]

A tolerable risk profile

The notion of a tolerable risk profile for a system may be a useful organising principle for risk governance purposes. Achieving and maintaining over time the alignment of multiple stakeholders around a common vision of a tolerable risk profile may serve as a useful overarching objective for sound governance. Delineating such a profile on a case by case basis will require common agreement on specific answers to the following questions:

- Which type of risk or crisis (and of what order of magnitude) is the system designed or targeted to survive?
- What are the relative weights of the probability/frequency and severity components as determinants of risk tolerance?
- How robust and resilient does a given system need to be for the combined and cumulative impact of emerging risks to be contained within the acceptable level of tolerance?
- How do the costs of risk prevention, mitigation or recovery enter into the tolerable-risk determination?

Strategies to deal with the contributing factors and the emergence of risks

Not all of the contributing factors will be relevant to the emergence of risks in all domains, and thus an obvious first step is to identify – using specific knowledge about the context of the organisation and the type of risks that it faces – which factors are most relevant. For each of these factors, there are three important questions to consider:

1. Is the factor — **amplifying** / **attenuating**

Are actions taken to attenuate the role of the factor?

2. Is the factor — **uncontrollable** / **controllable**

Are actions taken to control the factor?

3. Is the factor dependent on — **technological dimension** / **social/psychological dimension**

Are actions taken to
- reduce/attenuate the likelihood and severity of the risk?
- avoid the neglect of the risk emergence by managers?

1. Whether the factor in question is acting to amplify or to attenuate the likelihood or severity of an emerging risk determines the direction and goals of possible future actions. If the factor is attenuating, then any action taken will either be to simply monitor the situation and make sure that this attenuating trend continues, or else to actively promote or strengthen this attenuating trend. In the case of scientific unknowns, for example, a trend towards decreasing important unknowns and solving scientific mysteries can attenuate risk, and in both public and private sectors it is common to find policies aimed at promoting research to this end. If the factor is amplifying, actions will be required to reduce this trend.
2. Whether or not the factor is controllable (or rather, the degree to which it is controllable) determines the possibilities for taking action. Even if a factor is identified as having an important amplifying effect on risk, if it is uncontrollable, the best that may be done is to monitor it and prepare to anticipate and deal with the consequences. For professionals in charge of risk anticipation, at least some capacity development should therefore be oriented in this direction. Malicious acts for example, frequently stem from greed or opportunism on the part of the attacker, which many would recognise as traits inherent to human nature and thus impossible to eradicate (although creating the correct incentives could help minimise such tendencies). In instances where there is some degree of controllability, the options are greater and, in some cases, it may even

be possible to take actions to increase the degree of controllability. Strategies to cope with uncontrollable risks require adaptation or avoidance. Strategies to reduce controllable emerging risks call for mitigation or risk transfer. The choice of these options often depends on the context of the organisation affected by the emerging risk. For example, strategies to deal with the spread of new diseases as a result of the changing climate depend on the economic capabilities of the countries affected.

3. Whether the factor is predominantly dependent on technological or on social/psychological dimensions determines the type of actions that should be taken in order to reduce the likelihood or severity of an emerging risk. It is possible that both dimensions will need to be addressed simultaneously, though using different means. Addressing technological dimensions is likely to be more straightforward and offer a much wider range of potential management options than is possible for addressing psychological dimensions. For the latter, it may be a case of raising awareness about the existence of important cognitive biases and heuristics and their potential consequences (how they affect thinking in general, plus how their effects could lead to risks being amplified or overlooked). Even with strong incentives, it may not be possible to overcome psychological biases – people do not make mistakes on purpose, but because they do not know how to do better [Yudkowsky, 2008]. Therefore, understanding how and why thinking and reasoning about the contributing factor may be impaired and admitting that you are not immune from these biases and heuristics is important.

Overcoming obstacles to emerging risk anticipation and management

The focus of this report has been on the contributing factors to risk emergence and therefore it has only scratched the surface of the complex challenge faced by risk managers in industry and government of how to improve their own anticipation of and response to emerging risks.

Because many systemic risks occur in contexts in which their future evolution is difficult to control, those working to anticipate and manage them face specific challenges:

- Uncertainty and gaps in knowledge are frequently present;
- In the face of this incomplete and uncertain knowledge, consensus is not the norm and conflicting values and interests can lead "facts" to be contested;
- Cognitive biases, heuristics and emotions may have a greater effect on decision-making;
- "Normal" accidents and unexpected surprises may increase, or may be perceived to be increasing, as an outcome of both the desire and the inability to predict or anticipate possible threats.

Given the many different kinds of emerging risks and the wide range of potential responses by risk managers, it is not feasible to identify a creative management strategy that will be optimal – or even satisfactory – in all situations. But for emerging risks that arise from the behaviour of complex systems, there are certain elements of organisational capability that may prove to be particularly effective. Those elements include:

- Enhancing the capabilities for surveillance, data collection, knowledge development, scenario planning and forms of formal uncertainty analysis;
- Developing an understanding of human behaviour and "sensemaking" (defined as the process of generating and evaluating hypotheses to explain ambiguous data) and acknowledging that logic and traditional rationality are not the sole basis for human decision-making;
- Regularly and systematically reviewing decision-making and communication processes, including any assumptions that are factored into these processes;
- Allowing for enough organisational flexibility and decentralisation to accommodate adaptation and innovation in response to changing situations and new indications of emerging risk;
- Building robustness, redundancies and, mainly, resilience as a strategy to combat uncertainties (and thereby attenuate the likelihood/severity of an emerging risk).

It is, however, not an easy task to develop the above capabilities. In order to justify the allocation of resources to building up such capabilities, key actors may have to publicly and explicitly acknowledge difficult realities, such as the limitations of their current risk management procedures or the extent of their susceptibility to emerging risks. The admission that an emerging risk has been identified and may not be completely avoidable or preventable has the potential to create serious communication difficulties and credibility problems for many leaders in business and government. Therefore, keeping quiet may seem the preferable option. The role of legal liability can also be an important influence in discouraging early anticipation of an emerging risk, because legal counsel may recommend that an organisation deliberately not engage in surveillance for emerging risks in order to avoid any legal ramifications if the emerging risk turns out to have adverse consequences and it can be proven that the organisation was aware of its existence (whether or not it could effectively do anything to treat the risk). Even in cases where potential emerging risks have been identified and deemed of concern, it may not be an easy task to find the resources to study them if this requires the diversion of resources away from the study and management of known risks.

These obstacles are only a few of many that organisations will have to overcome in order to improve their anticipation and management of emerging risks. Effectively, it is a question of creating an appropriate organisational risk culture that can serve as a strong foundation upon which the above capabilities can be built. Indeed, it is often the risk culture of the organisation that determines what is seen as “a risk” and how to deal with the uncertainty that accompanies almost every emerging risk. This risk culture, which embodies the organisation’s risk appetite, reflects its goals and strategies and informs how its risk-related decisions are made, will likely be quite different in the public versus in the private sector. In the public sector, the culture is predominantly reactive and linked to public opinion, whereas in the private sector, profit-maximisation policies have a strong influence on risk culture, with an aggressive business policy, for example, producing a different kind of risk culture from one aimed at sustainable development and long-term growth.

Whether in the public or private sector, IRGC emphasises that organisations should strive to establish a climate of openness and humility during the early phases of identifying and responding to emerging risks. Such a change in risk culture will be difficult, but it may be a necessary precondition for truly adaptive approaches to emerging, systemic risks. The importance of risk culture plus insights into how to overcome some of the key obstacles to changing risk culture and to building the necessary capabilities are the focus of phase 2 of IRGC’s emerging risks project.

Glossary

Complexity: Refers to the difficulty of identifying and quantifying causal links between a multitude of potential causal agents and specific observed effects [IRGC, 2005].

Complex system: systems composed of many parts that interact with and adapt to each other [OECD, 2009a]

Emerging risk: A new risk, or a familiar risk in a new or unfamiliar context (re-emerging). These risks may also be changing (in nature) rapidly. Although they may be perceived as potentially significant, at least by some stakeholders or decision-makers, their probabilities and consequences are not widely understood or appreciated.

Risk: An uncertain (generally adverse) consequence of an event or an activity with regard to something that humans value [definition originally in Kates et al., 1985: 21].

Risk assessment: The task of identifying and exploring, preferably in quantified terms, the types, intensities and likelihood of the (normally undesired) consequences related to a risk. Risk assessment comprises hazard identification and estimation, exposure and vulnerability assessment, and risk estimation [IRGC, 2005].

Risk governance: The identification, assessment, management and communication of risks in a broad context. It includes the totality of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated, and how and by whom management decisions are taken.

Risk management: The creation and evaluation of options for initiating or changing human activities or (natural or artificial) structures with the objective of increasing the net benefit to human society and preventing harm to humans and what they value; and the implementation of chosen options and the monitoring of their effectiveness [IRGC, 2005].

Risk profile: In the case of a single risk, a profile captures several dimensions, qualitative and quantitative, that describe the risk in ways useful to a risk manager who is making initial decisions about what should be done. A profile may also describe a set of risks of concern to an organisation.

Risk tolerance: An organisation's or stakeholder's readiness to bear the risk after risk treatment (process to modify the risk) in order to achieve its objectives. (Note: Risk tolerance can be influenced by legal or regulatory requirements) [ISO, 2009].

Systemic risk: Risks affecting the systems on which society depends. The term "systemic" was assigned by the OECD in 2003 and denotes the embeddedness of any risk to human health and the environment in a larger context of social, financial and economic consequences and increased interdependencies both across risks and between their various backgrounds [IRGC, 2005]. Systemic risks are characterised by complexity, uncertainty and ambiguity. Most often, they are also trans-boundary.

Uncertainty: A state of knowledge in which the likelihood of any effect, or the effects themselves, cannot be precisely described. (Note: This is different from ignorance about the effects or their likelihood) [IRGC, 2005].

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About IRGC

The International Risk Governance Council (IRGC) is an independent organisation based in Switzerland whose purpose is to help improve the understanding and governance of emerging, systemic global risks. It does this by identifying and drawing on scientific knowledge and the understanding of experts in the public and private sectors to develop fact-based recommendations on risk governance for policymakers.

IRGC believes that improvements in risk governance are essential if we are to develop policies that minimise risks and maximise public trust and effectiveness in the processes and structures of risk-related decision-making. A particular concern of IRGC is that important societal opportunities resulting from new technologies are not lost through inadequate risk governance.

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