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PART I: EXECUTIVE SUMMARY

1.1 Introduction

Today's high-income countries have developed the capability to manage conventional disaster risks – earthquakes, floods, droughts, etc. – very successfully (Kellenberg and Mobarak 2007). This capability is based on the combination of the wealth resulting from economic growth with a powerful intellectual framework – the rational actor paradigm (Jaeger et al. 2001). As a result, today's high-income countries are capable to avoid or drastically reduce the impact of disasters that have threatened humans over thousands of years. They do so by using insurance markets and regulations upheld by nation states. The first task of the Integrated Risk Governance Project (IRG Project) is to make this capability available to more and more countries and people on Earth.

The growth path taken by today's high-income countries, however, has generated new systemic risks of planetary relevance – pandemics, mass extinction of species, climate change, global financial breakdowns, and more. These risks are unintended consequences of actions driven by a highly effective, but also problematic way of thinking (van der Leeuw 2012). As Charles Perrow (1984) observed long ago, it is the way of absolute rationality: a way of thinking that can be pursued by isolated actors optimizing the use of scarce resources for their respective ends. But the capability to manage global systemic risks cannot be based on the thinking and institutions that generated them. The second task of IRG Project, then, is to develop new ways of thinking that are adequate to this challenge and to investigate what kinds of institutions might turn them into adequate pattern of risk governance (Renn 2008).

Figure 1 Planet boundary (Steffen et al. 2015)
A key step in this direction is to understand how resilience in the face of global risks can be generated by better coordination between the relevant agents. Building on Chinese thinking, IRG Project has begun to explore the link between coordination and resilience with a mathematical measure of consilience (Shi et al. 2014). This work progresses in a frame of use-inspired research, where theory and practice evolve hand-in-hand, both in research concerning conventional disaster risks and in research concerning global systemic risks.

The consilience approach to integrated risk governance has the additional advantage that it allows to identify factors that enable low-income countries to improve their ways of dealing with traditional risks even before they have grown at higher income levels. And it can help to identify factors that allow low-income countries to avoid the risks generated by the traditional growth pattern of the past and to develop along new paths of green growth.

Figure 2 Conceptual Framework of Consilience

1.2 IRG Project and Future Earth

The Integrated Risk Governance Project is a Core Project of Future Earth, the international platform for research on global environmental change (Future Earth 2015a). The goal of Future Earth is to provide “the knowledge required for societies in the world to face risks posed by global environmental change and to seize opportunities in a transition to global sustainability” (Future Earth 2015b).
IRG Project shares this goal. It works to identify those situations where opportunities for a sustainability transition can be created and realized precisely by facing the risks of global environmental change. The result are win-win options in risk governance. An important example is opportunities for green growth that develop out of efforts to address anthropogenic climate risks (Jaeger et al. 2012). Win-win options in the face of global environmental risks are rarely ready-made. They must be discovered, sometimes created. This involves a major scientific challenge that is relevant for the whole of Future Earth. The challenge refers to the rational actor paradigm, introduced in the preceding section. In fact, this paradigm is both indispensable and insufficient to tackle the problems of global environmental change and sustainable development.

By combining the notions of utility functions, probability distributions and market equilibrium, the rational actor paradigm has enabled the development of private insurance industries and of public policies that together successfully address a wide range of risks. Meanwhile, the increasing impacts of human action are generating risks that exceed the coping capacities of these institutions. At the same time, research has identified a series of anomalies that point to serious limitations of the rational action paradigm (Machina 2006).

In the coming years, IRG Project will explore avenues to overcome these limitations in view of a sustainability transition, without losing sight of the indispensable insights the paradigm has provided in the past. As explained in the previous section, IRG Project will do so by developing a consilience-based approach to risk governance.

Fortunately, there are several strands of research that can be used for this purpose. Two of the most important are Ortwin Renn’s (2008) framework for integrated risk governance and Lin Ostrom’s (2012) analysis of governance patterns for common pool resources. Both rely heavily on the careful study of practical problems like waste disposal, forest management, etc. IRG Project will proceed in this spirit with a strong focus on disaster risk reduction.

This implies that the work of IRG Project is rooted firmly in what has been called Pasteur’s Quadrant (Stokes 1997) – the area of use-inspired basic research. Engaging with stakeholders, designing and developing research with them while helping them to solve practical problems is therefore vital for the approach of IRG Project.

1.3 Organization

In the coming years, the work of IRG Project will be organised by strong formal and intellectual ties between three institutions:
- Beijing Normal University, (BNU, China). ESPRE and ADREM will be related institutions at this node, Profs. Shi Peijun and Ye Qian key individuals.

- Arizona State University, (ASU, USA). The Global Institute of Sustainability (GIOS) and the Santa Fe institute (SFI) will be related institutions at this node, Profs. Sander van der Leeuw and Gary Dirks key individuals.

- Potsdam University, (Germany) The Center of Excellence for Global Systems Science (CoeGSS) and the Institute for Advanced Sustainability Studies (IASS) will be related institutions, Profs. Carlo Jaeger and Ortwin Renn key individuals.

Each one of these institutions has an exceptional record on risk governance, ranging from natural disaster risk (a main focus at BNU) to technological risks (a main focus at ASU) and to questions of integrated risk governance (as investigated at the Potsdam node in relation to both natural and anthropogenic disaster risks). This triangle has been fostered by the Global Climate Forum, a think-tank operating as a small, but worldwide network with a hub in Berlin. In the coming years, one or two additional nodes may be added, depending on circumstances.

Nothing would be farther from the truth than to see this core as a closed alliance. Quite the opposite, IRG Project will develop as an open network, involving researchers and stakeholders worldwide. Our capacity to do so is documented by the collaboration of the three core partners with:

- Governments in Europe, China, America and other countries
- Major (Re-)insurance companies like Munich Re, Swiss Re, Allianz etc.
- International bodies like UNISDR, IPCC, the Global Risk Forum etc.
- Large and small NGOs like WWF and Germanwatch
- Scholars at leading institutions in developed and developing countries

IRG Project operates as an idea-driven network, consciously mixing senior and junior scholars, academics and practitioners as well as professionals with very different disciplinary, cultural and geographical background.

### 1.4 Methods

One of the most important outcomes of IRG Project shall be a set of methods that can be used by researchers and practitioners to address specific disaster risks as well as comprehensive questions of integrated risk governance. The following kinds of methods will be pursued systematically.

**Disaster cascade analysis:** The Fukushima disaster has become a paradigmatic example of disaster cascades, and the difficulties of attributing and assessing impacts of anthropogenic climate change show its future relevance. Methods of disaster cascade analysis find applications over all dimensions of
socio-ecological systems, from purely physical processes through food webs all the way to financial markets.

**Simulations:** The importance of simulations for modern risk analysis, especially in view of integrated risk governance, can hardly be overestimated. The capability to integrate big data in risk simulations is one of the frontiers of present-day research, and IRG Project will actively engage in expanding and using it.

**Experiments:** Making sound experiments in the social sciences is notoriously difficult, but in recent years sophisticated experimental designs have been successfully implemented both in laboratory settings and in field work. In both areas creative use of game theory has proved to be extremely helpful. A particularly promising framework for integrated risk governance, already used in the IRG Project community, is the Institutional Assessment and Development framework.

**Synthetic populations:** Synthetic populations are a very promising method for the study of systemic risks and IRG Project will develop them further in this direction. Cooperation with the Centre of Excellence for Global Systems Science, coordinated by Potsdam University and involving key players in European high-performance computing will provide initial access to supercomputing resources, to be complemented by similar resources in China, the US and elsewhere.

**Stakeholder dialogues:** The widely felt need for more open forms of co-design of research and co-production of knowledge has not yet led to consolidated methods of engaging in these activities. IRG Project is in an excellent position to make progress towards such methods, because stakeholder involvement is often essential to understand patterns of risk governance, and because it can build on previous experiences with stakeholder dialogues.

### 1.5 Theory of Integrated Risk Governance

The rational actor paradigm (see section 2.3) has led to a view of the modern economy as realizing a social optimum by combining public policies with market competition. The social optimum includes an optimal degree of risk exposure and damage compensation. Of course this view recognizes that there are both market imperfections and policy limitations, so that from time to time improvements should be attempted here and there, but no far-reaching overhaul is required.

Unfortunately, this rosy view is not up to the challenge of new systemic risks (see section 2.2). In the standard view of global environmental change, e.g., constraining the activities of the present generation in order to avoid risks for future generations necessarily makes the present generation worse off (Nordhaus 2008). This means that win-win options are excluded by construction,
making effective policies to tackle global systemic risks very difficult, often impossible, to implement.

More generally, if integrated risk governance is to tackle the new systemic risks it will require major innovations in the institutional fabric for risk governance as well as in the paradigm that has provided the essential scientific threads in that fabric. In section 2.3 we will discuss some core ideas for the breakthrough in risk research that a successful development of integrated risk governance will imply. In order to contribute to this breakthrough from a theoretical side, IRG Project will focus on the following ideas that not only look promising but on which members of IRG Project have a strong record of own work:

**Risk spectra:** The institutions that shape the present global economy and world society systematically lead to a shift from short-term to long-term risks (van der Leeuw 2012). Studying the mechanisms driving this dangerous shift and developing practices of risk governance that counteract them are critical tasks of IRG Project.

**Rationalities:** Coping with the uncertainty of new systemic risks, especially at a global scale, will require Western rationality as we know it to engage in a new kind of dialogue with other traditions. The fact that IRG Project very much started with a dialogue between Chinese and European thinking about disaster risk (Shi et al., 2013) suggests that it can be a fertile growth for new insights about how new rationalities can evolve to cope with new risks.

**Complex systems:** To become able to uncover and/or create win-options for sustainable development, it is necessary to study human agents as components of socio-ecological systems. Disaster risks reduction then can be studied in view of transitions from disaster-prone equilibrium to ones that are capable to avoid critical disasters while being more resilient in the face of other ones we will continue to live with.

**Consilience:** When studying socio-ecological systems, one would like to have some measures of overall characteristics of the – usually complex – network one is dealing with. In view of integrated risk governance, it is often essential to distinguish connections depending on the states of the respective nodes. IRG Project has begun work in this direction by introducing the concept of consilience and defining quantitative measures for it (Shi et al. 2014).

**Institutional assessment and development framework IAD:** Last not least, the theoretical work of IRG Project will build on the institutional assessment and development framework (IAD, see Ostrom, 2011). This framework was developed as part of a comprehensive answer to one of the most influential applications of the rational actor paradigm, and one of direct relevance for global environmental risks: the idea of a tragedy of the commons (Hardin, 1968). IRG Project offers a unique opportunity to develop the IAD framework into a key component of a theory of integrated risk governance.
In line with the idea of Pasteur's Quadrant and of stakeholder involvement, IRG Project will not develop separate projects for each one of these theoretical points. Rather they will be integrated into the study of the following research topics dealing with integrated risk governance.

1.6 Focal Research Topics

In the coming years, the work of IRG Project will be structured by the following five focal research topics. Other issues may be added in the course of time, but these form the points of reference to begin with.

Natural Disasters and Advanced Technologies: In view of the integrated governance of natural disaster risks, a first contribution of IRG Project will be to develop and maintain its world risk atlas. Taking advantage of advanced technologies like big data from remote sensing and processing capabilities from high-performance computing in producing the world risk atlas is both mandatory and feasible at the present stage. Second, comparisons of regional case studies will be conducted systematically to understand how one and the same society deals with different risks and how different societies deal with one and the same risk. Third, by working closely with UN-ISDR, IRG Project will help turning good science into good decision making. By taking advantage of fast developments in information and communication technology (ICT), IRG Project will launch a range of initiatives to support more effective interaction between the two communities.

Figure 3 World Nature Disaster Risk Map produced by IRG Project (2015)
**Coastal Zones and Climate Change**: Integrated risk governance in coastal zones will be a key area of inquiry for IRG Project, not least because of the involvement of the IPCC lead author on coastal zones, Jochen Hinkel, and of excellent contacts with coastal zone experts in The Netherlands, the UK, China and other countries (Hinkel et al. 2015). Cooperation with the Future Earth project LOICZ – Land-Ocean Interactions in the Coastal Zone, will be an important aspect of this work. IRG Project will look at coastal zones from a different angle, though, by emphasising the perspective developed in the present document. An important aspect will be the study of coastal zones along the 21st Century Maritime Silk Road that shall connect the Southern shores of Asia with East Africa, the Middle East and Europe. Addressing local risks like extreme events so as to pay attention to possible disaster cascades is one example of the tasks IRG Project will perform with regard to this research topic.

![Figure 4 Illustration of scenarios for GMSL rise](Hinkel, et al., 2015)

**Urbanization and Agriculture**: Since its beginnings thousands of years ago until today's development of megacities, urbanization has been a key factor fostering innovation, but also new systemic risks. This has happened in two ways. On the one hand, the generation and spread of non-sustainable patterns of urban development has led to risks like local air pollution and global climate change. On the other hand, the generation and spread of non-sustainable agricultural practices has led to risks of its own. Examples include concerns about biodiversity but also about food safety, both in terms of quantity and perhaps...
even more so of quality. IRG Project will look at both sides of this dynamics, paying special attention to new systemic risks as unintended consequences of actions aiming at other goals.

**Urban Expansion**

The proportion of China’s population living in cities has risen steadily since the 1970s (1). Workers moving from rural areas to cities are prevented from integrating, however, by a household registration system that restricts them from officially changing their permanent residence. Urban populations concentrate in the eastern part of the mainland (2).

1. **Relocation trends**

   ![Graph showing relocation trends](image)

   - Urban Proportion
   - Proportion registered
   - Rural living in cities as living in cities
   - Population (100 millions)
   - Proportion (%)
   - 52.6% in 2010
   - 35.3% in 1980

2. **Mainland cities**

   ![Map showing mainland cities](image)

   - Population density in 2010 (people per km²):
     - Below 10
     - 10-50
     - 50-100
     - 100-500
     - 500-1,000
     - Above 1,000
   - Urban population: Below 200,000, 200,000-500,000, 500,000-1 million, 1 million-2 million, 2 million-5 million, Above 5 million

**Figure 5 Challenges of China’s urban dream** (Bai、Shi and Liu, 2015)

Financial Markets and Global Systems: IRG Project will look at financial risks in view of similarities and differences with disaster risks in other global systems.
A key tool for this purpose will be the notion of consilience (Shi et al., 2014). It shall be used to analyze the relevance of the May-Wigner theorem for the stability of financial markets and other global systems. This theorem contradicts the widespread hypothesis that in ecosystems greater biodiversity implies greater resilience. With regard to financial markets, it provides an argument for broad, simple measures and against increasingly complex regulatory schemes. An example of such an approach is the proposal to stabilize stock markets via qualitative easing (Farmer 2013). This would complement the present actions of central banks to ensure monetary stability with actions to dampen excess volatility on stock markets. Consilience analysis can help assessing and improving such proposals, and it can do so in ways that draw on the transdisciplinary character of much Future Earth research, including IRG Project.

Figure 6 Differences between some connection degree (CND) based and consilience degree (CSD) based network models (Hu, et al., 2015)

**Green Growth and Integrated Risk Governance:** In the 21st century, humankind as a whole will have to learn to avoid the systemic risks generated by traditional economic growth. This will require huge investments into infrastructures with which we are not yet familiar. As a result, there is an additional kind of risk to be dealt with: the risk of misplaced and mismanaged investments aiming at sustainable development. This kind of risk is especially serious with the large-scale investments that will be necessary to create and maintain the critical infrastructures of the future (Flyvbjerg et al. 2003). A case in point is the Silk Road Economic Belt. It offers an opportunity to realize a trajectory of green growth on the Eurasian continent, with obvious relevance to
the world as a whole. IRG Project will look into the challenges of integrated risk governance for critical infrastructures like those involved in the Economic Belt. This cannot happen by proposing some allegedly risk-free scheme for managing critical infrastructures. Rather a long-term monitoring and analysis of how the Economic Belt and similar infrastructures evolve is required.

Research on these focal topics can help to establish integrated risk governance as an on-going process of learning how to keep risks in an acceptable domain, including learning from experiences of disaster, relief and reconstruction. The work of IRG Project in the past years as well as its cooperation with UNISDR make it an ideal platform for this purpose.

![Figure 7 China’s “One Belt One Road” Strategy](image)

1.7 Conclusion

IRG Project will contribute to Future Earth by expanding and consolidating the knowledge presently available for the purposes of risk management and governance. It will do so in different ways for each one of the three broad research themes defined by Future Earth: Dynamic Planet, Global Development, and Transformations towards Sustainability (Future Earth 2015c).

With regard to the research theme “Dynamic Planet”, an essential part of it consists in “Anticipating global thresholds and risks”. IRG Project will contribute to this both by the study of specific risks, especially risks of disasters like breakdowns of critical infrastructures, and of slow-onset events like sea-level rise. But the key contribution will be in the integrative perspective. IRG Project
will help to establish risk maps and metrics to facilitate an orientation and prioritize not only sectorial, but also in terms of integrated strategies of risk governance.

This ties in organically with a key task under the research theme “Global Development”, namely to provide knowledge for the “stewardship of food, water, biodiversity, energy, materials, and other ecosystem functions and services”. The key challenge here for IRG Project is to relate the risks identified in view of the first theme to the needs of global development. In the rational actor paradigm, the related decision problems are structured along the two axes of utility and probability. Useful as this is, it needs to be embedded in a much larger variety of dimensions. To identify these, however, requires precisely the enhancements of the paradigm that IRG Project is aiming at.

No doubt the theme closest to the intent of IRG Project is “Transformations Towards Sustainability”, with the key tasks of “Understanding transformation processes and options” as well as “Evaluating strategies for governing and managing the global environment across sectors and scales”. According to Future Earth, “This might include significant shifts in political, economic and cultural values, changes in institutional structures and individual behaviors”. Developing the factual, methodical and theoretical knowledge about key risks of global environmental change, but also of policies to address them, is indispensable to achieve successful transformations towards sustainability. Equally important will be the emergence of institutions and practices that embody this knowledge. The sustainability transition will consist to a large extent in developing the capability to deal with systemic risks in a reasonable and responsible way. This is what IRG Project will work on in the period 2016-2020.
PART II: THE CHALLENGE

2.1 Growing out of Natural Disasters

There is a shocking difference between the impact of natural disasters in industrialized and in developing countries. Generally speaking, rich countries have found ways to reduce the impact of natural disasters to socially acceptable levels. In developing countries, however, reducing the number of casualties as well as the impact on productive capacity has proved extremely difficult. Even if hurricane Katrina caused a death toll of nearly 2'000 and the Tohoku earthquake caused a death toll of more than 15'000, these are exceptional impacts in rich countries while in developing countries much larger death tolls are frequent. The 2004 tsunami in the Indian ocean, that hit mainly developing countries, killed more than 200'000.

The damages from Katrina were in the order of 100 billion USD and those of Tohoku twice as large. But these figures still represent relatively small fractions of the American and Japanese capital stock in comparison with the damages experienced in poor countries. Moreover, the impact of both Katrina and Tohoku would have been much smaller if the respective countries had used the best available and – for these countries – affordable technologies for early warning and protection.
As a consequence of this gap, in the coming years it will be one of the tasks of IRG Project to help developing countries to acquire as fast as possible the material resources and the know-how that enable rich countries to successfully manage natural disaster risks. This will happen in close cooperation with UNISDR as well as with international projects targeted at specific countries and/or disaster types. The considerable successes of China in reducing the impact of natural disasters over the past decades – with significant contributions from scholars and institutions now involved in IRG Project – show that significant progress is possible and should be intensified.

2.2 Western Rationality and Global Risks

The impressive successes of industrialized countries in managing natural disasters are due to the development of science and technology together with the accumulation of capital and the establishment of professionally organized institutions. Altogether these are successes of Western rationality, a way to mobilize the self-interest of individuals, organizations and nations in order to solve problems considered in isolation. Over the past centuries, this kind of rationality has shaped the world economy. It has enabled industrialized nations to manage natural disasters with the help of insurance and re-insurance companies. And it has enabled all sorts of companies to manage business risks with the help of national governments and the financial sector.

Meanwhile, however, it is becoming clear that Western rationality itself has created a new kind of risks that it does not know how to deal with. Awareness of this situation goes back at least to the invention of the atomic bomb, that led Einstein to say (in a quote that has been reformulated in many ways): “Our situation is not comparable to anything in the past. It is impossible, therefore, to apply methods and measures which at an earlier age might have been sufficient” (Green, 2003, p.52). A first characteristic of the new kind of risks is that they affect humankind as a whole. This holds for the risks of global environmental change as well, especially climate risks and risks to biodiversity. It also holds for global financial instabilities, for the danger of pandemics, and more generally for what the OECD (2011) calls future global shocks.

A second characteristic of the new kind of risks is that they are the result of incredibly successful scientific and technological advances. This has created a profound tension between knowledge claims by scientifically trained experts and the doubts and beliefs entertained by other stakeholders and the public at large. Renn (2008, see also Renn and Klinke, 2004, and Renn and Walker 2008) has reacted to this tension by developing the concept of integrated risk governance and successfully testing procedures to reduce and sometimes overcome it.

A third characteristic is the difficulty to consider those risks in isolation. This is due to a considerable extent to the fact that they arise as unintended consequences of a way of thinking that works precisely by considering problems
in isolation (van der Leeuw, 2008). Non-linearities, stochasticity, complex feedbacks all can result in severe problems for this approach, which is deeply rooted in Western rationality.

Altogether it seems useful to distinguish between traditional isolated risks – in particular, but not only those of natural disasters – and new systemic risks – in particular, but not only those of global reach. In the coming years, it will be a key task of IRG Project to improve the understanding of new systemic risks and the development of methods and procedures to successfully deal with them. It may well be that the encounter of Chinese and Western traditions that is happening in the daily work of IRG Project will be fruitful in this regard. A promising sign in this direction is work on a measure of network efficiency – called consilience – that has been inspired by traditional Chinese thinking and elaborated by means of advanced tools of complex networks science (Shi et al., 2014).

2.3 The Coming Breakthrough in Risk Research

Modern risk management emerged by the confluence of a theoretical and a practical development. On the one hand, mathematicians on the European continent laid the groundwork of probability theory in the 17th century. On the other hand, insurance contracts became increasingly common in London in the same century. The need for insurance became especially urgent with the expansion of trans-Atlantic slave trade, and then with the great London fire of 1666.

Meanwhile, the concepts and methods used to manage risks have been greatly expanded, sustained by the core ideas developed in those times. These ideas have shaped the paradigm of rational action in the face of risk and uncertainty. They can be summarized in the following way. Faced with risky prospect, a decision-maker should try to be as rational as possible. For this purpose, she needs first of all to identify three sets:

- the set of outcomes, \( X \), she is interested in (e.g. selling a successful new product, selling a new product without success, selling an old product with limited success).
- the set of Actions, \( A \), she can undertake (e.g. making a new product or not)
- the set of conditions, \( S \), that determine which actions may have which outcomes (e.g. the market may or may not be ready for a new product); this set then comes with a function \( E \) that takes an action and an outcome, \((a,x)\), and indicates under which conditions \( s=E(a,x) \) action \( a \) will have outcome \( x \).

Then she needs to assess two things:

- how likely it is for any consequence to occur for the different actions; this should then be represented by a probability, \( P(E(a,x)) \).
- how strongly she prefers one consequence over another; this should then be represented by a utility index, \( U(a) \).
On this basis, the expected utility of an act is defined as:

\[
EU(a) = \sum_{h=1}^{n} U(x_h) \cdot P(E(a, x_h)) \tag{1}
\]

In this view, rational actors will try to choose actions that maximize expected utility. Moreover, one should expect most actors to behave this way, because it is the best strategy and actors who don’t use it will be gradually marginalized.

In fact, the expected utility approach to action under uncertainty is a special case – and a very important one – of the rational actor paradigm that has shaped modern societies since centuries (Jaeger et al. 2001). In a way it started in the 17th century with the work of Thomas Hobbes, who introduced many ideas that later led to game theory (Eggers, 2011). One of the most important ideas of the rational actor paradigm is the strict separation of facts and values, that later led to the idea of exogenously given utility functions (Read, 2004).

Over the past centuries a huge amount of scientific research and practical application has gone into the refinement of the rational actor paradigm in general and in the expected utility approach in particular. The latter has become the cognitive basis on which modern societies have learned to manage naturally given risks – from earthquakes to infant mortality – with amazing success and to successfully engage in all sorts of projects – from shipping trade to space flight – that would have been impossible without new techniques of risk management.

It is useful to distinguish four kinds of elaboration of the expected utility approach (for an overview see Machina and Viscusi, 2014).

1) The collection of empirical data on all sorts of risks, from the first mortality tables compiled in London in the 17th century to the natural disaster database of Munich Re (2013).

2) The development of sophisticated mathematical tools to expand the scope of application of the approach. This includes methods to define probabilities over infinite sets, ways to use them as measures of uncertain beliefs, theorems about conditions for existence and uniqueness of the maximization problem and many more.

3) The linking of expected utility to public policy. This includes techniques for probabilistic cost-benefit analysis as well as ways to deal with the thorny problem of defining utility functions for political bodies, from city planning to national and even international policy-making.

4) The linking of expected utility to the analysis of market economies. It is often overlooked that expected utility has become deeply interwoven with the study not only of insurance and financial markets, but with the development of marketing strategies like product bundling, with the study of investment decisions etc. What is more, the pervasive role of game theory in shaping present understanding of economic, social and
biological phenomena would hardly be possible without the expected utility approach.

The expected utility approach enabled a cumulative growth of knowledge that enabled modern risk management. Since several decades, however, an increasing amount of evidence has emerged that increasingly challenges the whole approach (again, see Machina and Viscusi, 2014, for this). Two research lines deserve special attention in this regard:

5) Empirical research highlighting serious limitations of the expected utility approach. E.g. it has been shown that decision-makers – including successful professionals with explicit training in applying the expected utility approach – often don’t fit the expected utility format in their actual decision. This has led to a series of paradoxes and anomalies, often named after their discoverers, like the Allais paradox, the Elsberg paradox, the framing effects identified by Kahneman and Tversky, and more. These scientifically challenging results acquire significant practical relevance in view of the new systemic risks that have been triggered by the piecemeal approach of conventional risk management.

6) Theoretical research proposing alternatives to or generalizations of the expected utility approach in order to take those findings into account. This includes weighted utility theory, prospect theory and more. While these proposals still focus on an isolated decision-maker, advances in evolutionary game theory are opening up new avenues for the transition from the imaginary absolute rationality of an isolated actor to the social rationality advocated by Perrow (1984) in his seminal book on technological risks.

Against this background, two kinds of generalizations seem necessary in order to conserve the insights gained from the expected utility approach without getting trapped by its dangerous limitations. The first generalization recognizes that there are good reasons for people to anchor their expectations in a particular kind of outcome, e.g. the worst case. Based on this anchoring, the probabilities of utility differences get specific weights. These weights can express the fact that a decision-maker may see a particular action as too risky because the spread between the different outcomes is too big, even if the average outcome looks quite attractive.

Buchak (2013) has shown that this anchoring and weighting effect can be elegantly captured by defining a “Risk adjusted expected utility” as follows. One orders the outcomes from worst to best and gives weights to the probabilities of different outcomes by means of a risk function.

\[ REU(a) = \sum_{h=1}^{n} (U(x_h) - U(x_{h-1})) \cdot R(P(E(a, \{x_h...x_n\}))) \]  

(2)

Here, \(x_1\) is the worst case and \(x_0\) is a “null event” with utility and probability zero. \(R\) is the risk function giving weights to the different probabilities, with \(R(0)\)
=0 and \( R(1)=1 \). For the special case where \( R(y)=y \) for all \( y \), the risk adjusted expected utility of (2) reduces to the expected utility of (1). In the general case it gives decisions like those known from the Allais paradox as perfectly reasonable outcomes.

At first sight, it seems that REU cannot accommodate the ambiguity aversion documented in the Ellsberg paradox. There, one is faced with an urn containing 50 black and 50 white balls and a second urn containing 100 balls with an unknown proportion of black and white. If told that picking a white ball yields, say, 100$, most people prefer the urn with known proportions. If one considers risk adjusted expected utilities in a social setting with repeated bets, however, this turns out to be a perfectly reasonable norm: for the urn with known proportions, the worst case is to make 5000$, while for the urn with unknown proportions, it is to make naught. That repetition of action situations is a crucial ingredient of the human condition, in turn, leads to the second generalization of the expected utility approach.

This generalization recognizes that human beings live in social networks characterized by repeated action situations – from greeting each other to building airports and much more (Collins 2004). Through these repetitions, people learn from experience and – usually even more – by observing each other. Moreover, they try to repeat action situations that they experienced as gratifying and to avoid those they experienced as frustrating.

As a result of the second generalization, all the symbols in (2) implicitly or explicitly carry two additional indices: one for the actor and one for the time under consideration. This allows to combine the description of individual decisions with the indispensable description of how the individuals themselves as well as the networks they live in may evolve from one action situation to the next.

The result is a format of network games with a transition function that is more general than the replicator functions used in evolutionary game theory inspired from biology. The difference is due to the fact that at each stage, the actors do perform a bounded rational optimization. The bounds of rationality are set by their past experience and observations, and they shift as a result of current experience and observation (Gintis 2009).

An important example of a transition function results if one considers a population of actors that at each stage revise their probability estimates (perhaps by Bayesian updating) as a function of the outcomes resulting from their previous actions. In (3), such a function takes the actions and probability assessments of all agents, \((a, P)\), at time \( t-1 \), together with a random variable, \( \xi \), and yields the outcomes for all agents, \( x \), at time \( t \) together with their revised probability assessments, \( P \). The random variable, \( \xi \), here represents changes in the network connecting the different agents, changes that in turn may influence the updating of their probability assessments.
This kind of structure can be analyzed mathematically and implemented computationally in evolutionary agent-based models (Hallier 2014). It can be used to study systems with a single stable equilibrium, as usually assumed in economics, as well as metastable systems with several locally stable equilibrium, as seem particularly relevant for disaster risks. Catastrophic events like an earthquake, an industrial accident or a financial crisis can push a social system from one equilibrium into another one, and recovery from the catastrophe may lead to a still different equilibrium.

Of course, one can also study systems with no locally or globally stable equilibrium. Such an equilibrium consists in an action profile, \( a \), together with a neighborhood of similar action profiles such that the system stays in this neighborhood for a significant amount of time. If a society or social network is unable to maintain such equilibrium for sufficient amounts of time, it is bound to disintegrate, as patterns of communication and interaction will break down.

With the second generalization, the sets of possible conditions, \( S_{i,t} \), that matter for each agent include the possible actions by the other agents. Moreover, it is straightforward to consider objects as part of social networks (Latour, 2005). If their behavior is deterministic, for each possible condition, \( s_{i,t} \), their utility function give a positive utility only to the outcome resulting from that condition together with the resulting behavior, and their probability assessments give probability one to the actual actions of the last period.

The shift to risk adjusted expected utility and the one to iterated games with transition (not just replicator) functions has four major implications for risk management. First, risk adjustment means that worst case considerations that could be considered negligible from an expected utility perspective may now call for greater attention. Second, risk management must be seen much more systematically as an interactive process, often making reversible decisions more attractive and making explicit learning during implementation the rule, not the exception. Third, risk managers must see themselves as partners in complex webs of risk governance, paying attention to the effects of their actions on the future strategies of the other agents. And fourth, it is crucial to distinguish between marginal measures that work under the assumption that the system one is part of remains in the same basin of attraction and inframarginal measures where transition from one such basin to another one are essential.

All four implications can be spelled out with the specific format of transition functions considered in (3). This format, however, presupposes that for each agent the decision problem (2) has a unique solution, that action spaces and utility functions don’t change and that the overall network changes only in a random way.

By relaxing these assumptions, one gets the following format for a transition function:

\[
(x, P)_t = \Phi (a, P, \xi)_{t-1} \quad \text{(3)}
\]
(4) can be used to structure one’s thinking about a wide array of important phenomena and problems. Moreover, it leads to an additional, critical insight for risk management and governance. This is due to the fact that in order to get practically useful consequences for specific situations, (4) needs to be specified with the help of major additional assumptions. The question then arises of whether it is reasonable to look for practically relevant additional assumptions at this level of generality. If such attempts should succeed, that would be an astonishing achievement in the social sciences. And even if they should fail, attempts in this direction may turn out to be fruitful in other respects (for an interesting example of such an attempt, see Gintis, 2010).

It is likely, however, that many more practically relevant insights can be gained by a different strategy: specializing and modifying the generic transition function (4) in view of particular practical problems. This is less in line with the attempt to use mathematics according to the template of physics, and closer to the spirit of “phronetic research” advocated and practiced by Flyvbjerg et al. (2003) in their work on the specific risks arising in the management of megaprojects.

Why then not discard generic mathematical structures like (4) altogether and limit the role of mathematics to help in fitting equations to statistical data and to provide intuitively appealing metaphors like the prisoner’s dilemma? Because the fabric of insights and beliefs that is currently available to orient ourselves in the global economic system is firmly rooted in mathematical structures: the supply, demand, production, utility and other functions that inform economic discourse as well as decision-making. If integrated risk governance were to develop so as to ignore these structures, it would become at best irrelevant, more likely misleading. Therefore, if integrated risk governance is to be useful in the face of the risks of the future it is vital to embrace the two generalizations introduced in this section: from expected utility to risk adjusted expected utility and from plain optimization problems to a framework of iterated network games.

In this perspective, integrated risk governance needs mathematics to overcome the limitations of current economic analysis in the face of new systemic risks, and can do so best in combination with well-documented stories about particular practical experiences, be they the management of megaprojects or experiences of droughts, failed strategies to overcome organized crime or successful instances of environmental policy. So far, in-depth case studies have rarely involved sophisticated mathematical research, and path-breaking mathematical modeling has rarely related to the “thick descriptions” provided by sophisticated narratives (Kaploun, 2013). Integrated risk governance will provide plenty of opportunities to overcome this impasse in what will be a true breakthrough in risk research.
PART III: FOUNDATIONS IN PREVIOUS WORK

3.1 A Brief History of IRG Project

The task that IRG Project will perform in the frame of Future Earth during the years 2016/2019 would be impossible without the foundations laid in the work of IRG Project in the years 2006/2015.

The Integrated Risk Governance Project (IRGP) was initiated by the Chinese National Committee for IHDP (CNC-IHDP) with supports from the Ministry of Science and Technology of the People’s Republic of China in 2006. Designated by the IHDP Scientific Committee, the IRG Project Scientific Planning Committee was formed to prepare the IRG Project science plan. After careful preparation, the IHDP Scientific Committee approved IRG Project as an IHDP pilot project.

Later on, upon further revision by the IRG Project Scientific Planning Committee in view of high-level reviews, IRG Project was officially approved as one of the 8 core science projects of IHDP at the Bonn Meeting of the IHDP Scientific Committee in October 2010. IRG Project was then formally approved and launched in Beijing in 2011.

As one of the core science projects of the International Human Dimensions Programme on Global Environmental Change, IRG Project was initially designed as a ten-year international scientific research project from 2010-2019, with the mission of improving the management of new risks that exceed current human coping capacities. With research foci on the transitions in and out of the occurrence of relevant risks by combining case study, modeling, and survey methods, IHDP-IRG Project defined 6 research themes including Socio-ecological Systems, Entry- and Exit-Transitions, Early Warning Systems, Models and Modeling, Comparative Case Studies, and Governance and Paradigms.

IHDP-IRG Project is governed by its Scientific Committee and coordinated by an International Program Office (in Beijing) with five regional offices around the world (Europe Regional Office, Southeast Asia Regional Office, Northern America Regional Office, Africa Regional Office, and Latin America Regional Office). For the first five years, IHDP-IRG Project members were awarded more than 10 million EURO for related research from various government agencies worldwide.

One of the purposes of establishing the Integrated Risk Governance Project (IRG Project) was to provide network and platform support to share models, data sets, knowledge and open source technologies, as well as to coordinate the training and dissemination of these tools to the international risk governance research and education community. To fulfill this purpose, IRG Project co-sponsored and participated in various international conferences such as the Global Risk Forum in Davos, Switzerland and the Natural Hazard Center Annual
Workshop in USA, as well as the International Association for Disaster Risk Management in Japan. Moreover, IRG Project launched its designated international journal in 2010. The journal provides an excellent opportunity to share up-to-date research results and IRG Project activities with the international risk research community.

In the past five years, about 11 new initiatives (several have been separately funded by now) were developed. As one of the highlights, as a multi-institutional, interdisciplinary community of natural scientists, social scientists, engineers, policy makers as well educators around the world, the Global University Consortium for Integrated Risk Governance (GUC-IRG) was launched in September 2012. Currently, more than 50 universities’ graduate certificate programs have joined the GUC-IRG and worked together to develop and apply theoretic, mathematical and computational tools for the decision making processes in the case of very large-scale disasters around the globe.

Several papers published in the IRG Project journal have already been well cited by other researchers. By signing the publishing contract with the world-known publishing house, Springer, the first book of the IRG Project book series – “Integrated Risk Governance - Science Plan and Case Studies of Large-scale Disasters” was published in August 2012.

3.2 Organization

3.2.1 Project Scientific Advisory Committee

IRG Project is governed by its Scientific Advisory Committee (SAC). The IRG Project SAC was formally inaugurated on August 11, 2011. It consists of 17 members covering a wide spectrum of academic disciplines (Table 1). The committee meets twice a year hosted by regional offices. The first SAC meeting was held in Beijing Normal University during August 11-12, 2011. Dr. Dagmar Schröter was elected by the committee as the SAC chair.

<table>
<thead>
<tr>
<th>Name</th>
<th>Discipline</th>
<th>Country working now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. Carlo Jaeger</td>
<td>Economics</td>
<td>Germany/China</td>
</tr>
<tr>
<td>Prof. Peijun Shi</td>
<td>Geography</td>
<td>China</td>
</tr>
<tr>
<td>Prof. Qian Ye</td>
<td>Atmospheric Sciences</td>
<td>China</td>
</tr>
<tr>
<td>Prof. Adrian Gheorghe</td>
<td>Engineering</td>
<td>USA</td>
</tr>
<tr>
<td>Dr. Armin Haas</td>
<td>Economics</td>
<td>Germany</td>
</tr>
<tr>
<td>Name</td>
<td>Discipline</td>
<td>Country working now</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Dr. Dagmar Schröter</td>
<td>Ecology</td>
<td>Austria</td>
</tr>
<tr>
<td>Dr. Michael H. Glantz</td>
<td>Politic Sciences</td>
<td>USA</td>
</tr>
<tr>
<td>Prof. Sander van der Leeuw</td>
<td>Anthropology</td>
<td>USA</td>
</tr>
<tr>
<td>Prof. Ilan Sandor Chabay</td>
<td>Chemistry</td>
<td>Germany</td>
</tr>
<tr>
<td>Dr. Xiubin Li</td>
<td>Geography</td>
<td>China</td>
</tr>
<tr>
<td>Prof. Urbano Fra</td>
<td>Urban planning</td>
<td>Spain</td>
</tr>
<tr>
<td>Prof. Norio Okada</td>
<td>Disaster Sciences</td>
<td>Japan</td>
</tr>
<tr>
<td>Prof. T. C. Pan</td>
<td>Civil Engineering</td>
<td>Singapore</td>
</tr>
<tr>
<td>Prof. Roger E. Kasperson</td>
<td>Risk Management</td>
<td>USA</td>
</tr>
<tr>
<td>Prof. Diana Mangalagiu</td>
<td>Policy</td>
<td>France</td>
</tr>
<tr>
<td>Prof. John Finnigan</td>
<td>System Sciences</td>
<td>Australia</td>
</tr>
<tr>
<td>Dr. Myanna Lahsen</td>
<td>Science Policy</td>
<td>Brazil</td>
</tr>
</tbody>
</table>

### 3.2.2 Regional Offices

To better coordinate the research work at regional levels and disseminate the results to the local stakeholders more efficiently, IRG Project worked with several universities in different continents which volunteered to host a regional office. Five regional offices were launched, although the regional offices in Africa and Latin America are now temporally out of function due to funding restrictions.

#### Table 2 IRG Project Regional Offices

<table>
<thead>
<tr>
<th>Region Covered</th>
<th>Host Institute</th>
<th>Contact Person</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Global Climate Forum</td>
<td>Christiane Völker</td>
<td><a href="mailto:christiane.voelker@globalclimateforum.org">christiane.voelker@globalclimateforum.org</a></td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>Nanyang Technological University</td>
<td>Prof. Tso-Chien Pan</td>
<td><a href="mailto:cpan@ntu.edu.sg">cpan@ntu.edu.sg</a></td>
</tr>
<tr>
<td>Northern America</td>
<td>University of Colorado</td>
<td>Prof. Michael Glantz</td>
<td><a href="mailto:michael.glantz@colorado.edu">michael.glantz@colorado.edu</a></td>
</tr>
<tr>
<td>Africa</td>
<td>Mekelle University</td>
<td>Dr. Kiros Meles Hadgu</td>
<td><a href="mailto:kirhadgu@gmail.com">kirhadgu@gmail.com</a></td>
</tr>
<tr>
<td>Latin America</td>
<td>Universidad de Chile</td>
<td>Prof. Alejandro Leon</td>
<td><a href="mailto:aleon@renare.uchile.cl">aleon@renare.uchile.cl</a></td>
</tr>
</tbody>
</table>
3.2.3 Research Team

In order to coordinate the research themes identified in the IRG Project Science Plan, i.e., Socio-ecological Systems, Entry- and Exit-Transitions, Early Warning Systems, Models and Modeling, Comparative Case Studies, and Governance and Paradigms, six research teams were formed.

Table 3 IRG Project Research Teams

<table>
<thead>
<tr>
<th>Research Theme</th>
<th>Host Institute</th>
<th>Leading Scientists</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social-ecologic system</td>
<td>Arizona State University</td>
<td>Prof. Sander Van de Leeuw</td>
<td><a href="mailto:vanderle@asu.edu">vanderle@asu.edu</a></td>
</tr>
<tr>
<td>Model and modeling</td>
<td>Nanyang Technological University, Old Dominion University</td>
<td>Prof. Tso-Chien Pan</td>
<td><a href="mailto:cpan@ntu.edu.sg">cpan@ntu.edu.sg</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. Adrian Gheorghe</td>
<td><a href="mailto:adriangheorghe9145@gmail.com">adriangheorghe9145@gmail.com</a></td>
</tr>
<tr>
<td>Entry/exit mechanism</td>
<td>Global Climate Forum</td>
<td>Prof. Carlo Jaeger</td>
<td><a href="mailto:carlo.jaeger@globaclimateforum.org">carlo.jaeger@globaclimateforum.org</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. Armin Haas</td>
<td><a href="mailto:armin.haas@pik-potsdam.de">armin.haas@pik-potsdam.de</a></td>
</tr>
<tr>
<td>Early warning system</td>
<td>Mekelle University, China National Disaster Mitigation Center</td>
<td>Dr. Kiros Meles Hadgu</td>
<td><a href="mailto:kirhadgu@gmail.com">kirhadgu@gmail.com</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dr. Yida Fan</td>
<td><a href="mailto:fanyida@ndrcc.gov.cn">fanyida@ndrcc.gov.cn</a></td>
</tr>
<tr>
<td>Case comparison</td>
<td>University of Colorado, Beijing Normal University</td>
<td>Prof. Michael Glantz</td>
<td><a href="mailto:Tierneyk@colorado.edu">Tierneyk@colorado.edu</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. Peijun Shi</td>
<td><a href="mailto:spj@bnu.edu.cn">spj@bnu.edu.cn</a></td>
</tr>
<tr>
<td>Risk governance paradigms</td>
<td>Beijing Normal University, Kyoto University</td>
<td>Prof. Peijun Shi</td>
<td><a href="mailto:spj@bnu.edu.cn">spj@bnu.edu.cn</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. Norio Okada</td>
<td><a href="mailto:n_okada@drsprikkyoto-u.ac.jp">n_okada@drsprikkyoto-u.ac.jp</a></td>
</tr>
</tbody>
</table>

3.2.4 Budget

The members of IRG Project provided their own resources to conduct research, education and outreach activities. In the past five years, the IRG Project IPO got 1 million RMB (equivalent to about 100K EURO) per year for its daily operation from the Ministry of Science and Technology of China and $20K USD from IHDP to support IRG Project SAC activities.
3.3 Scientific Achievements

3.3.1 Selected research initiative and funded projects

IRG Project comprises a multi-institutional, interdisciplinary team of natural scientists, social scientists, engineers, policy makers as well educators around the world who have come together to develop and apply theoretical, mathematical and computational tools for decision-making processes in view of very large-scale disasters around the globe. In the past five years, the IRG Project community has initiated more than a dozen research proposals and many of them have been funded by China, EU, USAID and other international agencies, with a rough total amount of 10 million EURO.

Table 4: Highlights of research initiatives and funded projects since 2011

<table>
<thead>
<tr>
<th>Name</th>
<th>Proposed date</th>
<th>Leading Institutes</th>
<th>Leading Scientists</th>
<th>Main Themes</th>
<th>Main Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Health Initiatives</td>
<td>October, 2010</td>
<td>Colorado State University and Beijing Normal University</td>
<td>Mike Manfredo (CSU), Lou Anru (BNU)</td>
<td>Human, wildlife and ecosystem health Modeling</td>
<td>Sponsored &quot;One Health Summit&quot; in GRF Davos Conference</td>
</tr>
<tr>
<td>Southeast Flood Toolbox</td>
<td>May, 2011</td>
<td>Nanyang Technology University, Beijing Normal University, and University of Vermont</td>
<td>Tso-Chien Pan (NTU), Lixin Wu (BNU), Zia (UVM)</td>
<td>Flood model Remote sensing Social system</td>
<td>Research project funded and in progress</td>
</tr>
<tr>
<td>Global University Consortium for IRG</td>
<td>September, 2012</td>
<td>MU, BNU, NTU, KU, GCF/PIK, CSU, CU, ODU</td>
<td>Kiros Meles Hadgu (MU), Peijun Shi (BNU), Tso-Chien Pan (NTU), Yan Wangli (KU), Armin Haas (PIK), Mike Manfredo (CSU), Micky Glantz (CU), Adrian Gheorghe (ODU)</td>
<td>Developing a global education network for training future generation</td>
<td>Three Summer Institutes in Beijing and three International Conference in Japan</td>
</tr>
<tr>
<td>Name</td>
<td>Proposed date</td>
<td>Leading Institutes</td>
<td>Leading Scientists</td>
<td>Main Themes</td>
<td>Main Achievement</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---------------</td>
<td>--------------------</td>
<td>------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Comparison Studies on Integrated Risk Governance Technology and Paradigm for Typical Vulnerable Regions</td>
<td>May, 2011</td>
<td>IBNU, NTU, MU and CU</td>
<td>Li Ning (IBNU), Tso-Chien Pan (NTU), Kiros Meles Hadgu (MU), Kathleen Tierney (CU)</td>
<td>Prevention Technology for Yunnan Earthquake Greensburg Recovery in USA Droughts in Africa</td>
<td>2nd Workshop in Nanjing, textbooks published in early 2012</td>
</tr>
<tr>
<td>Global System Dynamics and Policy</td>
<td>May, 2011</td>
<td>Global Climate Forum</td>
<td>Carlo Jaeger</td>
<td>Bridging scientific community and policy makers</td>
<td>Workshops</td>
</tr>
<tr>
<td>Global System Sciences and Green Development</td>
<td>May, 2013</td>
<td>GCF/PIK, DRC</td>
<td>Carlo Jaeger (GCF/PIK), Yongsheng Zhang (DRC)</td>
<td>New Thinking for Global Systems</td>
<td>Workshops in Germany and China funded 1 million RMB</td>
</tr>
<tr>
<td>Risk Governance Toolbox</td>
<td>December, 2011</td>
<td>IGES, KU, IBNU, PIK, DRC/CN, CU and CICERO</td>
<td>Mokama Hironori (IGES), Kobayashi and Yan Wanglin (KU), Qian Ye (IBNU), Armin Haas (PIK), Yongsheng Zhang (DRC), Mickey Glantz (CU), Ilan Kelman (CICERO)</td>
<td>Climate Change Risks, Low-carbon Society and Green Development</td>
<td>Side events in UNFCCC conferences in Qatar and Poland</td>
</tr>
<tr>
<td>Climate Change Risk Disclosure</td>
<td>October, 2010</td>
<td>CU, IBNU, XMU, GCF/PIK, GIZ</td>
<td>Micky Glantz (CU), Qina Ye (IBNU), Duan Hongxia (XMU), Carlo Jaeger (GCF/PIK), Hu Qiying (GIZ), Yongsheng Zhang (DRC)</td>
<td>The Role of Financial Markets and Engineers in Green Development</td>
<td>2nd Workshop in Nanjing, textbooks published in early 2012</td>
</tr>
<tr>
<td>Global Change, Environmental Risk and Its Adaptation Paradigms</td>
<td>March, 2010</td>
<td>IBNU, IGSNRR, IAP, NDRCC</td>
<td>Peijun Shi and Ning Li (IBNU), Jianqi Sun (IAP), Qihong Tang (IGSNRR)</td>
<td>Understanding formation mechanism of environmental risk, investigating governance paradigm of environmental risk</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Name</td>
<td>Proposed date</td>
<td>Leading Institutes</td>
<td>Leading Scientists</td>
<td>Main Themes</td>
<td>Main Achievement</td>
</tr>
<tr>
<td>-------------------------------------------</td>
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<tr>
<td>Lessons learned from Disaster Recovery</td>
<td>June, 2011</td>
<td>CU, BNU, MU</td>
<td>Micky Glantz (CU), Qian Ye (BNU), Tsegay Wolde-Georgis (MU)</td>
<td>Case Comparisons around the World</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Super-Ensemble Projection and Attribution of Climate Change Based on the Coupled Model Inter-comparison Project phase 5 (CMIP5) (Major national scientific research projects, 973)</td>
<td>August, 2010</td>
<td>BNU</td>
<td>Wenjie Dong (BNU)</td>
<td>quantitative assessment of the contributions of the greenhouse gas emissions from developed and developing countries to global warming</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Relationship Between Global Change and Environmental Risks and Its Adaptation Paradigm (Major national scientific research projects, 973)</td>
<td>December, 2011</td>
<td>BNU</td>
<td>Peijun Shi (BNU)</td>
<td>Global change and environmental risks mechanism, evolution processes, integrated assessment model, adaptation paradigm</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Observational and Modeling Studies of Cloud, Aerosol and Their Climate Effects (Major national scientific research projects, 973)</td>
<td>January, 2013</td>
<td>BNU</td>
<td>Zhanqing Li (BNU and UMD)</td>
<td>Observation of aerosol-cloud droplet nucleation process, modeling and mechanism studies of aerosol-cloud-precipitation process</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Integrative Modeling and Strategic Planning for Regional Sustainability under Climate Change (Major national scientific research projects, 973)</td>
<td>April, 2014</td>
<td>BNU</td>
<td>Jianguo Wu (BNU and ASU)</td>
<td>Relationship between climate change and human activities on landscape and regional scales</td>
<td>Books and high-level papers</td>
</tr>
<tr>
<td>Name</td>
<td>Proposed date</td>
<td>Leading Institutes</td>
<td>Leading Scientists</td>
<td>Main Themes</td>
<td>Main Achievement</td>
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<tr>
<td>Basic Theories and Assessment for Impacts of Geoengineering (Major national scientific research projects, 973)</td>
<td>January, 2015</td>
<td>BNU</td>
<td>John Moore (BNU)</td>
<td>Mechanism studies of geoengineering, impact on climate system and international governance of geoengineering</td>
<td>Project will be initiated in 2015.</td>
</tr>
</tbody>
</table>

### 3.3.2 Highlights of scientific achievements

In a new and uncertain geological era, the Anthropocene, large scale disasters, which are caused by many known and unknown human and natural causes and exceed the current coping capacity of even the most capable socio-ecological systems, are increasingly threatening global sustainability. Reducing losses caused by natural disasters and reinforcing public safety have now become an arduous but important task for all levels of governments in the world to achieve their sustainable development goals.

To better govern global systemic risks, however, it has been fully recognized by the scientific community that a multi-institutional, interdisciplinary community of natural scientists, social scientists, engineers, policy makers and other practitioners as well as educators from around the world is needed in order to deal with complex and inter-connected disaster chains. By coordinating efforts of the global risk research community, IRG Project tackled a broad spectrum of important issues in the past three years. Some important research highlights can be summarized as follows:

1) Case comparison studies on disaster chains. Due to the increasing degree of global connectivity and fast social-economic development both in developed countries and more significantly in emerging market countries, it has been observed recently that the local disasters often spread out affecting not only the global economy but also generating severe social and political impacts. A major example is the extraordinary earthquake in northeast Japan which triggered a Tsunami and in turn caused the failure of nuclear power plants. The impact of this triple disaster then had impacts as far as in Germany with a policy of phasing-out nuclear energy, including the instantaneous shutdown of some nuclear plants. To better describe such phenomena, the concept of disaster chains was first introduced by the Chinese scientist Guo Zhenjian in 1987, and then studied extensively recently. It provides an approach to develop a comprehensive understanding of logical relationships and correlations between various hazards driven by a single large-scale disaster. By structuring disasters into a hierarchic causality graph, techniques of
Bayesian Risk Management are used to improve the frequently underestimated loss of very large-scale disasters by using individual hazard or multi-hazard methods.

2) Applying scientific knowledge to better service decision and policy makers. Supporting policy makers to develop national disaster policies and plans is one of the top priorities for IRGP. Global experience has shown that if a country is to introduce and maintain effective and appropriate disaster risk reduction, it must first understand the temporal and spatial patterns of the hazards and disaster risks it faces. For example, The Atlas of Hazards and Disaster Risks in China developed by Chinese scientists has been used extensively and efficiently to support disaster risk reduction plans in China. Data for the Atlas was systematically identified from a national database of natural disasters, official government statistics and from newspapers and other media sources. Collated data was validated by scientists and then brought together for spatial and temporal analysis of hazards, exposure and vulnerability in a comprehensive risk assessment process. This allowed disaster risks to be quantified, prioritized and communicated in an accessible, meaningful manner, based on results from risk communication science.

3) New approaches to deal with regional impacts of climate change. Currently, climate change is generally recognized at a global scale. More and more research demonstrates that with current rates of global warming, the frequency, intensity, and duration of extreme weather and climate events may increase. Rare events of low-temperature freezing rain and snow disasters in Europe, Asia, and North America in recent years, heat waves in Europe in 2003 and 2010, and other disasters have greatly affected people's safety and economic security, with losses of tens of thousands of lives and damages equating to several hundred billion US dollars. The whole world is susceptible to extreme weather and climate events. Our research shows that it will remain a major challenge for governments to relieve the enormous pressure of extreme weather and climate events on people and their activities. Therefore, more effort should be paid to improve the ability of people and their activities to adapt to climate diversity on a temporal scale. Measures such as enhancing disaster prevention systems, risk transfer, risk awareness, and science and technology for coping with extreme weather and climate events should be adopted as soon as possible. More investment in manpower, building reliable financial structures, and preparing sufficient disaster relief supplies are needed accordingly.

4) Applying the concept of consilience for very large scale disaster governance. With the consideration of the more than 20 years of experiences and lessons of the United Nations on disaster mitigation and reduction, the IRG Project research team has proposed to develop a new
governance model by applying the concept of consilience. In the new model, the responsibilities and rights of stakeholders, the generality and individuality of disasters at different spatial-temporal scales, similarity and differences of social-economic systems before, during, and after disasters, and the peculiarities and limitations of different measures will be integrated with common goals. Under this model, one should first consider wide spectra for both spatial and temporal scales in the action dimension, so as to integrate economic, political, cultural, social and ecological activities. Second, any action taken should integrate vulnerability-reducing, resilience-improving, and adaptation-enhancing measures in order to optimize safety, disaster relief and rescue, emergency response and risk transfer. The disaster risk reduction system can then integrate disaster preparation, emergency response, restoration and reconstruction.

3.4 Key Products

3.4.1 Publications

3.4.1.1 Books

IRG Project signed a publishing contract with Springer to publish a book series based on IRG Project research findings. So far, the following books have been published.

- IHDP-IRG Science Plan and the Integrated Risk Governance of Large Scale Disasters
- Infranomics: Sustainability, Engineering Design and Governance (with more than 3000 download from Springer’s open access website)
- Altas of World Disaster Risks
- Natural Disaster Risks in China

Figure 9 IRG Project book serise
3.4.1.2 Research papers

IRG Project launched its designated International Journal of Disaster Risk Science in 2010, published by the world-known publishing house, Springer. The journal provides an excellent platform to share up-to-date research results and the IRG Project’s activities with the international risk research community. Until June 2014, there have been a total of 16 issues with 92 papers. Several papers have already been well cited by other researchers. In early 2015, the journal was accepted by various international citation indexes.

![IRG Project journal](image)

**Figure 10** IRG Project journal

3.4.2 Workshops/Conferences

IRG Project made substantial progress with a focus on forging alliances around the world to assure that the efforts of the planned research foci were well integrated toward the attainment of common and specific goals. To make IRG Project stand out from many existing risk related international academic organizations and international and national government sponsored programs, our science team has taken all possible opportunities to promote ourselves by co-sponsoring and attending other international activities including workshops, conferences and community network development.
### Table 5 Co-sponsored and co-organized workshops and conferences

<table>
<thead>
<tr>
<th>Name</th>
<th>Place and time</th>
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<tbody>
<tr>
<td>UNFCCC COP Conference side events co-organized with Chinese Association for Sciences and Technology</td>
<td>Durban, Qatar, Warsaw late year, 2012</td>
</tr>
<tr>
<td>Special Conference on National Disaster Day co-organized with Chinese National Disaster Reduction Center</td>
<td>Beijing, China around May 12 (2010-2014)</td>
</tr>
<tr>
<td>One Health Conference co-sponsored with Global Risk Forum Davos</td>
<td>Davos, Switzerland (2011-2014)</td>
</tr>
<tr>
<td>Natural Hazard Center Annual Conference co-sponsored with University Colorado</td>
<td>Colorado, USA every July (2011-2014)</td>
</tr>
<tr>
<td>IDRiM Annual Conference co-sponsored with IDRiM</td>
<td>Around world in fall (2010-2014)</td>
</tr>
<tr>
<td>International Symposium on Catastrophe Risk Management co-sponsored with Nanyang Technology University</td>
<td>Singapore in spring, 2011-2014</td>
</tr>
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</table>

### 3.4.3 Training and Education

One of the purposes of establishing the Integrated Risk Governance Project (IRG Project) is to provide network and platform support to coordinate the training and dissemination of new knowledge and information to the international education community. Starting in 2010, an International Summer Institute on Disaster Risk Sciences has been conducted at Beijing Normal University. This summer institute is co-sponsored by IRG Project and the “111” Project – “Integrated Disaster Risk Sciences” of the Ministry of Education, China. So far, there have been more than 180 graduate students and early career scientists and managers participating in two-week summer training programs (2010-2012; 2014).
Figure 11 “111” Project
PART IV: The Plan FOR THE FUTURE

4.1 IRG Project and Future Earth

At the UN Conference on Sustainable Development in Rio in 2012, broad sustainability objectives have been adopted (UN, 2012). The global scientific research community, however, has warned for decades that the world is now living in a new and uncertain geological era, the Anthropocene (IGBP, 2010). In this new era, large scale disasters, caused by a mix of known and unknown human and natural causes and exceeding the current coping capacity of even the most capable socio-ecological systems, are increasingly threatening global sustainability (Integrated Risk Government Project Science Plan, 2012).

Reducing losses caused by natural disasters and reinforcing public safety have become arduous but important tasks for all levels of governments in the world to achieve their sustainable development goals. To better govern new systemic risks, however, a multi-institutional, transdisciplinary community of natural scientists, social scientists, engineers, policy makers and other practitioners as well as educators from around the world is needed in order to deal with complex and inter-connected disaster chains.

As the international global environmental change research community is now moving into the new joint effort of Future Earth, IRG Project will continue working with the established international scientific network developed by IHDP with an overall goal of supporting global sustainable development by reducing risks induced by very large-scale disasters.

The Integrated Risk Governance Project is a Core Project of Future Earth, the international platform for research on global environmental change (Future Earth 2015a). The goal of Future Earth is to provide “the knowledge required for societies in the world to face risks posed by global environmental change and to seize opportunities in a transition to global sustainability” (Future Earth 2015b).

IRG Project shares this goal. It works to identify those situations where opportunities for a sustainability transition can be created and realised precisely by facing the risks of global environmental change. The result are win-win options in risk governance. An important example are opportunities for green growth that develop out of efforts to address anthropogenic climate risks (Jaeger et al. 2012).

Win-win options in the face of global environmental risks are rarely ready-made. They must be discovered, sometimes created. This involves a major scientific challenge that is relevant for the whole of Future Earth. The challenge refers to the rational actor paradigm, that has shaped modern risk management through the expected utility approach. In fact, this paradigm is both
indispensable and insufficient to tackle the problems of global environmental change and sustainable development.

By combining the notions of utility functions, probability distributions and market equilibria, the rational actor paradigm has enabled the development of private insurance industries and of public policies that together successfully address a wide range of risks. Meanwhile, the increasing impacts of human action are generating risks that exceed the coping capacities of these institutions. At the same time, research has identified a series of anomalies that point to serious limitations of the rational action paradigm (Machina 2006).

In the years from 2016 to 2020, IRG Project will explore avenues to overcome these limitations in view of a sustainability transition, without losing sight of the indispensable insights the paradigm has provided in the past. Fortunately, there are several strands of research that can be used for this purpose. Two of the most important are Ortwin Renn’s (2008) framework for integrated risk governance and Lin Ostrom’s (2012) analysis of governance patterns for common pool resources. Both rely heavily on the careful study of practical problems like waste disposal, forest management, etc. IRG Project will proceed in this spirit with a strong focus on disaster risk reduction.

This implies that the work of IRG Project is rooted firmly in what has been called Pasteur’s Quadrant (Stokes 1997) – the area of use-inspired basic research. Engaging with stakeholders, designing and developing research with them while helping them to solve practical problems is therefore vital for the approach of IRG Project.

4.2 Organization

In the coming years, the work of IRG Project will be organized by strong formal and intellectual ties between three institutions:

- Beijing Normal University, (BNU, China). ESPRE and ADREM will be related institutions at this node, Profs. Shi Peijun and Ye Qian key individuals.
- Arizona State University, (ASU, USA). The Global Institute of Sustainability (GIOS) and the Santa Fe institute (SFI) will be related institutions at this node, Profs. Sander van der Leeuw and Gary Dirks key individuals.
- Potsdam University, (Germany) The Center of Excellence for Global Systems Science (CoeGSS) and the Institute for Advanced Sustainability Studies (IASS) will be related institutions, Profs. Carlo Jaeger and Ortwin Renn key individuals.

Each one of these institutions has an exceptional record on risk governance, ranging from natural disaster risk (a main focus at BNU) to technological risks (a main focus at ASU) and to questions of integrated risk governance (as investigated at the Potsdam node in relation to both natural and anthropogenic
disaster risks). And each one of these institutions has an exceptional record in the co-production of knowledge by researchers and stakeholders.

This triangle has been fostered by the Global Climate Forum, a think-tank operating as a small, but worldwide network with a hub in Berlin. It is from the interaction between those institutions that the work of IRG Project will find its core dynamism. In the coming years, one or two additional nodes may be added, depending on circumstances.

Nothing would be farther from the truth than to see this core as a closed alliance. Quite the opposite, IRG Project will develop as an open network, involving researchers and stakeholders worldwide. Our capacity to do so is documented by the collaboration of the three core partners with:

- Governments in Europe, China, America and other countries
- Major (Re-)insurance companies like Munich Re, Swiss Re, Allianz etc.
- International bodies like UNISDR, IPCC, the Global Risk Forum etc.
- Large and small NGOs like WWF and Germanwatch
- Scholars at leading institutions in developed and developing countries

Over the past years, various forms have evolved to stabilize this collaborative network while keeping it flexible and creative. They include:

- Coordination through co-chairs, executive office, scientific committee
  - Regional offices of IRG Project (presently for China, South-East Asia, Europe, Africa, North America, Latin America)
- The Journal for International Disaster Risk Science (SCI indexed, Profs. Shi and Jaeger editors)
- Annual Summer Schools
- Workshops on specific topics
- Regular participation in events of the risk research community (e.g. the Global Risk Forum, Davos)
- Intellectual exchange and joint research projects

IRG Project operates as an idea-driven network, consciously mixing senior and junior scholars, academics and practitioners as well as professionals with very different disciplinary, cultural and geographical background.

4.3 Methods

One of the most important outcomes of IRG Project shall be a set of methods that can be used by researchers and practitioners to address specific disaster risks as well as comprehensive questions of integrated risk governance. Five kinds of methods will be pursued systematically.
4.3.1 Disaster cascade analysis

The Fukushima disaster has become a paradigmatic example of disaster cascades, and the difficulties of attributing and assessing impacts of anthropogenic climate change show its future relevance. Disaster relief is prone to disaster cascades, too (Berariu et al. 2015). And global systemic risks cannot be understood without analyzing the cascading effects of initial shocks through vast complex systems. Indeed, methods of disaster cascade analysis find applications over all dimensions of socio-ecological systems, from purely physical processes through food webs all the way to financial markets.

4.3.2 Simulations

The importance of simulations for modern risk analysis, especially in view of integrated risk governance, can hardly be overestimated. Often, the role of computer simulations of risky situations is seen primarily in gaining estimates for the probabilities of different disaster occurring. Important as this is, two other purposes are becoming as least as important. First, to identify key mechanisms involving both natural and social processes, especially in view of unintended consequences of human actions. Second, to explore possible strategies to deal with risks by actors who have only partial control of the situation. All three purposes become more and more interesting as an increasing amount of data becomes available. This includes big data gathered by means of remote sensing as well as from social media. The capability to integrate big data in risk simulations is one of the frontiers of present-day research, and IRG Project will actively engage in expanding and using it.

4.3.3 Experiments

Making sound experiments in the social sciences is notoriously difficult, but in recent years sophisticated experimental designs have been successfully implemented both in laboratory settings and in field work. In both areas creative use of game theory has proved to be extremely helpful. The creativity may then lead to hybrid schemes where some game theoretic concepts – e.g. those referring to strategies and payoffs – are combined with much more data driven variables, like the dread factor in risk perception and with variables from other theoretical frameworks. A particularly promising framework for integrated risk governance, already used in the IRG Project community, is the Institutional Assessment and Development framework (Ostrom, 2011; for applications and limitations see Robson et al., 2014).
4.3.4 Synthetic populations

Synthetic populations are widely used in studies where a large number of agents interact in complex networks, as in studies of epidemics, traffic and more (Namazi-Rad 2014). They are a very promising method for the study of systemic risks and IRG Project will develop them further in this direction. For this purpose, insights from multi-agent modelling of socio-ecological systems will be used, and probabilistic dynamics will be systematically explored. As a result, massive computer power will be needed in order to process big datasets and explore high-dimensional parameter space. Cooperation with the Centre of Excellence for Global Systems Science, coordinated by Potsdam University and involving key players in European high-performance computing will provide initial access to supercomputing resources, to be complemented by similar resources in China, the US and elsewhere.

As with the theoretical issues discussed in the previous section, IRG Project will not develop separate projects for each methodological point discussed so far. Rather these points will be integrated into projects dealing with specific instances of the following research topics.

4.3.4 Stakeholder dialogues

The widely felt need for more open forms of co-design of research and co-production of knowledge has not yet led to consolidated methods of engaging in these activities. IRG Project is in an excellent position to make progress towards such methods, because stakeholder involvement is often essential to understand patterns of risk governance, and because it can build on previous experiences with stakeholder dialogues (Welp et al. 2006). Moreover, judgements of probability and possibility are often essentially subjective (which does not mean: arbitrary), and reflecting on how to deal responsibly with subjective judgements is as vital for risk assessment (e.g. in IPCC) as for stakeholder dialogues.

4.4 Towards a Theory of Integrated Risk Governance

The rational actor paradigm (see section 2.3) has led to a view of the modern economy as realizing a social optimum by combining public policies with market competition. The social optimum includes an optimal degree of risk exposure and damage compensation. Risk optimization is analyzed with the expected utility approach and achieved by insurance markets or, where these cannot deal with externalities, by public policies (Arrow 1971). Of course this view recognizes that there are both market imperfections and policy limitations, so that from time to time improvements should be attempted here and there, but no far-reaching overhaul is required.
Unfortunately, this rosy view is not up to the challenge of new systemic risks (see section 2.2). In the standard view of global environmental change, e.g., constraining the activities of the present generation in order to avoid risks for future generations necessarily makes the present generation worse off (Nordhaus 2008). This means that win-win options are excluded by construction, making effective policies to tackle global systemic risks very difficult, often impossible, to implement.

More generally, the rational actor paradigm fosters a complacent view of the present institutional setting available for risk governance. After all, this setting and paradigm have evolved hand in hand. The new systemic risks, however, challenge the present institutional setting, they challenge the paradigm, too. If integrated risk governance is to tackle the new systemic risks it will require major innovations in the institutional fabric for risk governance as well as in the paradigm that has provided the essential scientific threads in that fabric. In section 2.3 we have discussed some core ideas for the breakthrough in risk research that a successful development of integrated risk governance will imply.

In order to contribute to this breakthrough from a theoretical side, IRG Project will focus on the following ideas, that not only look promising but on which members of IRG Project have a strong record of own work:

### 4.4.1 Risk spectra

The complexity of socio-ecological systems inevitably generates surprises for the agents involved. The institutions that shape the present global economy and world society systematically neglect this problem, leading to a shift from short-term to long-term risks (van der Leeuw 2012). Studying the mechanisms driving this dangerous shift and developing practices of risk governance that counteract them are critical tasks of IRG Project. This raises fundamental theoretical issues about time discounting, closely linked to the role and dynamics of interest rates in the present world economy.

### 4.4.2 Rationalities

As discussed in sections 2.2 and 2.3, modern societies have developed ways of handling risks that are intimately connected with a particular understanding of rationality (Jaeger et al., 2001). Coping with the uncertainty of new systemic risks, especially at a global scale, will require new forms of rationality (Renn and Walker, 2008). Western rationality as we know it will need to engage in a new kind of dialogue with other traditions that are not only being transformed by globalization but also actively transforming it (Chabal 2012). The fact that IRG Project very much started with a dialogue between Chinese and European thinking about disaster risk (Shi et al., 2013) suggests that it can be a fertile
growth for new insights about how new rationalities can evolve to cope with new risks.

### 4.4.3 Complex systems

To become able to uncover and/or create win-options for sustainable development, it is necessary to study human agents as components of socio-ecological systems (Costanza 2014). Such systems display multiple equilibria, some of which may be optimal in a broad sense, many of which may not. Disaster risks reduction then can be studied in view of transitions from disaster-prone equilibria to ones that are capable to avoid critical disasters while being more resilient in the face of other ones we will continue to live with.

### 4.4.4 Consilience

If we consider the framework of iterated games outlined in section 2.3, clearly there are two different basic mechanisms involved. On the one hand, there is the – spatially and temporally – local optimization by each agent during each iteration. On the other hand, during each iteration there is an updating of a whole set of variables. Some of the updating happens internally to the agent, as when an agent changes her probability assessment due to observation of others and own experience. Other updating processes are external to the agent, as when her action space and her relations to other social agents are modified by the – possibly random – dynamics of the system. When trying to characterize the latter dynamics, one would like to have some measures of overall characteristics of the – usually complex – network one is dealing with. Often, such measures are based on the idea of connectivity, i.e. the fraction of actual connections out of a set of possible connections. Useful as this is for many purposes, in view of integrated risk governance it is often essential to distinguish connections depending on the states of the respective nodes. IRG Project has begun work in this direction by introducing the concept of consilience and defining quantitative measures for it (Shi et al. 2014).

### 4.4.5 IAD

Last not least, the theoretical work of IRG Project will build on the institutional assessment and development framework (IAD, see Ostrom, 2011). This framework was developed as part of a comprehensive answer to one of the most influential applications of the rational actor paradigm, and one of direct relevance for global environmental risks: the idea of a tragedy of the commons (Hardin, 1968). The IAD has been successfully used to investigate small communities that need to manage some common pool resource – including large numbers of similar such communities. The key challenge in view of new systemic risks is how this kind of research can be expanded to much larger systems, all the
way up to global systems. IRG Project will use this challenge to develop the IAD into a key component of a theory of integrated risk governance.

In line with the idea of Pasteur's Quadrant (see section 4.1) and of stakeholder involvement, IRG Project will not develop separate projects for each one of these theoretical points. Rather they will be integrated into the study of specific research topics dealing with integrated risk governance. To these topics we now turn.

4.5 Focal Research Topics

In the coming years, the work of IRG Project will be structured by five focal research topics. Other issues may be added in the course of time, but these form the points of reference to begin with.

4.5.1 Natural Disasters and Advanced Technologies

In view of the integrated governance of natural disaster risks, a first contribution of IRG Project will be to develop and maintain its world risk atlas. The atlas can be used by policy and decision makers in all governments for making appropriate prevention and contingency plans. A global risk ranking system is also important to measure a country’s effort, capacity and vulnerability in order to better allocate international resources for the national capacity building efforts. Taking advantage of advanced technologies like big data from remote sensing and processing capabilities from high-performance computing in producing a world risk atlas is both mandatory and feasible at the present stage.

Second, comparisons of regional case studies will be conducted systematically to understand how one and the same society deals with different risks and how different societies deal with one and the same risk.

Third, by working closely with UN-ISDR, IRG Project will help turning good science into good decision making. It has been recognized for quite a long time that to make systematic decisions across different spatial and temporal scales, a two-way communication between scientists and decision-makers is needed. Unfortunately, developing appropriate applications of relevant scientific understandings of risk to policy problems has always been a major challenge. And bridging the gap between policy-making and scientific expertise is even harder because there is no common language between both ends. By taking advantage of fast developments in information and communication technology (ICT), IRG Project will launch a range of initiatives to support more effective interaction between the two communities, including development of a visualization toolbox which integrates relevant scientific understandings of risk and policy makers’ needs, and so to support more effective dialogues.
4.5.2 Coastal Zones and Climate Change

Globally, 15 of the last 23 greatest natural disasters from 2000 to 2011 were coastal disasters. At the same time, population and economic resources are increasingly concentrated in coastal zones worldwide. Last not least, extreme events enhanced by sea-level rise from climate change will become a key concern for urban and regional planning along the coasts of the world.

Integrated risk governance in coastal zones will be a key area of inquiry for IRG Project, not least because of the involvement of the IPCC lead author on coastal zones, Jochen Hinkel, and of excellent contacts with coastal zone experts in The Netherlands, the UK, China and other countries (Hinkel et al. 2015). Cooperation with the Future Earth project LOICZ – Land-Ocean Interactions in the Coastal Zone, will be an important aspect of this work. IRG Project will look at coastal zones from a different angle, though, by emphasizing the perspective developed in the present document. This will lead to better assessments of the vulnerabilities of coupled infrastructure systems in coastal zones, as well as to suggestions for improving existing monitoring and disaster preparedness systems.

An important aspect will be the study of coastal zones along the 21st Century Maritime Silk Road that shall connect the Southern shores of Asia with East Africa, the Middle East and Europe. Addressing local risks like extreme events so as to pay attention to possible disaster cascades is one example of the tasks IRG Project will perform with regard to this research topic.

4.5.3 Urbanization and Agriculture

Since its beginnings thousands of years ago until today’s development of megacities, urbanization has been a key factor fostering innovation. While this has helped to increase welfare and manage many risks of the past, the city-based innovation system has generated new systemic risks. This has happened in two ways. On the one hand, the generation and spread of non-sustainable patterns of urban development has led to risks like local air pollution and global climate change. On the other hand, the generation and spread of non-sustainable agricultural practices has led to risks of its own. Examples include concerns about biodiversity but also about food safety, both in terms of quantity and perhaps even more so of quality.

IRG Project will look at both sides of this dynamics. On the one hand, we will study the role of urban innovation systems in generating new systemic risks as unintended consequences of actions aiming at other goals. On the other hand, we will look for opportunities of green growth in rural areas, where sustainable agriculture can transform neglected possibilities in resources for the people in those areas and enable them to alleviate concerns about food safety in urban centers. This kind of research could lead to synthetic population models for
urban regions with their hinterland. Such models could then be helpful for some of the most pressing policy problems in such regions.

4.5.4 Financial Markets and Global Systems

There are few areas where disaster cascades are more relevant than on financial markets. The speed of trade and the interdependence of transactions make it extremely difficult to manage the global systemic risks arising on those markets. The financial crisis of 2007 has shown that the institutions and know-how developed in Western economies so far are not sufficient to avoid massive economic damages from the propagation of shocks through financial markets. The Shanghai stock market plunge of 2015 has highlighted the importance of this challenge for emerging economies in general, and China in particular.

IRG Project will look at financial risks in view of similarities and differences with disaster risks in other global systems. A key tool for this purpose will be the notion of consilience (Shi et al, 2014). It shall be used to analyze the relevance of the May-Wigner theorem for the stability of financial markets and other global systems. This theorem contradicts the widespread hypothesis that in ecosystems greater biodiversity implies greater resilience. With regard to financial markets, it provides an argument for broad, simple measures and against increasingly complex regulatory schemes.

An example of such an approach is the proposal to stabilize stock markets via qualitative easing (Farmer 2013). This would complement the present actions of central banks to ensure monetary stability with actions to dampen excess volatility on stock markets. Consilience analysis can help assessing and improving such proposals, and it can do so in ways that draw on the trans-disciplinary character of much Future Earth research, including IRG Project.

For Future Earth, it is not sufficient to ask how financial markets can be stabilized. Rather it is essential to find ways for financial markets to become engines of sustainable investment and green growth. IRG Project will pursue this question in an exchange with the Munich Climate Insurance Initiative. This initiative brings together financial intermediaries, researchers and NGOs with the goal of designing and implementing feasible steps towards a low-carbon economy. Clearly, this is an ambition of great relevance for Future Earth.

4.5.5 Green Growth and Integrated Risk Governance

For a long time, disaster research has focused mainly on what were considered unequivocally natural disasters. Historically, such disasters acquired huge relevance with the establishment of civilizations based on large-scale infrastructures. Nowadays, disasters threatening critical infrastructures cannot be neatly separated into natural and man-made anymore. The Future Earth project IHOPE – Integrated History and Future of People on Earth, has analyzed
these developments in view of sustainability challenges. Through the involvement of one of IHOPE’s founders and long-time co-chairs, Sander van der Leeuw, IRG Project will bring its distinctive perspective to this research. It will do so by considering infrastructures of critical importance for green growth.

In the 21st century, billions of people will strive – one hopes successfully – to overcome poverty, attain a decent standard of living and share the affluence of high-income societies. As the example of these societies shows, even massive natural disasters like major earthquakes will lose much of their present scare. But in the 21st century, humankind as a whole will have to learn to avoid the systemic risks generated by traditional economic growth. Both tasks imply a need for huge investments into infrastructures with which we are not yet familiar. As a result, there is an additional kind of risk to be dealt with: the risk of misplaced and mismanaged investments aiming at sustainable development. This kind of risk is especially serious with the large-scale investments that will be necessary to create and maintain the critical infrastructures of the future (Flyvbjerg et al. 2003).

A case in point is the Silk Road Economic Belt. It offers no less than an opportunity to realize a trajectory of green growth on the Eurasian continent, with obvious relevance to the world as a whole. IRG Project will look into the challenges of integrated risk governance for critical infrastructures like those involved in the Economic Belt. This cannot happen by proposing some allegedly risk-free scheme for managing critical infrastructures. Rather a long-term monitoring and analysis of how the Economic Belt and similar infrastructures evolve is required.

Research on these focal topics can help to establish integrated risk governance as an on-going process of learning how to keep risks in an acceptable domain, including learning from experiences of disaster, relief and reconstruction. The work of IRG Project in the past years as well as its cooperation with UNISDR make it an ideal platform for this purpose.

4.6 Conclusion

The Future Earth research agenda could hardly be more ambitious then presently formulated. In view of the challenges arising in the 21st century, the ambition is appropriate, and IRG Project shares it wholeheartedly. IRG Project will contribute to the overall endeavor by expanding and consolidating the knowledge presently available for the purposes of risk management and governance. It will do so in different ways for each one of the three broad research themes defined by Future Earth: Dynamic Planet, Global Development, and Transformations towards Sustainability (Future Earth 2015c).

With regard to the research theme “Dynamic Planet”, an essential part of it consists in “Anticipating global thresholds and risks”. IRG Project will contribute
to this both by the study of specific risks, especially risks of disasters like breakdowns of critical infrastructures, and of slow-onset events like sea-level rise. But the key contribution will be in the integrative perspective. Presently, the resources dedicated to particular risks are driven to a problematic extent by processes of social amplification or attenuation that can make action in the face of global risks ineffective and even impossible. IRG Project will help to establish risk maps and metrics to facilitate an orientation and to prioritize measures not only at a sectorial level, but also in terms of integrated strategies of risk governance. We will conduct research to integrate natural and social science models to better understand the mechanisms leading to very large-scale disasters and related vulnerability, exposure and risk distributions. Increased attention will be paid on the risks associated with complex dynamics of trends, variabilities and extremes, e.g. in view of climate change at global, regional and local scales.

This ties in organically with a key task under the research theme “Global Development”, namely to provide knowledge for the “stewardship of food, water, biodiversity, energy, materials, and other ecosystem functions and services”. The key challenge here for IRG Project is to relate the risks identified in view of the first theme – “Dynamic Planet” – to the needs of global development. One very straightforward but extremely useful task will be to combine the risk maps mentioned above with maps of development. This needs to be done both with maps based on geographical space as with maps based on more abstract spaces. In the rational actor paradigm, the key maps are structured along the two axes of utility and probability. Useful as this is, it needs to be embedded in a much larger variety of dimensions. To identify these additional dimensions requires precisely the enhancements of the rational actor paradigm that IRG Project is aiming at.

No doubt the theme closest to the intent of IRG Project is “Transformations Towards Sustainability”, with the key tasks of “Understanding transformation processes and options” as well as “Evaluating strategies for governing and managing the global environment across sectors and scales”. According to Future Earth, “This might include significant shifts in political, economic and cultural values, changes in institutional structures and individual behaviors”. Developing the factual, methodical and theoretical knowledge about key risks of global environmental change, but also of policies to address them, is indispensable to achieve successful transformations towards sustainability.

Equally important will be the emergence of institutions and practices that embody this knowledge. The sustainability transition will consist to a large extent in developing the capability to deal with new systemic risks in a reasonable and responsible way. This is what IRG Project will work on in the period 2016-2020.
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