Ecological Viability or Liability? Insurance System Responses to Climate Risk

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ABSTRACT

Climate change is a phenomenon of the Earth system, which is characterized by thresholds and non-linear change. This analysis considers the adequacy of insurance (in its broadest sense) responses to climate risk. This paper provides novel critiques of insurance system responses to climate change and of the attendant political economy perspective on the relationship between insurance and climate change. A complex adaptive systems (CAS) analysis suggests that ecologically effective (i.e. strong) mitigation is the only viable approach to manage medium- and long-term climate risk – for the insurance system itself and for human societies more widely. In contrast, we find that even the most substantial insurance system responses to date are generally adaptive and weakly mitigative. This analysis extends an earlier political economy perspective that explains the limitations of insurance system responses to climate change, but provides little guidance to the ecological implications of such responses. As such, this paper raises questions about the ongoing viability of the insurance system, and hence about the many aspects of human societies globally reliant on the insurance system as their primary risk governance tool. We conclude that the CAS approach provides new insights, which could prompt insurance system evolution in support of effective climate risk governance. Copyright © 2011 John Wiley & Sons, Ltd and ERP Environment.

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Insurance is a means of constructing the promise of economic security in a precarious and uncertain world (Knights and Vurdubakis, 1993, p. 734).

Insurers themselves have not understood the scale of the implications of global warming (Dlugolecki, 2009a, p. 1).

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Introduction

ANTHROPOGENIC CLIMATE CHANGE PRESENTS A 'DIABOLICAL POLICY PROBLEM' (GARNAUT, 2008, P. XVIII). THE NATURE OF the phenomenon and its impacts, combined with the characteristics and socio-economic role of insurance, invite questions about the potential impact of climate change on insurance. In turn, this raises questions about the potential for insurance to play a constructive role in climate change mitigation¹ and adaptation (see, e.g., Leigh *et al.*, 1998; Paterson, 2001; Albrecht and Rapport, 2002; Dlugolecki and Keykhah, 2002; Crichton, 2005; Mills, 2005; Kunreuther and Michel-Kerjan, 2007; Ross *et al.*, 2007; Botzen and Van den Bergh, 2008). Our specific interest is the potential for engaging the insurance system² – established to transfer and pool financial risk – in support of ecological sustainability: mitigating climate change by driving down atmospheric greenhouse gas levels by reducing emissions and by protecting surviving carbon sinks such as forests.

Our engagement is with insurance as a system (Phelan *et al.*, 2011). We use the term *insurance system* to bring focus to all of the participants and their relationships that together allow ongoing provision and use of financially viable insurance. For the purposes of this paper the insurance system is delineated as a key subsystem of the global, carbon-based economy, acting as a primary financial risk governance tool. A definitive financial value for the insurance system overall is elusive: incomplete data are available for elements of the insurance system. However, including both commercial and publicly funded social insurance gives rise to an overall insurance system that is a significant component of the global economy. This perspective is broader than others common in the literature, which focus on the commercial insurance industry, to the exclusion of welfare state forms of insurance (e.g. Leggett, 1993a; Haufler, 1997; Faure and Fenn, 1999; Crichton and Salt, 2001; Paterson, 2001; Jagers and Strippel, 2003; Mills, 2005; Kunreuther and Michel-Kerjan, 2007; Maynard, 2008; Dlugolecki, 2009b; Herweijer *et al.*, 2009; Schwarze *et al.*, 2010). A conservative estimate values the insurance system at more than US\$8 trillion (in 2007 – see below). This represents at least 15% of global GDP of US\$54 trillion in 2007 (Swiss Re, 2008, p. 8). Of the estimated ~US\$8 trillion value of the system overall, ~US\$3 trillion (in annual expenditure) represents social forms of insurance and ~US\$5 trillion (in annual revenue) represents commercial forms of insurance.

We conceptualize the insurance system at global scale, as a subsystem of the global economy. In turn the economy is embedded in the Earth system, by which we refer to the integrated social–ecological system (Berkes and Folke, 1998) that is planet Earth and all life on it, including humans and our societies. We focus on the relationships between each of the three systems. This perspective is similar to Lovelock's (2007) 'Gaia', which refers to 'the interconnectedness of the Earth system, including all its life forms' (p. 156). The perspective is also consistent with the 'Anthropocene' of Crutzen and Stoermer (2000; Crutzen, 2002), which conveys the sense of a co-evolutionary process engaging ecological and human-social systems at global scale.

We purposely make our adoption of a systems perspective explicit because insurance invites a range of approaches. Denenberg (1963) for example refers to a

fourfold classification [of] insurance. . . as a business, a legal institution, a technique for averaging loss, and an instrument of social planning, [with] many faces and forms, which continue to confound simple classificatory schemes (p. 323).

Anthropogenic climate change represents a strategic threat to human societies generally, and specifically to the world's (in the broadest sense) insurance system. Climate change is not simply a partial, temporary or episodic threat to the insurance system's financial viability. The failure of the insurance system to respond appropriately to climate risk is sadly consistent with broader societal inability to resolve the climate crisis (see, e.g., Hamilton, 2010).

¹We note an important semantic point here in the interests of clarity, necessary given the interdisciplinary character of this paper. As noted by Mills *et al.* (2001, p. 8), climate change researchers use the word mitigation with reference 'to measures that promise to *reduce the process* of climate change', whereas 'the insurance community uses the term to refer to measures that *reduce the likelihood of losses* from climate-related (and other) events' (emphasis in the original).

²We refer to 'insurance system' in the singular. Willard Gibbs, a pioneer of systems thinking, defined a system as 'any portion of the universe [including ourselves and everything we have created, such as social systems] which we choose to separate in thought from the rest of the universe for the purpose of considering and discussing the various changes which may occur within it under various conditions' (Rueysey, 1964, p. 445; see also p. 235).

The insurance system as we conceptualize it is defined in some detail in the following section. Our approach varies from a narrower focus prevalent in the scholarly and grey literatures on the insurance *industry* as a whole, or some part of it.³ In that section we also examine insurance system responses to date. We find that the strongest of these are limited to being adaptive or weakly mitigative, as opposed to strongly mitigative. In the next section we highlight elements of an international political economy (IPE) perspective on insurance system responses to climate change. This perspective explains limits to insurance system responses, but provides little insight into the implications of such responses for the ongoing viability of the insurance system, or for the elements of human societies dependent on the insurance system.

In the fourth section we then consider the adequacy of current insurance system responses to climate change, as opposed to strongly mitigative responses, given that climate change is a phenomenon of the Earth system, characterized by non-linear change and thresholds. Our critique of the IPE perspective on the insurance system–climate change relationship is made on the same basis. We undertake an initial complex adaptive systems (CAS) analysis of the insurance system and climate change, and raise questions about the merit of the insurance system's adaptive and weakly mitigative responses. CASs, 'unlike the natural systems that environmental and earth sciences have traditionally addressed', are human-dominated systems, which 'display learning, adaptation and complex non-linear feedbacks' (Finnigan, 2006, p. xi). Systems thinking generally emphasizes connectedness, context and feedback, and focuses on interactions, relationships and patterns (Kay, 2008, p. 7). The fourth section introduces the concept of reflexive mitigation as a theoretical basis for an alternative and strong insurance system response to climate change. An insurance basis for carbon prices is also introduced, as one theoretically viable example of an opportunity for the insurance system to contribute to a strong mitigation response to anthropogenic climate change. The fifth section concludes the paper and discusses the proposition that a systems perspective may offer insights for a sound basis for viable insurance system governance of climate risk into the medium and longer term.

Insurance System Responses to Climate Change: Adaptive and Weakly Mitigative

Responses to climate change originating in the insurance system vary from non-engagement through to detailed policy positions. The focus of this paper is on insurance system (as a subsystem of the global economy) responses that have engaged with climate change most substantially. At best, the insurance system's most substantive climate change action to date is limited to adaptive and weakly mitigative responses. We have reviewed primary sources, such as policy documents and position statements of actors in the insurance system (e.g. Association of British Insurers, 2005; CCWG, 2007; Munich Re, 2008; Lloyd's, 2010; Swiss Re, 2010). We have also drawn on others' perspectives on the relationship between insurance and climate change, which have centred on commercial elements of the insurance system (i.e. a part or the whole of the insurance industry). The literature on insurance responses to anthropogenic climate change is also comprehensively focussed on adaptation rather than mitigation, whether the focus is on insurance specifically (e.g. Dixit and McGray, 2009; Herweijer *et al.*, 2009; Warner *et al.*, 2009; Botzen *et al.*, 2010; Schwarze *et al.*, 2010) or whether the focus is on public policy more broadly (e.g. Bailey and Rupp, 2004; Foljanty Jost and Jakob, 2004; Heltberg *et al.*, 2009; Aakre and Rübhelke, 2010; Tompkins *et al.*, 2010).

The Insurance System

The insurance system as conceptualized for this paper comprises all forms of social insurance such as state-provided universal health care as well as commercial forms of insurance. The conceptualization is made broadly

³The literature on the insurance industry and climate change comprises two main bodies. One conceives the industry in political economic terms, for example with interests in the context of climate politics, or perhaps with potential to play a role in global environmental governance (see Leggett, 1993a, 1993b; Brown, 1996; Leggett, 1996; Gelbspan, 1998; Newell and Paterson, 1998; Sachs *et al.*, 1998; Paterson, 1999, 2001; Jagers and Strippel, 2003; Jagers *et al.*, 2005). The other is uncritical, focuses on the socio-technical potential for insurers to play a role in managing emerging climate risks, and generally includes more attention to diversity within the industry, i.e. distinguishing between property and life insurance lines, and between insurers and reinsurers (see Crichton and Salt, 2001; Dlugolecki and Keykhah, 2002; Mills, 2005; Kunreuther and Michel-Kerjan, 2007; Dlugolecki, 2008; Hecht, 2008; Maynard, 2008; Ward *et al.*, 2008; Dlugolecki, 2009b; Mills, 2009).

and includes for-profit and mutual insurers, government providers of insurance, reinsurers, specialized service suppliers such as loss modellers and brokers, regulatory authorities and industry representative bodies. The term also includes the legal and institutional frameworks created and used to facilitate access to insurance. Investors in insurance companies as well as insurers' own substantial investments are also included. Conceptualized this way, the insurance system is a key subsystem of the global, carbon-based economy, acting as a primary⁴ financial risk governance tool in the economy.

The global economy is the source of anthropogenic greenhouse gas emissions and attendant climate change risks. The insurance system, as with other subsystems of the carbon-based economy, is implicated in generating climate risks by virtue of its integral role in emission-producing economic activity. Simultaneously, the insurance system is potentially well placed to support ecologically effective mitigation efforts. By *ecologically effective* we mean mitigation designed to avoid dangerous climate change. Mitigating climate change requires rapid and deep cuts in greenhouse gas emissions and removing greenhouse gases from the atmosphere, by conserving surviving carbon sinks. Industrialization has produced a rise in atmospheric CO₂ concentrations from pre-industrial levels of 280 ppm to current levels of ~389 ppm (King, 2009; Tans, 2010) – and concentration levels continue to rise. In contrast, a drop in concentrations to at least 350 ppm – and perhaps lower – is required (Hansen *et al.*, 2008).

A definite financial value for the insurance system overall is elusive. Incomplete data are available for elements of the insurance system including both commercial and publicly funded social insurance, suggesting that the insurance system overall is a significant component of the global economic system. Here we draw on disparate data sources centring on (but not limited to) the year 2007 to provide a guide to the financial value of the insurance system. The year 2007 is the most recent year for which we could source sufficient disparate but complementary data to provide a comprehensive sketch of the global insurance system.

Social insurance financing for health expenditure alone totalled US\$1.2 trillion globally in 2006 (WHO, 2009). Other key areas of state-financed social insurance expenditure are unemployment benefits and age and disability pensions.⁵ The modern welfare state, which includes forms of social insurance, is most developed in Europe, and some data and projections are available for European Union (EU) countries: unemployment benefit expenditure (for 2007) is projected at 0.85%⁶ of EU GDP (Economic Policy Committee and DG ECFIN, 2006, p. 190), i.e. circa US\$142 billion. Gross public pension expenditure (for 2010) is projected at 10.3%⁷ of EU GDP (Economic Policy Committee and DG ECFIN, 2006, p. 71), i.e. US\$1.8 trillion.

Turning to commercial elements of the insurance system, insurance is the world's largest industry, with US\$4 trillion in yearly premium revenue in 2007 (Swiss Re, 2008, p. 33) and an additional US\$1 trillion in annual investment income (Mills, 2009, p. 13), and therefore larger than the defence, oil, electricity generation or pharmaceutical industries. Many insurers and reinsurers are themselves global firms. Munich Re and Swiss Re for example, the two largest reinsurance firms globally, wrote premiums in 2007 valued at US\$30.3 billion and US\$27.7 billion respectively (Standard and Poor's, 2008, p. 26).

Despite its size, the insurance market's socio-economic penetration is extremely uneven. Whilst insurance premiums accounted for a significant 7.5% of global GDP in 2007 (Swiss Re, 2008, p. 41), industrialized countries accounted for 90% of the global market (Swiss Re, 2008, p. 33). Even as insurance markets are largest in industrialized economies, historically and currently the major source of anthropogenic greenhouse gas emissions,

⁴This paper describes the insurance system as a primary financial risk governance tool. In contrast, Hecht (2008), focussing solely on commercial elements of the insurance system in the US, refers to the insurance industry as *the* primary financial risk governance tool: 'The insurance industry is our society's primary financial risk manager' (p. 1559). The difference in perspective perhaps stems from variations in breadth of focus. The perspective adopted in this paper recognizes that insurance provision extends beyond commercial elements of the insurance system, i.e. to include social forms of insurance. Furthermore, the management of financial and other risks extends beyond the insurance system as a whole. A still broader conceptualization of risk management would acknowledge other, non-formal approaches to coping with risk such as family ties and reciprocal community relationships (see, e.g., Anderson, 2005).

⁵The OECD (2007, pp. 76–77) aggregates data on 'public social spending' across OECD member states, accounting for around 20% of GDP across member states. The category includes benefits that 'address one or more contingencies, such as low income, old age, unemployment and disability'. This categorization is larger than our interest and applies to OECD members (i.e. industrialized countries) only.

⁶Unemployment benefit spending projection for the EU25 group of countries. Combined GDP for the EU27 countries in 2007 totalled €12.3 trillion (European Union, 2009). Currency figures converted using mid-2007 exchange rates.

⁷Figure for the EU25 group of countries (excluding Greece).

the majority of the world's population – in low income countries and most vulnerable to climate risk – is without access to either social or commercial elements of the insurance system.

On the basis of the above information, we conservatively suggest the value of the global insurance system (broadly defined) to be in excess of US\$8 trillion (in 2007). This represents at least 15% of global GDP of US\$54 trillion in 2007 (Swiss Re, 2008, p. 8). As such the insurance system is a significant socio-economic subsystem of the global economy.

Climate change has moved toward centre stage for some actors in the insurance system over recent years but responses to climate change are uneven. Our focus is the more substantial insurance system responses, which are found in only a small number of larger, more established insurers, reinsurers and industry associations. The remainder of this section focuses on examples of these actions.

The Association of British Insurers declared in 2005 that '[c]limate change is a key issue for the world in the 21st century' (2005, p. 3). A 2006 report, *From Risk to Opportunity: How Insurers Can Proactively and Profitably Manage Climate Change*, opens with a number of quotations, including the following attributed jointly to Chief Risk Officers of 19 major insurance houses:

Climate change has the potential to develop into the greatest environmental challenge of the 21st century. The recent period of intense tropical cyclone activity most likely reflects the effects of both natural climate variability and a superimposed global warming trend due to human causes (Mills and Lecomte, 2006, inside cover).

However, it would appear that insurance industry behaviour more generally belies the strong rhetoric above. Andrew Dlugolecki (2009b), with reference to Mills (2007a), notes that

Across the global insurance industry, activity on climate change is low. [A] recent survey identified just 190 organisations engaged in meaningful ways, from amongst the tens of thousands of underwriting and intermediary firms in existence. While this was double the number a year before, it is still tiny (p. 17).

A more recent survey (Mills, 2009) identifies an increase in the number of commercial insurance system actors (insurers, reinsurers, brokers and industry associations) engaging in climate activity, up to 224. Nevertheless Dlugolecki's point still stands. Given the variation in the above perspectives, insurance system responses to climate change warrant careful attention. Mills (2009) provides an impressive global listing of commercial elements of the insurance system's responses to anthropogenic climate change, organized into a ten-part categorization, comprising (i) understanding the climate problem, (ii) promoting loss prevention, (iii) aligning terms and conditions with risk reducing behaviour, (iv) crafting innovative insurance products, (v) offering carbon risk-management and offsets, (vi) financing customer improvement, (vii) investing in climate change solutions, (viii) building awareness and participating in public policy, (ix) leading by example and (x) carbon risk disclosure. Our view is that the activities described in the listing are all adaptive and/or weakly mitigative in character. We draw on this listing in the next sections of the paper to illustrate the limitations of current insurer responses to climate change. Mills' listing of actions is extensive, although described by Mills (2009, p. 14) as 'certainly not comprehensive'. We refer here to limited representative examples only by way of illustration.

Adaptive Responses

Since the mid-1990s some commercial insurance system actors have attempted to adapt to climate (and other) risks by shifting financial risk outside the insurance system and onto capital markets via insurance-linked securities. Some in the insurance system have also attempted to make better use of forecasting extreme weather events. Paterson (2001, 2005) refers to both these strategies in the context of the IPE critique of commercial elements of the insurance system's responses to climate risk and we review them in some detail separately, in the following section, in the context of our discussion of the value and limitations of the IPE critique of the insurance–climate change relationship. In this section we briefly introduce and discuss other representative examples of adaptive insurance responses to climate change.

Mills (2009) listing includes steps by commercial elements of the insurance system to provide insurance products that support insureds' adaptation to climate change. Hecht (2008) separates these further into two groups. The first is products that mitigate losses (as opposed to mitigate climate change, i.e. lead to reduced losses from insured events rather than a cut in greenhouse gas emissions causing climate change). An example would be adoption of more stringent building standards, or changes in approaches to land-use planning leading to reduced premiums for hurricane or flood insurance. Some climate adaptation products may also incidentally support climate change mitigation efforts, e.g. more robust building construction leading to reduced need for internal heating and cooling. The second is products that allow those insured to pass on some climate-implicated weather risks. An example is microinsurance programs (see Churchill, 2006) being piloted in some rural communities in low income countries, to mitigate catastrophic weather event-related losses. The Munich Climate Initiative is an example of a such a program drawing on the understanding that 'insurance solutions can play a role in adaptation to climate change' (MCII, 2010).

Mills (2009) also describes insurers aligning terms and conditions of insurance policies with risk-reducing behaviour. One example is insurers addressing climate change liability implications, e.g. the possibility of directors and officers facing damages claims by shareholders for not having disclosed climate risks. Mills (2009) cites Swiss Re, which includes climate change risks 'amongst the many criteria. . . used to evaluate its exposures under corporate [directors and officers] policies' (p. 27). Mills goes on to note that 'to our knowledge, Swiss Re has yet to actually decline a policy or apply exclusions based on climate risks alone', and that '[t]he potentially positive effect of this activity is to stimulate the policyholders to focus on their climate-related exposures' (p. 27).

Weakly Mitigative Responses

We categorize weakly mitigative insurance system responses to climate change into three broad groups: (i) public policy-related research, lobbying and networking, (ii) support for corporate carbon disclosure initiatives and (iii) insurance products that support limited reductions in policy holders' emissions, or that support other emission reduction initiatives, for example investments in renewable energy projects perceived to be financially risky. We describe activities in all three groups as weakly mitigative in that, whilst they all may deliver some limited positive climate benefits, they do not directly or significantly contribute to ecologically necessary deep and rapid cuts in greenhouse gas emissions.

Public Policy Related Research, Lobbying and Networking

This grouping of research, lobbying and networking in support of public policy changes links most directly to two of Mills' (2009) categories: understanding the climate change problem, and building awareness and participating in public policy. Research and analysis to understand the socio-economic implications of climate change is an area where some actors in the insurance system have been comparatively proactive in relation to climate change mitigation: a number of research reports have been released by major reinsurance houses on climate change related material. For example, Munich Re, Swiss Re and Lloyd's in recent years have produced and made accessible through their websites research materials including statistical records and analyses (Munich Re, 2008; Swiss Re, 2008; Lloyd's, 2010). The Association of British Insurers (2005) is another commercial insurance system actor active in this regard.

In 2008 *The Geneva Papers: Issues and Practice* published a special issue on 'Insurance and adaptation to climate change'. This is significant in itself, given that the journal is a publication of The Geneva Association (2008), an association constituted of the Chief Executive Officers of the 80 largest commercial insurers globally. The focus on adaptation is certainly necessary given that climate change impacts are already manifest. However, mitigation received substantive attention in only three (Dlugolecki, 2008; Leblanc, 2008; Maynard, 2008) of the nine papers included in the issue.

Recent years have also seen a small flurry of insurance system public relations activity on climate change to build awareness and participate in shaping public policy. One representative example is Allianz Group partnering with the World Wide Fund for Nature to produce the report *Climate Change and the Financial Sector: an Agenda for Action* (Allianz and World Wildlife Federation, 2005). Lloyd's 360° project (Lloyd's, 2010) is another. The research

output from a small number of insurers, reinsurers and representative associations, while commendable, is a far cry from strong mitigative action on climate change by the insurance system. This is perhaps surprising given the insurance system's core capacities in the risk and loss governance area, and long and rich history of active engagement in loss reduction activities (Mills and Lecomte, 2006).

Some insurance system actors in recent years are beginning to demonstrate a greater commitment to networking and lobbying in support of shaping climate policy. Internationally, the establishment of the United Nations Environment Program Finance Initiative's Insurance Working Group (Dlugolecki, 2007) and the Climate Change Working Group (CCWG, 2007) are examples. In Australia two insurers – one domestic (Insurance Australia Group) and one international (Swiss Re) – joined in 2006 with other major corporations and an environment non-government organization to establish the briefly active Australian Business Roundtable on Climate Change (ABRCC, 2007). In both the UK and the US, representative associations are also beginning to focus on the implications of climate change for a functional insurance system.

Climate change remains an intractable issue and we do not suggest that the wider societal failure to grapple with ecologically effective mitigation is wholly or even largely attributable to the insurance system. However, support for effective policy responses from any quarter is surely constructive. And as Mills (2009, p. 47) argues, 'insurers regularly engage in proactive public policy discussions, whether concerning terrorism, public health or natural hazards. It is in the business interest of insurers to support public policies that reduce and make risks more predictable'. However, Mills (2009, p. 47) goes on to note that some 'excellent examples exist, but industry-wide engagement in these pursuits is nowhere near its potential'. Paterson's (2001) IPE critique discussed in the following section provides an explanation for the constrained nature of commercial insurers' lobbying and networking efforts on climate change. To illustrate the sector's limitations in this regard, Paterson (2001) contrasts the record of effort and achievement of commercial elements of the insurance system with that of fossil fuel lobbies in national contexts and internationally.

Support for Voluntary Carbon Reporting Initiatives

Mills (2009) also describes insurers' involvement in carbon risk disclosure: '[t]he process of assessing and disclosing climate risks enhances the ability of insurers to evaluate the impacts of climate change on their business, leading insurers to take steps to address the risks and opportunities that climate change presents (p. 56). A small number of the insurance system's commercial actors (including insurance firms and investors in insurance firms) have participated in voluntary carbon disclosure initiatives such as the UK-based Carbon Disclosure Project (CDP) and the US-based Investor Network on Climate Risk (INCR). Both initiatives seek to use institutional investors' financial clout to encourage the large corporations in which they invest to monitor and report publicly on the climate impact of their businesses (Newell and Paterson, 2010). The CDP in particular has been successful in encouraging a large proportion of the world's largest firms to participate voluntarily, but the information reported has been of limited use for investors due to its variability from firm to firm, and also across reporting periods (Kolk *et al.*, 2008). Further, with reference to the question of what impact – if any – reporting might have on behaviour, for firms in emission-intensive sectors such as electricity generation, fossil fuels and mining, 'the trend shows increasing emissions' (Kolk *et al.*, 2008, p. 742).

Some insurance system actors have also committed to reduce their own emissions, consistent with Mills' (2009) reference to some insurers leading by example. This commitment applies to Swiss Re's operations, for example emissions generated through building and operating offices and business travel, and a preference for using suppliers that make similar commitments (Swiss Re, 2010). It does not include reference to Swiss Re's investments and falls well short of a meaningful contribution to an ecologically effective response to climate change. Insurers' operational emissions are surely small in comparison to the emissions attributable to the substantial financial assets held by commercial elements of the insurance system – of the order of US\$55 trillion (Dlugolecki, 2007, p. 10).

Products That Support Emission Reductions

Commercial elements of the insurance system have also begun offering insurance products that support emission reductions. Mills (2009) identifies two categories. The first is 'aligning terms and conditions with risk-reducing behaviour' (Mills, 2009, p. 24). Some actors in the insurance system now offer products that support reductions in

policy-holders' emissions (see Dlugolecki, 2007, pp. 40–47; Mills, 2009). One example is pay-as-you-drive insurance, 'offered by at least 26 insurers around the world, recognising the link between accident risk (as well as energy use) and distance driven' (Mills, 2009, p. 24). This approach is innovative in the sense that it provides a climate dividend as a side-effect of more accurately pricing accident risk. However, emission reductions of this magnitude, although a positive innovation, are well short of the deep and rapid cuts required across the global economy to avoid dangerous anthropogenic climate change.

Mills' second category is 'crafting innovative insurance products & services' (Mills, 2009, p. 29). Some actors in the insurance system provide products that facilitate the commercialization of renewable energy technologies, which can avoid anticipated increases in greenhouse gas emissions, but which entail substantial financial and regulatory risks (Leblanc, 2008). New insurance products for energy service providers is one example, although Mills (2009, p. 29) notes that '[r]enewable energy has seen a flurry of activity, but most appears to be little more than bundling/repackaging of existing offerings, rather than pure innovation to fill coverage gaps or carefully tailor coverage to unique features of these technologies'. One example of a potentially effective support role is insurance system products that facilitate investment in renewable energy projects through the Clean Development Mechanism (CDM) and Joint Implementation (JI), under the Kyoto Protocol (see Mills and Lecomte, 2006, pp. 22–24). However, the record of CDM and JI in reducing CO₂ emissions is extremely poor (Lohmann, 2008). As such, the potential for reducing emissions via this path is at present limited.

Effective Governance of Climate Risk?

Effective climate change risk governance requires a rapid and fundamental shift away from the global economy's reliance on burning fossil fuels (Stern, 2006; IPCC, 2007a; Garnaut, 2008). Societal responses to date are utterly inadequate, a point underscored by the course of climate negotiations in Copenhagen in December 2009 and the preceding two-year preparatory effort (Phelan, 2010). Despite decades of policy discussion, design and implementation, global CO₂ emission rates and atmospheric concentrations continue to rise well beyond (rather than reduce to within) biogeophysical limits: '...the acceleration of both CO₂ emissions and atmospheric accumulation [in the period 2000–2007] are unprecedented and most astonishing during a decade of intense international developments to address climate change' (Global Carbon Project, 2008).

Etkin (2010, p. 404) provides an excellent figure, which represents clearly anthropogenic atmospheric CO₂ concentrations as driving a radical shift outside the 'well-defined domain' the Earth's state has occupied for the past 420 000 years. Etkin (2010, p. 404, footnote 2) further notes that '[o]ther data suggests this pattern has existed for a million years, through ten ice-age cycles'. As the greenhouse gas levels in the atmosphere continue to increase, so too do climate risks. Moreover, there is no reason to believe that the relationship between atmospheric concentrations of greenhouse gases and climate risks is linear. On the contrary, many assessments point to the rapid approach of thresholds, past which risk escalates rapidly (e.g. Schellnhuber *et al.*, 2006). The effect of the insurance system's weakly mitigative efforts to date is both inconsistent with the risks of financial losses that unmitigated climate change entail, and negligible with regard to continued and increasing greenhouse gas emissions. Action by the insurance system is yet to lead to significant reductions in anthropogenic greenhouse gas emissions. On this basis we describe the insurance system's mitigative responses to climate change as generally weak. In the following section we review a political economy perspective on the limitations of insurance system responses to anthropogenic climate change.

Limits to Insurance System Responses to Climate Change: a Political Economy Perspective

Recent limited insurance system responses to climate change are fairly consistent with Paterson's (2001) earlier international political economy (IPE) perspective on the relationship between insurance and climate change. The IPE perspective is narrower than our systems approach and addresses the global insurance industry only, i.e. commercial elements of the insurance system. Paterson (2001) concludes that commercial elements of the insurance system have a limited commitment to a reduction in global greenhouse emissions, even though climate

change had been acknowledged as a potential phenomenon – and one with implications for risk governance – by some in the insurance system at least as far back as the 1970s (e.g. Munich Re, 1973).

The IPE perspective was generated in the context of expectations that the insurance system might provide a source of corporate leadership for climate change mitigation (see Newell and Paterson, 1998; Paterson, 1999). The bases for this proposition include insurance having a greater perceived vulnerability to climate change than other business sectors (a persistent perception – see for example Pinkse and Kolk, 2009, p. 93). Jeremy Leggett (1993b), in work for Greenpeace International and also published in this journal (Leggett, 1993a), proposed a three-part typology of potential strategic insurance sector approaches to global climate politics in the context of increasing levels of climate risk.

Leggett's belief was that while insurers might be tempted to go for the second of these [i.e. adaptation], they could be pushed from adopting the second towards the third [i.e. mitigation], arguing to insurers that when data cease to be actuarial, the second set of responses becomes inadequate (Paterson, 2001, p. 19).

The IPE perspective is detailed and we do not review it here.⁸ We note only that the perspective does not challenge the linear understanding of the Earth system reflected in adaptive and weakly mitigative insurance system responses to climate change (nor is it equipped to do so). In this regard we highlight two aspects of the IPE perspective below. The need for a non-linear understanding of the Earth system is the basis of our critique provided in the following section of both insurance system responses to climate change and the attendant IPE perspective.

Paterson (2001) argues that the commercial element of the insurance system considers climate change a manageable threat in part because it considers itself as having at its disposal two apparent opportunities for limiting exposure to climate risk. The first assumes increased accuracy in climate system prediction: the potential for better prediction of extreme weather events over periods of 12–18 months, roughly congruent with standard reinsurance contract periods. As such, reinsurers (key actors in the insurance system) may be able to prospectively (i) increase premiums or (ii) limit exposures to large claims, for example by declining cover in some years. The second assumes increased capacity to carry climate risk. Specifically, capital markets have the potential to provide an enlarged pool in which to spread financial risks, traditionally assumed exclusively by the insurance system. Insurance-linked securities (ILSs), such as catastrophe bonds, are financial instruments that allow climate risk to be shifted outside the insurance system and onto capital markets (Cabral, 1999; Tynes, 2000; Guy Carpenter & Company LLC, 2007).

In essence, both options are adaptive responses to climate change that may contribute to commercial insurance elements of the insurance system continuing to operate without needing to engage in climate change mitigation. The IPE perspective suggests that in effect, armed with better information about the Earth system and a larger pool in which to spread financial risk, commercial insurers consider themselves able to remain profitable in the face of global ecological crisis: climate change could even be a business opportunity for insurers.

Our argument is not that adaptation is of no value, but that (i) adaptation measures rarely make a contribution to climate change mitigation and (ii) mitigation is necessary for the long-term viability of the insurance system. The strongly dominant emphasis on the potential for insurance to play a role in adaptation and weak mitigation (e.g. Barriau and El Karoui, 2002; Jagers and Strippel, 2003; Mills, 2003; Allianz, World Wildlife Federation, 2005; Association of British Insurers, 2005; Churchill, 2006; Kunreuther and Michel-Kerjan, 2007; Mills, 2007b; Ross *et al.*, 2007; Botzen and Van den Bergh, 2008; Hecht, 2008; Leblanc, 2008; Maynard, 2008; Swiss Re, 2008; Ward *et al.*, 2008; CCRIF, 2009; Mills, 2009; MCII, 2010) obscures what is uncontroversial in the contexts of climate science (e.g. IPCC, 2007a) and international climate negotiations (e.g. United Nations, 1992). Mitigation remains necessary. Climate change poses a profound societal challenge and a successful mitigation response is inconceivable without the engagement of insurance – and all other socio-economic subsystems. In the following section we argue that ecologically effective mitigation in the short term is necessary for viable societal governance of climate risk in the medium and long term.

⁸We draw primarily on the work of Jagers *et al.* (2005), Jagers and Strippel (2003), Paterson (1999), Newell and Paterson (1998), and particularly Paterson (2001) for the IPE perspective on the relationship between insurance and climate change.

Mitigation as Effective Climate Risk Governance: a Systems Perspective

Mitigation is essential for human societies generally to avoid dangerous anthropogenic climate change (IPCC, 2007b). In late 2008, after the Presidential election in the United States and before the inauguration of President Obama, leading climate scientist James Hansen and his wife Annie wrote an open letter to Barack and Michelle Obama, 'as fellow parents concerned about the Earth that will be inherited by our children, grandchildren, and those yet to be born'. In their letter the Hansens urged the need for effective action on climate change, saying that

There is a profound disconnect between actions that policy circles are considering and what the science demands for preservation of the planet. . . Science and policy cannot be divorced. It is still feasible to avert climate disasters, but only if policies are consistent with what science indicates to be required (Hansen and Hansen, 2008).

In this section we introduce a complex adaptive systems perspective to demonstrate why adaptation to climate change in the absence of ecologically effective mitigation is not a viable strategy for the insurance system. The IPE analysis suggests that commercial elements at least of the insurance system are responding to anthropogenic climate change as though they have access to two potentially viable climate change adaptation strategies. Below we review each proposed adaptation strategy and argue that neither allows for ongoing viability of the insurance system as the climate changes. Considering the adaptation strategies' flaws is helpful for explaining why adaptation without mitigation is not a viable strategy for the insurance system, or for the human societies dependent on the insurance system for effective risk governance. The critique is also helpful for identifying limitations of the IPE perspective on the insurance system–climate change relationship.

The Earth system is a complex system, characterized by thresholds and non-linear change (Schellnhuber *et al.*, 2006). The Earth system changes over space and time in response to multiple influencing factors, such as massive increases in atmospheric concentrations of CO₂ emissions (Keller *et al.*, 2007). Complex systems such as the Earth system differ from simple, static systems, such as motors and computers, in that they are self-organizing and embody a degree of uncertainty as they experience transformation processes. One of the features of complex systems is their capacity for surprise (Schneider, 2004). Sometimes complex systems change their structures fundamentally and apparently suddenly. Apparently sudden change in these systems can occur in response to the cumulative impacts of influences that are not readily perceived and yet may have been building up over a long period (Keller *et al.*, 2007; Lenton *et al.*, 2008).

Adaptation Option 1: Better Information About the Earth System

This proposed adaptation option, described by the IPE perspective on the insurance system–climate change relationship, was made with reference to extreme weather events and relies on those in the insurance system attaining a markedly more precise understanding of the Earth system. This is unlikely to eventuate. The following three examples of extreme weather event research highlight the limitations of prediction in a complex adaptive system such as the Earth. First, some have suggested that '[a]fter accounting for changes in population and wealth. . . changes in extreme weather events [globally] may be responsible for a growth in losses by about 2 per cent a year since the 1970s' (and see Muir-Wood *et al.*, 2006; Ward *et al.*, 2008, p. 134). The trend 'corresponds with a period of rising global temperatures' (Muir-Wood *et al.*, 2006, p. 188). Second, increased probability of hurricane intensity in some areas of the Earth's surface was predicted by some climate scientists and has been observed (Henderson-Sellers *et al.*, 1998; Webster *et al.*, 2005). Third, Knutson *et al.* (2010), also with reference to links between climate change and hurricanes, find that

it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes. However, future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100 (Knutson *et al.*, 2010, p. 157).

Our argument in response to the better scientific information adaptive approach for insurers is fundamental: meaningful prediction in a period of climatic change is theoretically impossible due to the Earth system being a non-equilibrium system, characterized by non-linear change. By *meaningful prediction* we mean prediction accurate enough, at useful spatial and temporal scales, to allow insurers to pre-emptively adjust premiums, and in extreme cases decline to issue cover. In contrast, weather prediction over the short term, such as a few days, is possible but not helpful in avoiding climate risk.

Even if meaningful climate prediction were possible, varying premiums and declining to issue cover are complicated matters. With regard to social insurance, government simply denying insurance protection to vulnerable populations is politically untenable. With regard to commercial insurance, the industry is generally heavily regulated, and regulation can and does extend to forcing provision of cover and controlling price.⁹ Even so, commercial insurers' existence is dependent on their ongoing financial viability. Aside from important practicalities of providing or denying access to insurance is a deeper question about the purpose of insurance. Insurance provides socio-economic stability; flipping between providing and denying insurance because of rapid and significant changes in risk may undermine societal faith in the insurance system's products and providers, and therefore the insurance system overall.

Climate change is shifting the Earth system into an alternative state where the Earth system is no longer as reliable as it was. Under such circumstances, historical data describing climate are rendered non-indicative of probabilities for future extreme weather events. Operational concepts such as 'one in a one hundred year flood', which are grounded in reliable probabilities observed and recorded over time, lose their usefulness.

Whilst Hurricane Katrina and its aftermath, particularly the manifestly inadequate emergency response, made headlines because of resulting social, economic and ecological impacts, another hurricane with a similar name a year earlier was more remarkable in a climate science sense. Hurricane Catarina hit the coast of Brazil in March 2004. Catarina was the first ever recorded hurricane to form in the South Atlantic (Pezza and Simmonds, 2005). Hurricane Catarina was a surprise and unlike other hurricanes was only named posthumously and informally, after the Santa Catarina region of Brazil where it made land (Henson, 2005). Not only was Catarina not predicted: before it occurred it was considered inconceivable from a scientific perspective.

Beyond single weather events, changes in the Earth system are also visible in the aggregate of climate-linked disaster events. For example the 1980s saw on average 400 Earth system (or 'natural') disaster events globally. This increased in the 1990s to an average of 630 each year, and to 730 in the last ten years. Catastrophic Earth system events in 2007 totalled 960, the highest number since systematic recording began in 1980. Of these events 91% were climate linked (IAIS, 2008a, pp. 15–16).

The Earth system is intrinsically unpredictable. Over time, human endeavours – including the evolution of the insurance system – succeed because of Earth system stability: past experience provided a reasonable guide for future experience. However, a changing climate renders the Earth system unstable and characterized by unpredictable change (Roe and Baker, 2007). Albrecht and Rapport, considering sustainability overall, argue that

the world of relative predictability, with respect to reliability of ecosystem functions, has by degrees been transposed to a world of relative chaos in which surprise dominates, often with severe human consequences (Albrecht and Rapport, 2002).

Needless to say, the implications are profound for human societies generally, not simply the insurance system. Changes in Earth systems are better understood as thresholds that are crossed, rather than as linear, orderly and progressive change (Lenton *et al.*, 2008). Increasing rates of change in elements of the Earth system – continually in advance of predicted rates – are a feature of climate change as currently manifest, and are examples of non-linear and faster-than-predicted change. Such elements demonstrating faster-than-predicted rates of change over recent years include the Greenland ice sheet melt and sea level rise (Oppenheimer and Alley, 2005, p. 258; Rahmstorf *et al.*, 2007). The science is not well enough developed to provide certain prediction – or even detection – of these and other Earth system thresholds before they are crossed (Keller *et al.*, 2008; Lenton *et al.*, 2008). Some thresholds have already been crossed; others still lie ahead.

⁹Examples include statutory provision of compulsory automotive third party and workers' compensation insurance.

The extent to which the Earth system is moving generally into a period of greater unpredictability is uncertain. The manner in which the impacts of climate change will be distributed geographically across regions and across economic sectors poses difficult questions for scientists:

Until and unless major oscillations in the Earth System (El Nino–Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) etc.) can be predicted to the extent that they are predictable, regional climate is not a well defined problem. It may never be (Anonymous in Henderson-Sellers, 2008).

Focusing on insurance, a key question is what the impact of greater unpredictability might be on societal capacity to maintain a viable insurance system, and what forms the insurance system might take.

Additional to the theoretical impossibility of meaningful prediction are currently insurmountable practical considerations. Climate modelling at the level of spatial and temporal detail required for local planning or decision-making is not possible at present and unlikely to be possible in the near future. This is a practical rather than theoretical challenge, but significant nonetheless. The scale of models is currently too obtuse and increasing model resolution adequately is a significant technical challenge that is unlikely to be resolved in the near future (see Heffernan, 2008; *Nature*, 2008).

Adaptation Option 2: Spread Financial Risk Across the Global Economy

The search for greater capacity to assume risk has led to the spreading of financial risk outside the insurance system and into capital markets through catastrophe bonds and other financial instruments collectively known as insurance-linked securities (ILSs). The second adaptation option described by the IPE perspective on the insurance system–climate change relationship relies on a change in the relationship between the insurance system and the global economy, i.e. shifting financial risk more directly, and in larger quantity, to the global economy. In practice, the use of such bonds remains limited but is growing to the extent that some actors in the insurance system are beginning to suggest that the ‘convergence’ of the reinsurance and capital markets may become a long-term trend (Benfield Group Limited, 2008, p. 6; Magarelli and Harrison, 2008). However, our argument here extends beyond current practice and anticipated trends to what is theoretically possible – and impossible.

Spreading or transferring risk does not eliminate risk, it simply shifts it. From a systems perspective, shifting risk up a system scale from the insurance system to larger global capital markets may well provide a temporary increase in the capacity of an individual firm – or even the system as a whole – to bear financial risk. Longer term however, this shift invites larger-scale consequences in the event of (now larger) system failure. The apparent increased resilience of the insurance system to climate risk is achieved without attention to the cause of climate risk, and at the cost of the resilience of the larger system. Meanwhile, in the absence of ecologically effective mitigation, climate risks continue to increase.

Climate change is a globally coherent phenomenon. Whilst capital markets clearly have greater financial capacity than commercial elements of the insurance system to assume climate risk, capital markets too are part of the global economy, and thus also vulnerable to climate change as a function of the relationship between the global economy and the Earth system on which it is founded. Accordingly, if climate change is not effectively mitigated, in essence this strategy remains a temporary adaptation strategy and does three things.

First, whilst not addressing the problem directly, this strategy may buy an unspecified, and unknowable, amount of time, which may or may not be used to pursue more strategic (i.e. mitigation-focussed) responses. Second, by shifting system risk up a scale, this strategy invites system failure at larger scale. Third, the adaptation strategy opens up the insurance system to new potential vulnerabilities grounded in the relationship between the insurance system and the global economy. The 2008 global financial crisis is one example. Even though the world's largest insurer required bailing out by the US Government (Federal Reserve Bank of New York, 2008; Tienhaara, 2010), to date the insurance system overall has not failed as a result of the financial crisis. However, the potential for failure due to integration of insurance and financial markets through ILSs has attracted attention. In response, international insurance regulators were driven to make public announcements noting the resilience and stability of commercial elements of the insurance system in spite of linkages to financial markets (IAIS, 2008b).

Threatened and actual collapses of insurance firms are profound events and reverberate throughout financial and public administration systems, and societies more broadly. The collapse of HIH Insurance in Australia in 2001 (McIlveen, 2001; Commonwealth of Australia (HIH Royal Commission) and Owen, 2003) is a prime example.

Sea Level Rise: a Climate Risk Case Study

Current and anticipated changes in sea level illustrate the non-viability of the adaptive strategies for the insurance system critiqued above. Sea level rise is an Earth system phenomenon that differs from extreme weather events and other Earth system risks in key ways. First, it manifests globally and simultaneously, thus the spatial scale is larger.¹⁰ Second, it is effectively an irreversible change, where irreversible means a change likely to last 'at least 1,000 years' (Solomon *et al.*, 2009, p. 1704), thus the temporal scale impact is larger. Scientific certainty has solidified on the reality of anthropogenic climate change (IPCC, 2007a), yet great uncertainty of the timing and magnitude of impacts remains, including estimated rise in oceans over the course of this century. Rises in sea level are non-linear phenomena (Hansen, 2007), for which information will remain incomplete, significantly around the rate of melting of the Greenland and West Antarctic ice shelves, leaving open the possibility that the rise over the current century may be much higher. The 2007 Intergovernmental Panel on Climate Change report leans towards 20–43 cm (its mid-range projection), but acknowledges that this projection is made 'excluding future rapid dynamical changes in ice flow' (IPCC, 2007a, p. 45). Leading climate scientists have made the point that the IPCC's Fourth Assessment Report projections are highly conservative (see Kerr, 2007; Henderson-Sellers, 2008). More recent estimates anticipate a higher rise this century (Nicholls *et al.*, 2011). Others in the scientific community argue that over the coming decades changes in the melt of the ice sheets will be the major contributors to changes in sea level. James Hansen, noting the IPCC's caveat on sea level rise predictions, argues that, on the basis of existing evidence of non-linear change, business-as-usual climate change will result in sea level changes manifesting much more rapidly, yielding 'a sea level change of the order of meters on the century timescale' (Hansen, 2007, p. 4).

Uncertainty and unpredictability around the timing of global sea level rise presents a significant challenge to the insurance system. The stability of both the Greenland and the West Antarctic ice shelves is a major unknown, and advances in modelling are unlikely to provide more accurate information before being overtaken by physical melting. Steven Schneider made the point back in the 1970s that climate change would require action before climate models could provide policy-makers with certainty (1976, pp. 94–96, 148–149, 189–190, 329–330). Recent research (Roe and Baker, 2007, p. 629) notes that 'uncertainties in projections of future climate change have not lessened substantially in past decades', and argues that the persistent level of uncertainty 'is an inevitable consequence of a system in which the net feedbacks are substantially positive' (see also Allen and Frame, 2007, p. 631).

Accordingly, generating and making use of better information about climate change risk is not a viable long-term adaptive response for the insurance system. Spreading financial risk to capital markets is also not a viable adaptive response to impacts such as sea level rise. Many of the globe's major financial centres, such as New York, Tokyo, Shanghai and London, are physically threatened by sea level rise. Ten percent of the human population and 13 percent of the urban population globally live in low elevation coastal zones, defined as 'the contiguous area along the coast that is less than 10 metres above sea level' (McGranahan *et al.*, 2007, p. 17). This raises several challenges for the insurance system. First, the financial scale of the risk is huge. Second, the risk to varied geographic locations is correlated. Third, and with a systems perspective in mind, the magnitude of sea level rise challenges directly both the insurance system and the global economy in which the insurance system is contained.

Sea level rise is a significant threat but not the only threat. Climate change is implicated in changed timing, duration, frequency, intensity and location of all weather events and climatic trends, including cyclones, hailstorms, bushfires, droughts and floods (see Allen *et al.*, 2007). Many less dramatic, longer term changes in currently insurable circumstances such as changes to agricultural conditions and tourist seasons also manifest as economic threats (see, for example, Steffen *et al.*, 2006; Agrawala, 2007). The insurance system is vulnerable to such risks, as are human societies generally.

¹⁰Sea-level rise is a global phenomenon but not uniform (Nicholls and Cazenave, 2010).

Limits to Adaptation and to the Political Economy Perspective

Anthropogenic climate change represents a strategic threat to the global insurance system, rather than being limited to a partial, temporary or episodic threat to financial viability to elements within it. In this situation adaptive and weakly mitigative actions are insufficient responses to climate change: the unpredictability and scale of the phenomenon mean that climate change threatens the very existence of the insurance system as currently structured.

The failure of the insurance system to respond appropriately to climate risk is consistent with broader societal inability to resolve the climate crisis. However, the insurance system's failure is notable to the extent that insurance is a primary risk governance instrument of industrialized economies and societies. Adaptive and weakly mitigative responses to climate change, as opposed to strongly mitigative responses, are consistent with the assumption that climate change can be adapted to. Insurance has a long history (Trennery, 1926; Pfeffer and Klock, 1974), and one grounded in a linear understanding of the Earth system that is workable while the Earth system remains in a familiar and stable state. Such an approach is reflected in established probabilities for weather events and climate trends. The linear understanding was appropriate for those pre-climate change times. A necessary shift to a non-linear basis for insurance requires a profound rethinking of the relationship between the insurance system and the Earth system.

For its part, the IPE perspective does not explicitly challenge the merit of the linear understanding of the Earth system reflected in adaptive and weakly mitigative insurance system responses to anthropogenic climate change. As such, the IPE perspective can be read as implying that adaptive actions without mitigation may constitute viable insurance system responses to climate change. For example, Paterson (2001, p. 37) suggests that '[i]nsurance companies appear at present perfectly able to deal with climate change and its consequences'. A complex adaptive systems (CAS) analysis of the Earth system suggests otherwise. CAS analysis raises questions about the value of the insurance system's adaptive and weakly mitigative responses to climate change, with implications for both the ongoing viability of the insurance system specifically, and more broadly the human societies reliant on the insurance system for risk governance.

The implications for contemporary societies and their economies are also profound: the insurance system is a primary risk governance tool of industrialized societies. Yet failure of the insurance system does not mean the end of human civilization: as noted earlier, the majority of the world's population survives without direct access to the insurance system. However, it does signal massive changes in the scale and nature of the broader socio-economic system as currently constituted. As noted earlier, the threatened or actual failure of a single actor in the insurance system – such as a commercial insurer – can reverberate through a society. Accordingly, the wholesale failure of the insurance system overall implies major social upheaval.

Reflexive Mitigation and an Insurance Basis for Carbon Prices: a Theoretically Viable Alternative

Social learning (Folke *et al.*, 2005; Keen *et al.*, 2005) allows the possibility of constructive, iterative societal responses to a threatened or actual failure of the insurance system as currently constituted. Elsewhere, we have theorized a shift from a linear to a non-linear basis for insurance, based on a complex adaptive systems approach (Phelan *et al.*, 2011). 'Reflexive mitigation' is an adaptive approach to mitigating climate change recognizing that (i) atmospheric carbon dioxide equivalent concentrations consistent with Earth system stability will vary over time in response to changes in the Earth system and the global economy, and in the relationship between them, and (ii) relationships between the Earth system, the economy and the insurance system are evolving, and therefore understanding of them is necessarily incomplete. Reflexive mitigation offers the theoretical basis for a strong insurance system response to anthropogenic climate change in the non-linear Earth system. Such an approach suggests that successful insurance system adaptation to anthropogenic climate change depends on returning the climate to a stable, familiar and relatively predictable state: effective mitigation is therefore a necessary precondition for successful longer-term insurance system adaptation.

Extending on the theoretical grounding that reflexive mitigation provides, we have further proposed an insurance basis for carbon prices as a theoretically viable insurance system contribution to ecologically effective climate change mitigation (Phelan *et al.*, 2010). Market approaches to limit CO₂e emissions such as carbon taxes

and emission trading schemes (Ekins and Barker, 2001) aim to avoid dangerous anthropogenic climate change by ascribing a financial cost to emissions (Stern, 2006, p. 449). Yet such approaches have failed to establish either emission limits or carbon prices equal to the task: ‘. . .the acceleration of both CO₂ emissions and atmospheric accumulation [in the period 2000–2007] are unprecedented and most astonishing during a decade of intense international developments to address climate change’ (Global Carbon Project, 2008). The proposed insurance basis for carbon pricing better reflects the biogeophysical limits of the Earth system by drawing on aspects of social and commercial elements of the insurance system. The proposal achieves this by (i) creating a financial liability link between current emissions and attributable near future losses and (ii) applying fraction attributable risk analysis (Stone and Allen, 2005; Allen *et al.*, 2007) to determine the contribution of anthropogenic climate change to the increased probability of experienced damaging weather events. The proposal, a departure from current approaches to pricing CO₂e emissions, has aspects that are consistent with existing forms of insurance.

Conclusion: a Role for the Insurance System in Effective Climate Risk Governance

The insurance system is contemporary industrialized society's primary risk governance tool. A complex adaptive systems analysis suggests that climate change undermines the basis of the insurance system, i.e. the capacity to pool and spread financial risk on the basis of known probabilities. One possible conclusion from this is that the ongoing viability of the insurance system is dependent on successful climate change mitigation in the form of dramatic reductions in CO₂ emissions and protection of surviving carbon sinks such as forests. Whilst a succession of adaptive measures can increase system capacity to manage financial risk in the short term, in the absence of ecologically effective mitigation they sow the seed of larger-scale system failure later.

A systems approach highlights the linkages between the insurance system, the global economy and the Earth system, with one embedded in the next. The Earth system is complex and adaptive, characterized by non-linear change, and therefore inherently unpredictable. It was always thus. Changing the climate means pushing the Earth system outside the familiar, stable state on which human social systems have been reliant.

A complex adaptive systems approach to the relationship between climate change and the insurance system promises a more comprehensive understanding of cross-system interaction, and thus perhaps a better account of the threat that climate change presents to the insurance system. A systems approach may also guide new policy responses to engage the insurance system in effective climate change mitigation.

We argue that there may be potential for gearing the insurance system in support of effective climate change mitigation. However, even the strongest current insurance system responses to climate change are adaptive and weakly mitigative as opposed to strongly mitigative. We suggest that transdisciplinary research (Somerville and Rapport, 2000; Albrecht *et al.*, 2001, pp. 72–73) anchored in a complex adaptive systems approach (Holling, 2001; Scheffer and Westley, 2007) may usefully complement and extend on the insights provided by the IPE account of inaction by elements of the insurance system. This approach would explore the relationship between the Earth system, the global economy and the insurance system, consider the threat that climate change presents to the insurance system and investigate the potential for insurance system responses geared towards mitigation. Reflexive mitigation has been proposed as a theoretical foundation for strong insurance system responses to anthropogenic climate change. An insurance basis for carbon prices has been proposed as one theoretically viable approach grounded in the reflexive mitigation concept.

Climate change is a globally coherent phenomenon of unprecedented magnitude. Shifting from the current carbon basis of the global economy implies socio-economic change on an unprecedented scale. Ecologically effective mitigation requires the engagement of the insurance system, together with all other subsystems of human societies. We suggest that, consistent with the systems approach, and recognizing the inadequacy of insurance system responses to date, effective insurance system governance of climate risk will require engagement of all participants in the insurance system, including policy makers, and providers of social and commercial forms of insurance.

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Ecological Viability or Liability? Insurance and Climate Risk

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Ecological Viability or Liability? Insurance and Climate Risk

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