This article was downloaded by: [Phelan, Liam]

On: 17 April 2010

Access details: Access Details: [subscription number 921365792]

Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

International Journal of Sustainable Development & World Ecology

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t908394088>

Climate change, carbon prices and insurance systems

Liam Phelan ^a; Ann Henderson-Sellers ^b; Ros Taplin ^c

^a Graduate School of the Environment, Macquarie University, Sydney, Australia ^b Department of Environment & Geography, Macquarie University, Sydney, Australia ^c Mirvac School of Sustainable Development, Bond University, Robina, Australia

Online publication date: 16 April 2010

To cite this Article Phelan, Liam , Henderson-Sellers, Ann and Taplin, Ros (2010) 'Climate change, carbon prices and insurance systems', International Journal of Sustainable Development & World Ecology, 17: 2, 95 – 108

To link to this Article: DOI: 10.1080/13504500903541806

URL: <http://dx.doi.org/10.1080/13504500903541806>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Climate change, carbon prices and insurance systems

Liam Phelan^{a*}, Ann Henderson-Sellers^b and Ros Taplin^c

^aGraduate School of the Environment, Macquarie University, Sydney, Australia; ^bDepartment of Environment & Geography, Macquarie University, Sydney, Australia; ^cMirvac School of Sustainable Development, Bond University, Robina, Australia

Market approaches to limit CO₂e emissions such as carbon taxes and emissions trading schemes (ETSs) aim to avoid dangerous anthropogenic climate change by ascribing a financial cost to emissions. Yet such approaches have failed to establish either emissions limits or carbon prices equal to the task. We propose an approach to carbon pricing that better reflects the biogeophysical limits of the Earth system by drawing on aspects of insurance systems including forms of social insurance and the insurance industry. Our proposal achieves this by: (i) creating a financial liability link between current emissions and attributable near future losses; and (ii) applying Fraction Attributable Risk (FAR) analysis to determine the contribution of anthropogenic climate change to increased probability of experienced damaging weather events. Our proposal, a departure from current approaches to pricing CO₂e emissions, has aspects that are consistent with existing forms of insurance. It requires participation by states and a small number of larger and established reinsurers. Our proposal provides both the scientific–technical capacity and the political–economic incentive to shift the anchor point for carbon prices away from pressing short-term political and economic considerations and closer to strategic ecological requirements for Earth system stability: the balance is shifted to favour changes in the global economy necessary to avoid dangerous anthropogenic climate change over current estimations of what is politically and economically feasible or desirable. Our proposal is an example of reflexive mitigation, grounded in complex adaptive systems theory, and centres on relationships between the Earth system, the global economy and insurance systems.

Keywords: climate change; carbon price; insurance; reflexive mitigation; adaptation; complex adaptive systems

Carbon prices that reflect biogeophysical limits: a role for insurance systems

Market approaches to climate change mitigation are designed to drive CO₂e emissions¹ reductions in the global economy by ascribing a financial cost to emissions (Stern 2006: 449). Two common approaches that operationalise carbon pricing are carbon taxes and emissions trading schemes (ETSs) (Ekins and Barker 2001).² To date carbon emission prices have been unrealistically low. Andrew (2008: 339) notes for example that ‘European governments have been guilty of allowing their industries as much CO₂ as they could emit at little or no cost.’ This is perhaps not surprising: the *status quo* is a global economy dependent on limitless, uncosted fossil fuel emissions. Structurally powerful fossil fuel interests have been successful till now in organising effectively to defend their interests, in part by framing their interests as the interests of society in general (Paterson 2001).

Policy-makers implementing carbon pricing have failed to either aim for, or achieve, prices or limits to emissions that accurately reflect the biogeophysical limits of the Earth system. Despite decades of policy discussion, design and implementation, global CO₂e emissions 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 2008b). Carbon prices in such schemes instead closely reflect pressing and legitimate but short-term

political and economic considerations including decision-makers’ current estimations of what is politically and economically feasible or desirable. The Australian Government’s proposed ETS (Commonwealth of Australia 2008), and the preceding *Garnaut Review* (Garnaut 2008) that informed it, are examples. As such the ecological effectiveness and therefore the strategic value of such measures is unclear. We define ‘ecologically effective’ as reductions in emissions sufficient to avoid dangerous anthropogenic climate change.

In this paper we propose a means of generating carbon prices that draws on aspects of insurance systems to better reflect the biogeophysical limits of the Earth system. Our proposal’s theoretical basis in complex adaptive systems theory is presented in section two. Key features and elements are presented in sections three and four. Section five introduces important ancillary opportunities that our proposal provides in the areas of indirect support to other mitigation policies and action, and inter- and intragenerational equity. The paper concludes with discussion of our proposal and future directions for research in section six.

The earth, the economy and insurance: systems in relationship

Our proposal for carbon pricing linked with insurance systems is grounded in an understanding of the Earth system, the global economy and insurance systems as connected complex adaptive systems (Phelan et al. forthcoming). In theoretical terms this means recognising cross-scale linkages between systems and making changes in one system

*Corresponding author. Email: liam.phelan@newcastle.edu.au.

(insurance systems) to effect changes in another larger system (the global economy) and so foster its alignment with a yet larger third system (the Earth system).

We use the term 'insurance systems' and not 'insurance industry' purposely to bring focus to all of the participants in insurance systems and their relationships that together allow ongoing provision and use of financially viable insurance. This explicitly includes welfare state-style social insurances such as universal health care, unemployment benefits and age and disability pensions. 'Insurance systems' also includes participants in what is more commonly understood to be the insurance industry such as for-profit and mutual insurers, government insurers, reinsurers, specialised service suppliers such as loss modellers and brokers, government regulatory authorities and industry representative bodies. Investors in insurance companies as well as insurers' substantial investments are also included. The term also includes the legal and institutional frameworks created and used to facilitate access to insurance. We use the term 'global economy' to refer to the source of anthropogenic greenhouse gas emissions. We use the term 'Earth system' to describe the integrated socio-ecological system that is planet Earth and all life on it, including human societies. This theoretical approach is provided in more detail in Phelan et al. (forthcoming).

The scientific basis for anthropogenic climate change as a globally coherent phenomenon and the need for substantial cuts in CO₂e emissions are established (IPCC 2007a; Hansen et al. 2008). Our proposal proceeds on the uncontroversial assumption that climate change impacts will continue to grow with emissions and this will lead to substantial economic losses across the carbon economy. The threat climate change presents to human social systems is the motivation for climate change mitigation and adaptation, as articulated in the United Nations Framework Convention on Climate Change (United Nations 1992). The Intergovernmental Panel on Climate Change has repeatedly communicated the reality and implications of climate change (IPCC 2001, 2007a). The *Stern Review* (Stern 2006) and the *Garnaut Review* (Garnaut 2008) provide economic analyses of climate change impacts with regard to the global economy and the Australian economy respectively.

Reflexive mitigation: an adaptive approach

Reflexive mitigation (Phelan et al. forthcoming) describes an adaptive approach to mitigating climate change. Reflexive mitigation is an adaptive approach to mitigating climate change recognising: (i) maximum atmospheric CO₂e concentrations consistent with Earth system stability will vary over time in response to changes in the Earth system, the global economy (the source of anthropogenic CO₂e emissions), and the relationship between them; and (ii) relationships between the Earth system and smaller component systems including the global economy and insurance systems are evolving and therefore understanding of them is necessarily incomplete. Changes in complex

adaptive systems such as the Earth system are typically non-linear and unpredictable. As such climate change policy development and action proceeds under conditions of uncertainty (TERI & IISD 2006). Accordingly, mitigation measures must be adaptive to allow for consistency with continual and sometimes rapid changes in the Earth system, and in scientific understanding of the Earth system. One example is potentially rapidly changing scientific estimates of what constitutes a stable atmospheric CO₂e burden and required reductions in CO₂e emissions. In contrast standard approaches to mitigating climate change are more rigid, for example adopting a limit of 2°C warming (Meinshausen et al. 2009), and so less capable of responding rapidly should this target be shown in time to be inconsistent with climate stability.

Defining and then undertaking specific action necessary to avoid dangerous anthropogenic climate change is complicated, difficult and uncertain (Garnaut 2008). Against the backdrop of 'unequivocal' climate system warming (IPCC 2007a), there is considerable uncertainty about significant Earth system thresholds (Lenton et al. 2008) and our scientific capacity to identify tipping points in the Earth system, sometimes even long after they have been passed (Keller et al. 2007, 2008). Uncertainty is an inherent feature of the Earth system. Uncertainty will increase as the climate continues to change in response to continuing (and increasing) CO₂e emissions and as decision-makers continue to struggle to respond adequately.

Scientific understanding of climate change is continuously evolving and public policy responses to climate change will be more effective when they become more responsive to new scientific research as it is generated. Current best estimates for targets for atmospheric CO₂e concentrations consistent with climate stability indicate the need for a drop from current levels of *circa* 385 to 350 ppm or lower (Hansen et al. 2008). In contrast, public policy responses struggle to reflect scientific analysis. Exchanges between scientists and political leaders at the March 2009 Copenhagen Climate Change Congress held in preparation for the COP-15 negotiations revealed both the dynamism of effective emissions reductions targets, and the challenge of dealing politically with such Earth system dynamism (see Kalaugher 2009). Influential economic analyses (e.g. Stern 2006; Garnaut 2008) serving as bases for policy responses to climate change have stalled on assumed targets for global atmospheric CO₂e concentrations in the range 450–550 ppm – well short of adequate.

It would be prudent to anticipate some variation in these estimates as climate change continues to be experienced and as scientific understanding continues to evolve. In practice observed rates of climate change are repeatedly underestimated. One example is projected rates of sea level rise. In 2007 the IPCC's (2007c) mid-range projection for sea level rise over the course of the current century was in the order of 0.5 m. In less than 2 years that estimate has doubled (McLeod 2009). Under all realistic scenarios, avoiding dangerous (however defined) anthropogenic climate change requires rapid and deep cuts in global CO₂e emissions.³

Proposal features

In this section we outline our proposal for carbon prices as having two key features that partially address the relationship between the Earth system and the dependent global economy: (i) creation of a financial liability link between current emissions and attributable near future (*circa* 20 years) losses; and (ii) acceptance and application of the Fractional Attributable Risk method of analysis to demonstrate causation for financial losses (Allen and Stainforth 2002; Stott et al. 2004; Stone and Allen 2005; Allen et al. 2007, and discussed below). In combination, these features constitute the core of a climate change policy response that gives form to the reflexive mitigation approach described above.

Liability: current emissions and attributable near future financial losses

A liability link between current CO₂e emissions and attributable near future financial losses begins to account for the relationship between the carbon economy and the Earth system on which it depends. Our proposal adopts future financial losses in the global economy caused by current emissions as a proxy for future environmental damage in the Earth system.

Responsibility for potential future financial losses caused by current emissions is then dealt with via insurance; that is, liability is allocated to existing reinsurance organisations with the consent and support of governments. This creates a major financial incentive for those organisations to ensure payments (a *quasi*-premium) received for current emissions are sufficient to maintaining solvency and provide for future claims. Creating and maintaining liability links over time requires dependable rule of law, which relies directly on governments and in turn on broader social system stability.

Fraction attributable risk

Establishing climate change liability links requires technical capacity to attribute a weather event or trend resulting in financial losses to anthropogenic CO₂e emissions. This may never be directly possible in a complex adaptive system such as the Earth: particular loss-causing extreme weather events may occur by chance in the absence of any anthropogenic climate change. Instead, Stone and Allen (2005) draw on epidemiological approaches to causation to focus on Fraction Attributable Risk (FAR), or ‘the risk of [an] event occurring, rather than the occurrence of [an] event itself’ (p. 304). The FAR concept was developed for population studies in epidemiology, and Allen et al. (2007) apply it in ‘the analysis of an unprecedented change in a single system ... the world’s climate’ (p. 1357). Allen et al. (2007) use the term FAR ‘methodology’ to refer to the discrete modelling process they describe. We use the term ‘method’ to limit meaning to the process described, and so avoid confusion with common social science understandings of the term ‘methodology’, which typically refer to broader understandings of scientific inquiry, complete with ontological and epistemological foundations and standard forms of practice.

Applying FAR method results in a probabilistic quantity: the probability of a specific event occurring. A proportion of the probability of an event’s occurrence can be attributed to anthropogenic CO₂e emissions. This allows consideration of the extent to which ‘human influence on climate can be “blamed” for observed weather trends and specific weather events such as floods, storms or heat-waves’ (Stott et al. 2004).

The FAR method builds on earlier probabilistic approaches: Stone and Allen (2005) draw on Barsugli et al. (1999) and Palmer and Räisänen (2002). Its application (Stott et al. 2004) to the 2003 European heatwave that caused 35,000 premature deaths and in excess of €13.1billion (UK Met Office 2008) in lost agricultural production and fire damage is described as a ‘breakthrough: it is the first successful attempt to detect man-made [sic] influence on a specific extreme climatic event’ (Schär and Jendritzky 2004: 560). The initial application of FAR to the 2003 European heatwave combined with a conservative application of statistics concluded that very likely (i.e. greater than 90% chance) ‘human influence ... increased the risk of the 2003 heatwave by a factor of at least two, with the most likely increase ... considerably greater than two.’ (Allen et al. 2007: 1393).

A later study by Allen et al. (2007) on ‘Scientific challenges in the attribution of harm to human influence on climate’ applied a statistical approach described as more realistic and consistent with standard practice for modelling extreme value distributions. This study determined human influence increased in the risk of the event occurring by a factor of four to ten, with the most likely value being six (Allen et al. 2007: 1392–1393). Another way to say this is that 85% of the risk of the heatwave occurring was due to human interference with the climate (Allen et al. 2007: 1393).

This later study appears in a law journal and can be seen as an attempt by climate scientists to reach out to the legal community, seeking agreement ‘on an “industry standard” operational approach to the attribution problem’ (Allen et al. 2007: 1355). The authors argue that FAR analysis provides the capacity to determine the extent to which a recent past large scale, financially damaging weather event was more likely to have occurred because of human interference with the climate. Others have since extended the approach by linking the FAR method with sophisticated statistical techniques to render the FAR method applicable to smaller-scale events (Jaeger et al. 2008).

There are a number of constraints to applying the FAR method associated with the contexts in which the method can be applied with confidence. The starting point for the FAR method is the current state of the atmosphere, i.e. complete with the existing anthropogenic atmospheric CO₂e burden. The key question then becomes: ‘how not injecting that [already emitted] amount of carbon dioxide would alter our present-day and projected future climate’ (Allen et al. 2007: 1359). Note that FAR method does not make use of information from earlier historical and

prehistoric atmospheric states. As such the FAR method avoids reliance on scientific understanding of past states of the climate for which there is less reliable data. Allen et al. (2007) note that the reference conditions used by the scientific community are defined as 'the climate that would have occurred in the early twenty-first century in the absence of specific human influences' (p. 1366). In fact the climate has been subject to 'specific human influences,' and so those conditions can only be explored using computer simulation. The FAR method adopts the computer-simulated baseline as the 'natural' or reference climate.

Turning to quantifying human influence on climate, Allen et al. (2007: 1374), ask the legal community to reach agreement on what 'constitutes an adequate explanation of recent climate trends' for their purposes, adding that

Within the scientific community, an explanation that is both physically coherent and consistent with the available data – meaning the data provide no indication that anything is missing from either forcings or response – is generally considered adequate (Allen et al. 2007: 1374).

On this basis Allen et al. (2007) note that 'most of the global warming over the past 50 years is very likely to have been due to the observed (anthropogenic) increase in GHG [greenhouse gas] levels' (p. 1375), and refer readers to the IPCC's 2007 *Fourth Assessment Report* (IPCC 2007b). In highlighting the temporal scale constraints to confidence about causes of warming, Allen et al. (2007: 1375–1376) are at pains to point out that scientific certainty about the anthropogenic cause of climate change is strongest for the past 50 years, and that 'knowledge about recent climate change is most relevant to quantifying the impact of CO₂e emissions to date and to predicting future climate change' (Allen et al. 2007: 1376). Thus Allen et al. (2007: 1378–1383) use a property of the climate system, 'Transient Climate Response'⁴ which also attracts substantial scientific consensus and which can be employed over such a time scale as short as the past 50 years and the next two decades or so.

Allen et al. limit their perspective to present day and near future losses, where near future means 'within the next decade or two' (2007: 1383). They note that the climate responds to current atmospheric CO₂e concentrations, not changes in levels of emissions: as such changes in emissions levels 'will take at least a couple of decades to have a significant impact on the climate' (2007: 1383). Given this lag in the climate system, the climate of the next quarter century will be the result of human decisions that have already been made, combined with natural factors, some of which may be in the future, for example volcanic eruptions. Allen et al. (2007: 1383) also acknowledge a corollary of that system lag: decisions made now and in the immediate future are likely to have little impact on the climate before 2025.

Allen et al. (2007: 1385) present 'probabilistic event attribution' as a quantitative approach to causal attribution (Stone and Allen 2005). This approach focuses on 'attributing changes in the risk of an event occurring to external drivers of climate rather than attempting to dissect the event itself'

(Allen et al. 2007: 1385), and requires adoption of a probabilistic framework. The likelihood of an extreme weather event occurring can be proportionally allocated to multiple causes. In contrast, neither the event itself, nor its impacts (e.g. total rain in a freak storm and ensuing damage), can be proportionally allocated to multiple causes.

The FAR method requires careful definition of the event for which probabilistic attribution is being calculated and this is addressed in detail in Allen et al. (2007). Recalling that the reference climate used in the scientific community is 'the climate that would have occurred in the early twenty-first century in the absence of specific human influences,' the next question is how that risk might change if anthropogenic CO₂e emissions had not occurred. In short, the question the FAR method can answer is: How much more likely was a specific extreme weather event because of anthropogenic climate change?

Allen et al. (2007: 1394–1395) conclude their paper with a series of issues that require consideration if the FAR method is to be adopted by the legal community, centred on the parameters in which the method could be operationalised.

Adoption of the FAR method by insurance systems towards generating carbon prices similarly would require translating the method from the climate sciences across to the loss modelling and actuarial disciplines. We suggest that in comparison to legal systems' adoption of the method, this may be easier for insurance systems because of their existing focus on risk modelling and management.

A reflexive approach to climate change mitigation drawing on the FAR method would integrate continuous application of the method to extreme weather events and trends, towards continuously evolving understanding of climate and associated financial losses. Applying the FAR method produces probabilistic results, that is the contribution of climate change to the increased likelihood of a defined event occurring (Allen et al. 2007). This information would in turn inform carbon prices.⁵

Limits in the Earth system and insurance systems

The Earth system has biogeophysical limits, and is characterised by thresholds and tipping points (Steffen et al. 2003). Globally significant Earth system thresholds threatened by anthropogenic climate change include melting Arctic sea-ice, the Greenland and West Antarctic Ice Sheets and the Atlantic thermohaline circulation (Lenton et al. 2008). Some changes can occur apparently suddenly or more rapidly than anticipated (Schneider 2003; Schellnhuber et al. 2006). Some changes are likely to be irreversible over a period of at least 1000 years and so from a human perspective, are in effect permanent (Solomon et al. 2009).

Insurance systems too have limits: some risks are 'beyond the insurance limit' (Beck 1992: 88). Risks are uninsurable for example where potential financial losses are too great and where uncertainty of loss probabilities is too high. This proposal arguably lies within insurance systems' limits. Insurance systems' use of the FAR method is

designed to enforce limits on anthropogenic emissions consistent with Earth system limits. An approach to carbon prices that draws on aspects of insurance systems allows anticipated and attributable near future losses to be reflected in prices for current emissions. Anticipating increased likelihood or magnitude of attributable near future losses would provide a rationale for increasing current carbon prices. Conversely, anticipating decreased likelihood or magnitude of attributable near future losses would provide a rationale for reduced carbon prices.

Increasing uncertainty regarding probabilities (both frequency and magnitude) of future financial losses would also provide a rationale for increases in carbon prices. Conversely, decreased uncertainty regarding probabilities of future losses would allow decreases in carbon prices. As anthropogenic climate change continues to push the Earth system outside of a familiar stable state, Earth system unpredictability will increase. Therefore in the near term, if emissions continue to increase, carbon prices would be expected to increase.

Insurance systems can manage increased uncertainty to a point, for example by increasing premiums for insured assets (or in this case, by increasing carbon prices). However where uncertainty becomes too great, risks and therefore premiums move from less expensive to more expensive, and beyond to unpricable. Thus a carbon price generated, though insurance techniques would reflect (or feed back) to the economy, an indication of the capacity of the Earth system to bear additional CO₂e emissions and atmospheric concentrations, including biogeophysical limits. As such Earth system limits are not represented directly; anticipated financial losses in the global economy serve as a proxy for damages manifest in the Earth system. Ultimately, inability to price the risk associated with emissions represents climate risks increasing beyond the insurance limit.

The feedback provided by a carbon price that reflects Earth system limits may produce counterintuitive outcomes. Orthodox economic theory suggests that the more scarce a resource is compared to demand for the resource, the higher its price (*The Economist* 2009). Yet, for this carbon pricing scenario, the more available the resource (i.e. permission to emit), the higher the potential liabilities and, therefore, the higher the price of the resource. Higher current CO₂e emissions leads to higher atmospheric CO₂e concentrations and higher future risk, which would in turn lead to higher carbon prices currently. Conversely, lower current CO₂e emissions leads to lower atmospheric CO₂e concentrations and lower future risk, which would in turn lead to lower carbon prices. Thus, in this approach to carbon pricing the assumed relationship between scarcity and price is reversed. Systems theory labels this a negative feedback: a feedback that acts to dampen rather than reinforce a perturbation.

Continuous application of the FAR method provides a reference point for carbon prices that continuously refers to evolving scientific assessment of Earth system limits. Liability links current emissions and attributable estimated near future damages. In combination, this proposal provides the scientific–technical capacity and the political–economic incentive to shift the anchor point for carbon price away

from immediate political economic considerations and towards strategic ecological requirements for Earth system stability. The balance is shifted to emphasise changes in the global economy necessary to avoid dangerous anthropogenic climate change over current estimations of what are politically and economically feasible or desirable.

Roles for states and reinsurers

Our proposal is a departure from current approaches to pricing CO₂e emissions. Our proposal invites, and requires, participation of states and a small number of larger, more established reinsurers and loss modellers. In particular, our proposal requires a high degree of coordination between states and globally significant reinsurers. Climate change is an unprecedented challenge for human civilisation and successful mitigation requires effective government leadership. States alone have the capacity in times of rapid change to simultaneously (i) appropriately distribute powers between itself and other actors, (ii) maintain legitimacy domestically, and (iii) maintain legitimacy externally (Hirst 2000: 31). Effective climate change mitigation requires fundamental change throughout socio-economic systems and cannot be implemented without broad engagement across societies (Phelan et al. forthcoming). Heavy regulation of insurance systems by governments is required if insurance systems are to play a role in climate change mitigation. For example, this proposal addresses climate-attributed losses and not any other variable that may exacerbate or ameliorate losses such as changes to building codes.

States appropriately distributing powers between themselves and other actors invite engagement by others involved in insurance. Other participants in insurance systems such as larger reinsurers and loss modellers also need to engage in strong mitigation action. Since the early 1990s, insurers and reinsurers have disappointed environmental civil society organisations and others advocating climate action by not matching expectations of their leadership potential in mitigating climate change (Paterson 2001). However reinsurers have substantial capacity to conduct or commission risk research, modelling and management and therefore have the potential to contribute constructively in this regard (Mills 2005).

This proposal provides a powerful political–economic incentive for reinsurers and loss modellers to engage in strong climate change mitigation action. Treating carbon prices as *quasi*-premiums, to be collected by larger reinsurers licensed by states to do so, means the creation of a very large new market and therefore a significant opportunity for making profit. Global emissions from fossil fuels and cement in 2007 alone totalled 8.5 billion tons (Global Carbon Project 2008a). Even applying an unrealistically low current carbon prices such as US\$26⁶ a ton suggests a new market valued in the order of US\$221 billion. We suggest that emissions prices that better reflect the Earth's biogeophysical limits as reflected in anticipated financial losses would be higher, and therefore insurers' potential gross revenues would be higher. By creating such a substantial financial stake in future

climatic stability, our proposal creates a powerful and immediate political economic motivation for insurers and states to pursue climatic stability.

Long-tail risks

Our proposal creates a new and substantial opportunity for reinsurers to generate profit. Even so, reinsurers may remain wary of our proposal because of the challenges of profitably pricing and managing risk over large temporal scales (Parsons 2003). Climate change liabilities (as with other environmental, product, and workplace liabilities such as contaminated sites, pharmaceuticals with side effects and asbestos exposure) can be considered long-tail liabilities, where 'an injury or other harm takes time to become known and a claim may be separated from the circumstances that caused it by as many as 25 years or more' (Rubin 2008: 296). Long-tail risks are difficult to manage (Munich Re 2008; International Chamber of Commerce 2008). New dimensions to liabilities can emerge over such extended periods and legal contexts can also change (Six 2005). In particular, retrospective application of liability increases uncertainty for insurers (Faure and Fenn 1999). The regulatory context in which the industry operates can also change over time (O'Hara 2006; Schiro 2006; Serio 2006). More broadly, changes in social norms over time pose serious challenges to assessing real liabilities: sources of risk may be contextual rather than inherent in the activity being insured (personal communication George Walker, Senior Risk Analyst, Aon Benfield Asia Pacific, 5 May 2009). Both climate change impacts and mitigation responses imply substantial social change. Changes in social norms around the climate implications of past actions could therefore also be expected to change.

Our proposal overall calls for a substantial degree of co-ordination between governments and reinsurers. Challenges associated with long-tail liabilities are a key area that requires attention. Governments may be able to ameliorate some uncertainty inherent in long-tail climate risk associated with our proposal. Faure and Fenn (1999: 498) offer two mechanisms for dealing with long-tail risks generally: (i) legislating for compulsory compensation funds in relation to the long-tail risk; and (ii) the use by courts of 'prospective overruling' to liability, whereby 'courts announce that they will adopt the previous standard of car in a particular case but announce that from now on they will adopt a different standard in future as a consequence of new information' (1999: 498). Elsewhere Faure deploys an economic analysis to caution that making insurance compulsory as a response to market failure 'may create more problems than it cures' (2006: 149). In the eventuality that reinsurers are unwilling to participate in implementation of the proposal, states could assume some or all of the reinsurance role.

Standards of insurability, moral hazard and existing insurance practice

In this section we consider our proposal with reference to the standards of insurability and comment on our proposal in relation to moral hazard. We also draw out

consistencies between our proposal and aspects of existing insurance systems.

Standards of insurability

The 'time-tested' (Mills et al. 2001: 58) standards of insurability are a core consideration for commercial insurance practice (Hausmann 1998: 7; Kunreuther 1998). In theory, insurable risks are only those that meet the standards of insurability. Yet Denenberg et al. (1964: 146) describes the standards of insurability as key, but not cast in iron, arguing that in practice, 'it is fair to say that there is no peril currently being insured that meets fully and completely every requirement,' and that '[T]he elements of an insurable peril [are helpfully understood as] types of problems that must be considered in determining the insurability of a particular peril.' Whilst '[a] peril may fail to meet one or more ... requirements ... objections of this kind may be overcome ... through practical controls such as underwriting, policy provisions and [pricing] techniques.' In seeking to articulate how our proposal for a carbon price drawing on aspects of insurance systems would function we discuss the standards of insurability as provided by Mills et al. (2001: 58; with reference to Denenberg et al. 1964: 145–148), as a framework. Our proposal, which draws on aspects of both commercial and social insurance systems, displays some consistency with the first three standards of insurability. The relationship between our proposal and the latter two standards is more complex.

- (1) There should be a large number of homogeneous exposures to permit the operation of the theory of probability and setting of actuarial rates.

Climate change is anticipated to produce large and increasing numbers of exposures. Exposures are highly variable. Therefore, the insurance basis for our proposal is only partially consistent with this standard. Our proposal is for a compensation scheme, however, similar to national disaster insurance in that it is designed to provide coverage to whole populations and is not expected to provide total restoration for individual losses. Thus there may be opportunity to artificially homogenise exposures through constrained definitions of exposures.

- (2) The occurrence should be fortuitous; i.e. the timing or the severity of the loss should be out of the control of the insured.

The timing and severity of climate change-implicated losses is out of the control of the insured to the extent that the insureds (i.e. citizens in a jurisdiction in which our proposal operates) do not control the weather or the climate immediately preceding or at the time of the loss. Needless to say, the impetus for this proposal is loss-causing human interference with climate, but even attributable causation in this sense is well short of control of the climate.

- (3) The peril must produce a loss definite in time and amount. The insurer must be able to verify the loss promptly and measure its magnitude.

Meeting this standard is feasible. Applying the FAR method requires careful definition of an extreme weather event in question and so losses associated with the event should also be definable. As with standard (1) above, there may be opportunity to constrain definition of losses with regard to time and amount of compensation. Climate change would need to be treated as an attributable cause of losses as opposed to non-climate variables that may ameliorate or exacerbate losses. One example would be the existence and adequacy of building codes. Whilst Allen et al. (2007) are careful to note that the FAR method does not address this, a compensation scheme funded by a carbon price that reflects anticipated financial losses would need to do so.

Verifying and measuring losses would not necessarily be overly onerous. Various parametric triggers are used to initiate timely access to insurance funds after weather catastrophes (Agrawala and Fankhauser 2008). Parametric triggers link insurance cover to precisely and transparently defined severity of natural catastrophes, for example, magnitude of earthquakes, wind velocity or air pressure for windstorm (Munich Re 2001: 7). The main advantage of parametric insurance is it allows rapid claim settlement. The main disadvantage is that the loss may differ substantially from the available cover. Significant disparity between assumed and actual cover also entails reputational risk for insurance providers (Maynard 2008).

The Caribbean Catastrophe Risk Insurance Facility (CCRIF), launched in 2006 in the wake of Hurricane Ivan 2 years earlier, is an example of insurance cover using a parametric trigger to allow rapid compensatory payments in the immediate aftermath of disaster. The CCRIF was established through the cooperation of the World Bank and the Heads of Government of the Caribbean Community and provides participating governments with immediate access to funds if hit by a natural disaster, until other sources of financing become available (Maynard 2008; CCRIF 2009).

- (4) The insured group of risks must not be exposed to an incalculable catastrophe hazard. There must not be a significant concentration of values in vulnerable areas.

Our proposal does not fulfil this standard of insurability. Dangerous anthropogenic climate change as a globally coherent phenomenon is an unprecedented and incalculable catastrophic hazard. Instead, this proposal seeks to return and retain the Earth system to a familiar and stable state such that climate risks remain calculable.

- (5) The premium must be reasonable in relation to the potential financial loss (priced to attract purchasers)

and, simultaneously, actuarially sound to cover the losses while providing for insurer solvency.

Our proposal also does not fulfil this standard. The premium embodied in the carbon price in this proposal must be sufficient for insurer solvency and for anticipated liabilities. Affordability is a secondary issue: either anticipated liabilities on the basis of emissions volumes are affordable, or emissions volumes must drop until anticipated liabilities become affordable. We suggest affordability of emissions is dependent on achieving and maintaining emissions levels consistent with returning and retaining the Earth system to a familiar and stable state: the proposal's ambition emphasises mitigation rather than adaptation.

We argue that non-compliance of our proposal with the standards of insurability is justifiable. The proposal draws on insurance techniques to eliminate climate risk, rather than simply insure against it.

Moral hazard

Our proposal also raises challenging questions in relation to moral hazard. Moral hazard traditionally refers to the potential for insurance coverage to encourage insureds to take risks they would not otherwise take, or in other ways profit from access to insurance (Denenberg et al. 1964; Kunreuther 1998; Mills et al. 2001). Parsons (2003) describes this as 'moral hazard in the classic sense' and 'policyholder hazard' (p. 448), before extending the analysis of moral hazard associated with the existence of insurance to include 'claimant hazard' (relating to the behaviour of third parties potentially injured by insureds, for example by colluding with insureds to profit from insureds' coverage), 'jurisprudential hazard' (relating to the behaviour of lawmakers in legislatures and courts of law, for example by changing liability provisions retrospectively), and 'underwriting hazard' (relating to the behaviour of underwriters, for example lowering normal insurability standards in relation to some long-tail liabilities under some circumstances because substantial claims will likely not be received for many years) (Parsons 2003). This proposal raises very complex moral hazard issues through its novelty and through its potential spatial and temporal scales of operation (for example, across multiple states and therefore multiple legal jurisdictions, and across generations). A thorough exploration towards overcoming the moral hazard challenges our proposal generates is beyond the scope of this paper.

The creation of a substantial compensation fund carries moral hazards also: premium income and accumulated reserves are vulnerable to being exploited for purposes other than for which they are designed (Walker 2007). As noted elsewhere, this proposal calls for the creation of a very substantial compensation fund to be managed over an extended period. Thus there is the potential for pressure to be brought to bear for accumulated funds to be used for purposes other than for which they were collected, for example, for immediate climate emergency relief rather than losses attributable to earlier emissions.

Nevertheless large funds can and are accumulated and managed, for example sovereign wealth funds (Devlin and Brummitt 2007; Lyons 2008). Our argument is not that managing large sums is straightforward, simply that whilst clearly challenging, large funds set aside for accumulating liabilities have been managed over decadal timescales. Sovereign wealth funds (SWFs) may provide a model of long-term, strategic fund accumulation and management that could be modified for our proposal. SWFs, in some instances dating back more than 50 years, are examples of government-created and owned large-scale capital accumulation funds, often for the purpose of intergenerational wealth transfer, for example, for meeting accumulated pension liabilities (Devlin and Brummitt 2007). SWFs are managed either by states or by fund managers on behalf of states. SWFs have attracted increasing attention in recent years (Johnson 2007; Epstein and Rose 2009), in part because of fears for the potential for SWFs to be used as vehicles by foreign states to gain control over key domestic sectors, stoked by the recent rapid increase in SWF holdings: from US\$500 billion in 1990 to around US\$2.2 trillion in 2007, and with the potential to reach in excess of US\$13 trillion within a decade (Lyons 2008). Governance arrangements for the multilateral development banks such as the World Bank Group potentially also offer lessons for the structure and management of our proposal's compensation fund.

Consistencies with existing forms of insurance

Our proposal shares a number of consistencies with existing forms of insurance and these are identified below.

- Use of insurance in support of public policy goals.

Governments use social insurance in support of public policy goals. The welfare state is a primary example (Phelan et al. 2008). Mitigating climate change by cutting CO₂e emissions is also a public policy goal that supports public welfare, albeit at global rather than national scale.

- Heavy government regulation of insurance sectors.

Governments regulate insurance sectors heavily to ensure (i) financial stability and viability of the sector, and (ii) ongoing public access to insurance. Insurance firm failures are uncommon events with repercussions that ripple through socio-economic systems (Commonwealth of Australia (HIH Royal Commission) and Owen 2003).

- Direct government engagement in insurance systems.

Governments engage directly in insurance systems to ensure system operation and effectiveness. Common examples of government engagement in insurance systems are legislating to ensure provision of workers' compensation insurance in workplaces and third party injury insurance on roads (Phelan et al. 2008). Governments legislate to ensure that (i) a small number of insurers may and do provide such cover, and (ii) that employers (in the case of workers' compensation insurance)

and vehicle owners (in the case of third party personal injury insurance) are required to buy appropriate cover. In many cases governments also provide insurance directly. Common examples of governments as direct insurance providers are welfare states noted above and export credit insurance (Haufler 1997; Norlen and Phelan 2002; Phelan et al. 2008).

- Some forms of insurance provision operate at large temporal and spatial scales.

First, insurance houses are some of the longest established human organisations (Supple 1984; Westall 1984). Second, whilst subject to short-term pressures of business cycles, some have experience in planning and operating over substantially longer timeframes. Life insurers for example, are required to manage received premiums to ensure availability of funds when claims are made well in the future. The current proposal is consistent with operating over timeframes at this scale. Large reinsurers (and some insurers) operate at global scale, across multiple legal jurisdictions and with exposure to multiple risks. Our proposal therefore is consistent with aspects of existing reinsurance markets.

- Capacity for adaptive responses to changing circumstances.

Our proposal is an adaptive approach to climate change mitigation. Resetting carbon prices annually allows for prices informed by continually evolving climate and loss modelling. This is similar to standard practice for reinsurance contracts where annual terms allow for changes in risk assessment and changes in prices (as well as a limit to reinsurers' exposure to unanticipated liabilities).

Advantages over existing approaches

The primary advantage of our proposal over other current approaches to price greenhouse gas emissions is that our proposal supports deep cuts in emissions. It does this in two ways. First, our proposal operationalises the scientific–technical capacity to price near future losses attributable to current emissions. Second, through the creating of a new, heavily regulated and very large market, our proposal provides the political–economic impetus for both reinsurers and states to protect newly created and substantial financial stakes in near future climate stability. These two aspects of our proposal, together with ancillary aspects, provide a mechanism to create limits in the global economy consistent with Earth system limits.

Proposed and currently operating carbon taxes and ETSs are not designed to deliver deep cuts in emissions and have not done so. A market mechanism with any prospects at all for achieving deep cuts in emissions sufficient to avoid dangerous anthropogenic climate change requires carbon prices anchored to strategically important ecological constraints rather than carbon prices overwhelmed by immediate political and economic concerns.

A secondary advantage of the current proposal is that it provides a degree of stability to both carbon prices and

emissions volumes. The liability link, combined with the FAR method puts a floor under both price and volumes: states or reinsurers, when accepting payment for permission to emit, are also accepting a liability for anticipated future damages. Sudden drops in price that have the effect of undermining market confidence as experienced in the European Union ETS in recent years are extremely unlikely. Changes in the price will reflect changes in evolving understanding of the Earth system.

Our proposal provides a stable (not static) price and a stable (not rigid) cap on volumes. Within Earth system limits, the price and the cap inform each other. As volumes rise, so do liabilities and therefore so does price. As volumes drop, so do liabilities, and price also. As noted earlier, climate change means changes in the Earth system and the evolving relationship between that system and smaller component systems, and scientific understanding of those systems and their relationships. This demands a reflexive mitigation response (Phelan et al. forthcoming). Additionally, mitigation policies and action will evolve over time.

Key elements of reflexive systems proposal

There are many permutations of how this proposal could be applied. In this section we limit our focus to three closely interlinked and key elements: (i) continuously modelling risks and setting carbon prices; (ii) issuing permissions to emit; and (iii) making and paying claims. For each element we raise a number of important questions that require further investigation.

Continuously modelling risks and setting prices

Creating sound, stable and ecologically realistic carbon prices generated by drawing on aspects of insurance systems requires reinsurers and loss modellers to continuously model future financial losses potentially attributable to current CO₂e emissions. This raises many questions about the scope of our proposal overall and about key aspects of our proposal's operation. Significant issues regarding the scientific, social and political-economic feasibility of our proposal are discussed below.

- Temporal scales to be applied.

The timeframe for avoidance of dangerous anthropogenic climate change is uncertain, if indeed it is not already too late (Hansen et al. 2008). Allen et al. (2007) argue that over the next couple of decades or so scientists can with high confidence determine probabilistic attribution of anthropogenic climate change to large-scale damaging events. It is well within this timeframe that significant cuts in emissions must be made, even though damages will likely continue to be sustained beyond that period. However, this analysis has yet to grapple with the vexed question of an equitable treatment of financial responsibility for risks and losses attributable to historical emissions: even where technical challenges can be overcome, ethical dilemmas remain

unresolved. All nations currently face climate change losses resulting from emissions associated from the development paths followed by a subset of industrialised countries. Low-income countries that have contributed the least to climate change in historical and contemporary terms are particularly vulnerable to climate change impacts now and in the future.

One contribution towards resolving disparities in historical emissions in the context of this proposal would be for governments to contribute initial capital to the compensation fund on the basis of their historical emissions, estimated at 348 billion tons since 1850 (Global Carbon Project 2008a). Applying recent carbon prices (i.e. US\$26 per ton) suggests starting capital at a little over US\$9 trillion. Contributing initial capital to a compensation fund on this basis models other forms of comprehensive insurance cover, for example, universal public health insurance: access to health care is on the basis of citizenship and financed through tax revenues levied on the basis of capacity to pay.

- Spatial scales to be applied.

The most appropriate geographic scale for this proposal to operate is global. However, this prompts questions of how to accommodate industrialised and low income countries fairly as well as operationalising our proposal across multiple jurisdictions and very varied cultural contexts. Conceptualising our proposal globally comprehensively encompasses all the diffused sources of anthropogenic CO₂e emissions into the Earth system, and in turn, the global distribution of resulting financial losses. Clearly our proposal demands a level of international cooperation appropriate for a global threat. Most current ETSs are national and regional, not global. Carbon taxes are national and sub-national. A less comprehensive (and interim) approach might also be possible on a proportional basis with respect to CO₂e emissions and damages, as well as rights to make claims.

- Definitions of insured risks including type, scale and location of damages.

This proposal requires limits on what will and will not be insurable. In the agricultural sector, for example, some climate-implicated losses are caused by sudden shocks, for example hail damage. Others are caused by long-term stresses, for example droughts. Others may be permanent, for example changes in suitability of areas for particular agricultural crops. Even where attribution is technically possible, significant questions remain about what loss-causing weather events and trends will and will not be claimable. The more comprehensive our proposal, the greater its effectiveness and therefore the greater its strategic worth.

- Application of the FAR method to various damaging events.

Our proposal prompts the question as to which scenarios the FAR method is technically feasible. To date the FAR method

has been applied to large spatial scale extreme weather events: heatwaves and floods. In principle, the FAR method could be applied to smaller events (Allen et al. 2007: 1393). As noted earlier, others have since applied a variation of the FAR method on smaller scale (Jaeger et al. 2008). The FAR method has not yet been applied to large temporal scale events such as droughts, weather trends or climatic changes, such as temporary or permanent shifts in viable agricultural zones.

- Social acceptance of scientific methodology consensus.

Allen et al. (2007) ask the legal community if scientific consensus around method will be accepted into their fold. This proposal also requires social acceptance of evolving scientific methodology reflected in legislation, international agreements and market operations.

- Capacity for continuous modelling.

Climate modelling research is continuous and ongoing. So too is loss modelling. Pricing risks accurately requires ongoing access to information about changes in climate, insurable risks and assets.

Permission to emit

A small number of regulated large reinsurers would be licensed by governments to issue permissions to emit. Under this proposal, issuing and receiving payment for permission to pollute entails creating, pricing and accepting an attached near future financial liability. Businesses and other organisations wishing to emit CO₂e would be required to purchase permission to emit to cover anticipated emissions. An ecologically effective cap on total emissions would be supported by the use of insurance techniques providing upward pressure on the carbon price. Under this proposal, a small number of reinsurers licensed by governments would be required to retain and manage funds to ensure their availability to compensate future claims. Making and paying claims from such funds is addressed below and we return later to the management of such funds and the opportunities they provide.

Making and paying claims

The primary purpose of our proposal is mitigating climate change. An important related purpose is collecting and managing funds to ensure availability of funds when attributable climate impact liabilities arise. Making and paying claims presents several challenges. First, eligibility to claim needs definition; one option would be to limit potential claimants to national governments who would make claims in the name of their citizens. Second, triggers for paying claims eligible for compensation would need definition and, as noted above, there are many index-based triggers available in existing insurance arrangements, for example for extreme weather events and agriculture. Third, the amount of compensation to be allocated needs clear definition. The fractional results

generated by the FAR method (i.e. that anthropogenic climate change is most likely only ever a partial contributor to the probability of a damaging event occurring) are consistent with partial rather than comprehensive restitution of losses. Allen et al. (2007: 1357) are careful to note also that the FAR method addresses climate variables only, and does not address questions around land use decisions such as allowing or disallowing building in vulnerable areas, which may contribute to or prevent financial losses.

Important ancillary opportunities

Our proposal creates important ancillary opportunities in three overlapping areas: (i) intergenerational equity; (ii) indirect support for other mitigation policies and action; and (iii) intragenerational equity. These are associated with our proposal's creation and management of a fund from which to pay claims.⁷ Our proposal has the potential to create an extremely substantial fund with several necessary purposes. The fund would be managed principally to ensure its growth and future availability to fund anticipated claims as well as generate sufficient interest income to cover ongoing administrative costs. The fund's growth would be dependent on investments and these would be at minimum greenhouse neutral, consistent with our proposal's overall mitigation goal. Adopting an ethical investment approach and prioritising investment in renewable energy technologies would also further our proposal's overall mitigation goal. Finally, a proportion of income generated by the fund would be used to finance the transfer and diffusion of renewable energy technology on non-commercial terms from industrialised to low income countries.

Intergenerational equity: compensating our children's losses

Operational at a global scale, the fund could well dwarf existing international sources of loans and insurance, such as the International Monetary Fund, the World Bank Group and the regional development banks. In and of itself this is a profound step in support of intergenerational equity and is novel in its approach to pricing CO₂e emissions. Climate change impacts caused by earlier emissions are already manifest. Yet near future generations (children of people alive today) are likely to suffer even greater financial losses as a result of current emissions. This is already established and the ethics of neither acknowledging nor acting on this awareness are unjustifiable, unattractive and insupportable. Whilst the specifics of what damages will manifest cannot be predicted, it is certain that the financial costs of near future climate change impacts and adaptation measures will be high. Stern (2006), for example, applies a cost benefit analysis approach and estimates the costs of inaction as up to 20-times greater than mitigating climate change, where mitigation is costed at 1% of global annual Gross Domestic Product (GDP), and inaction at up to 20% of GDP annually in perpetuity.

Mitigation: rapidly decarbonising the global economy

Our proposal's primary purpose is to drive down CO₂e emissions in support of climate change mitigation by generating ecologically realistic prices for CO₂e emissions. In so doing, our proposal reinforces other well-designed policy measures and actions to cut emissions, and acts to counter policy measures and actions that are ineffective or obstructionist. As such, our proposal contributes both directly and indirectly to climate change mitigation.

The fund created by our proposal would also drive climate change mitigation in several ways. Managing the fund in a manner consistent with its purpose would mean an investment strategy that generates no net increase in emissions. The sheer magnitude of the fund combined with its purpose opens substantial opportunities for investment in renewable energy technologies to replace and augment large-scale decommissioning of existing fossil fuel energy infrastructure. Investment funds would be available for research and development through commercialisation and proliferation development stages.

Intragenerational equity: non-commercial financing for renewable energy technology diffusion

A portion of the investment income generated by the fund could be used to finance on non-commercial terms the transfer and proliferation of renewable energy technologies in low-income countries. This would be an act of intragenerational equity, consistent with the aims and objectives of the United Nations Framework Convention on Climate Change; specifically it addresses Article 4, which contains the principle of 'common but differentiated responsibilities,' and the commitment of industrialised country signatories to 'promote, facilitate and finance ... the transfer of ... environmentally sound technologies' (United Nations 1992). Populations of low-income countries (non- and recently industrialised countries) have contributed least to the problem and are most vulnerable to climate change impacts.

Discussion and future directions

The climate change challenge is manifest at very large temporal and spatial scales and at very great magnitude. Climate change has already been labelled by economists as the 'greatest market failure ever witnessed' (Stern 2006) and as a 'diabolical policy challenge' (Garnaut 2008). Existing carbon taxes and ETS frameworks for pricing CO₂e emissions have been unable to generate carbon prices that reflect the biogeophysical limits of the Earth system. We argue that they are not equipped to do so. Thinking and acting at Earth system scale and with the degree of uncertainty inherent in a globally coherent phenomenon such as climate change is an unprecedented challenge for policy-makers. Human social systems struggle with thresholds, tipping points and cascading effects typical of complex adaptive systems, including the Earth system (Duit and Galaz 2008; Phelan et al. 2009a).

This paper has explored the rationale and potential for applying insurance techniques to generate carbon prices that reflect the dependence of the global economy on Earth system stability. The FAR method described in this proposal provides the scientific-technical capability to determine probabilistic attribution of financial losses to earlier anthropogenic CO₂e emissions. The liability mechanism described in this proposal provides a form of financial discipline as part of its contribution to effective limitations in emissions. It does so by creating a political economic driver for ecologically realistic carbon prices: a liability that is then allocated to reinsurers, backed by governments, creating a specific and measurable financial interest in future climate stability that can be strategically defined and defended. The central feature of this proposal is its potential to drive cuts in emissions sufficient to avoid dangerous anthropogenic climate change. Our proposal does this by using insurance systems to more directly account for interaction between the global economy and the Earth system. Our proposal is an example of reflexive mitigation (Phelan et al. forthcoming) and a departure from current approaches to carbon pricing. However, our proposal is compatible with a number of aspects of existing forms of insurance. Under our proposal, the price ascribed to carbon shares similarities with insurance premiums.

Our proposal described in this paper uniquely provides the scientific-technical capacity and the political-economic incentive to shift the anchor point for carbon prices away from immediate political and economic considerations and nearer to strategic ecological requirements for Earth system stability: the balance is shifted to emphasise changes in the global economy necessary to avoid dangerous anthropogenic climate change over estimations of what is politically and economically feasible or desirable. Our proposal identifies a number of important challenges regarding feasibility and operation as well as directions for further research.

The following question can be asked: Is this proposal for an insurance basis for carbon prices feasible? Although clearly a challenge, a better question could be: What if it is not feasible? What does it say about the nature and magnitude of the risk if human social systems cannot provide themselves with insurance against dangerous anthropogenic climate change? A world with risks but without insurance to manage those risks is possible – much of the world's population is already living in such conditions. Attempting to adapt to changing conditions is also possible, even perhaps where the Earth system has been pushed outside of its familiar stable state. However adaptation with grace (adaptation undertaken in an orderly and planned manner, embodying important principles of justice and equity, and with some hope of longevity) is dependent on successful climate change mitigation (Phelan et al. forthcoming). Possible futures are more or less desirable. Simply adapting to circumstances as we cause them to change, without thinking as to how we are changing them, is a passive response and less than we are capable of. Creating a future that is sustainable and equitable is at once an inspirational vision, a strategic goal to which we can aim and perhaps our only viable option.

Acknowledgements

Many thanks to George Walker for insightful and helpful comments. Many thanks to the Graduate School of the Environment, Macquarie University, Sydney, Australia, and to colleagues in the Discipline of Geography & Environmental Studies, University of Newcastle, Newcastle, Australia, and the Australian Research Council (ARC) for research support.

Notes

1. CO₂e (equivalent carbon dioxide emissions) is a 'standard and useful metric for comparing emissions of different greenhouse gases' (IPCC 2007b: 945). In this paper, in the interests of flow, we use 'emissions', 'CO₂e emissions', 'carbon emissions', 'carbon' and 'greenhouse gases' interchangeably.
2. Carbon is also priced as part of assessing the anticipated benefits and costs of proposed projects and policies, for example infrastructure developments such as highways and airports. Similar to market-based instruments, approaches such as shadow price and social cost of carbon (Stanton and Ackerman 2008) are aimed at internalising the externality of carbon emissions. The approach to pricing carbon presented in this paper may be applicable and useful in these contexts also but is not considered here.
3. Washington et al. (2009) begin by conceding that significant warming this century cannot be avoided. Their objective is to model emissions reductions necessary to avoid the most serious climate change impacts. On this basis Washington et al. (2009: 5) suggest deep cuts in emissions in the order of 70% on today's levels by 2100 would still allow stabilisation of the Earth system, albeit at a warmer temperature.
4. 'Transient Climate Response' is defined as 'the warming we should expect at the time of carbon dioxide doubling – around year 70 – if carbon dioxide levels were to increase at 1% per year, starting with a climate in equilibrium' (Allen et al. 2007: 1353–1400). The alternative approach uses the more common stabilisation scenarios, about which there is less scientific consensus. See Frame et al. (2006) for a detailed discussion.
5. The FAR method is not applicable to future events: it is not a predictive tool. The FAR method provides a probabilistic assessment after the fact. Allen et al. (2007: 1390) however suggest as a future research direction exploring the predictive application of FAR method, i.e. attempting to catalogue and define damaging weather events before they occur.
6. Point Carbon (2009) calculates a 'weighted average world carbon price of €19 ([US]\$26) per tonne CO₂e in 2008', and notes that in 2008, '[t]he world's carbon market exchanged 4.9 billion tonnes (Gt) CO₂ equivalent in ... worth an estimated US\$125bn'.
7. Others have also proposed climate change-linked funds, for example the 'Earth Atmospheric Trust.' See Barnes et al. (2008).

References

Agrawala S, Fankhauser S. 2008. Economic aspects of adaptation to climate change: Costs, benefits and policy instruments. Paris, France: Organisation for Economic Cooperation & Development.

Allen MR, Pall P, Stone D, Stott P, Frame D, Min SK, Nozawa, T, Yukimoto S. 2007. Scientific challenges in the attribution of harm to human influence on climate. *Univ PA Law Rev.* 155(6):1353–1400.

Allen MR, Stainforth DA. 2002. Towards objective probabilistic climate forecasting. *Nature.* 419:228.

Andrew B. 2008. Market failure, government failure and externalities in climate change mitigation: the case for a carbon tax. *Public Adm Dev.* 28:393–401.

Barnes P, Costanza R, Hawken P, Orr D, Ostrom E, Umaña A, Young OR. 2008. Creating an earth atmospheric trust. *Science.* 319:724.

Barsugli JJ, Whitaker JS, Loughe AF, Sardeshmukh PD, Toth Z. 1999. The effect of the 1997/98 El Niño on individual large-scale weather events. *Bull Am Meteorol Soc.* 80(7):1399–411.

Beck U. 1992. Risk society: towards a new modernity. London (UK): Sage.

CCRIF. 2009. The Caribbean catastrophe risk insurance facility; [cited 2009 May 28]. Available from: <http://ccrif.org/>.

Commonwealth of Australia. 2008. Carbon pollution reduction scheme: Australia's low pollution future (White Paper). Canberra (Australia): Commonwealth of Australia.

Commonwealth of Australia. (HIH Royal Commission), Owen NJ. 2003. The failure of HIH Insurance. Canberra (Australia): Commonwealth of Australia.

Denenberg HS, Eilers RD, Hoffman GW, Kline CA, Melone JJ, Snider HW. 1964. Risk and insurance. Englewood Cliffs (NJ): Prentice-Hall.

Devlin W, Brummitt B. 2007. A few sovereigns more: the rise of sovereign wealth funds. *Economic Roundup.* (Spring): 119–136, Canberra, Australia, The Treasury, Commonwealth of Australia; [cited 2010 mar 31]. Available from: <http://www.treasury.gov.au/content/economic.asp?ContentID=327&titl=Economic>.

Duit A, Galaz V. 2008. Governance and complexity: emerging issues for governance theory. *Governance Int J Policy Adm Inst.* 21(3):311–335.

Ekins P, Barker T. 2001. Carbon taxes and carbon emissions trading. *J Econ Surv.* 15(3):325–376.

Epstein RA, Rose AM. 2009. The regulation of sovereign wealth funds: the virtues of going slow. *Univ Chic Law Rev.* 76:111–134.

Faure M. 2006. Economic criteria for compulsory insurance. *Geneva Pap Risk Insur Issues Pract.* 31:149–168.

Faure M, Fenn P. 1999. Retroactive liability and the insurability of long-tail risks. *Int Rev Law Econ.* 19:487–500.

Frame DJ, Stone DA, Stott PA, Allen MR. 2006. Alternatives to stabilisation scenarios. *Geophys Res Lett.* 33:L14707.

Garnaut R. 2008. Garnaut climate change review. Port Melbourne: Cambridge University Press.

Global Carbon Project. 2008a. Carbon budget and trends 2007; [cited 2009 Oct 15]. Available from: www.globalcarbonproject.org.

Global Carbon Project. 2008b. Growth in the global carbon budget (media release 25 September); [cited 2009 Oct 15]. Available from: www.globalcarbonproject.org.

Hansen J, Sato M, Kharecha P, Beerling D, Berner R, Masson-Delmotte V, Pagani M, Raymo M, Royer DL, Zachos JC. 2008. Target atmospheric CO₂: where should humanity aim? *Open Atmos Sci J.* 22:17–31.

Haufler V. 1997. Dangerous commerce: insurance and the management of international risk. Ithaca, NY & London: Cornell University Press.

Hausmann P. 1998. Floods – an insurable risk? Zurich: Swiss Re.

Hirst P. 2000. Democracy and governance. In: Pierre J, editor. *Debating governance: authority, steering and democracy.* Oxford (UK): Oxford University Press.

International Chamber of Commerce. 2008. Long-tail risks (Policy statement); [cited 2009 May 28]. Available from: http://www.iccwbo.org/uploadedFiles/ICC/policy/financial_services/Statements/195%20rev3%20final%20Policy%20Statement%20on%20Long-Tail%20Risks%2023-09-2008%20EN.pdf.

IPCC. Climate Change 2001. Synthesis Report. A Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge (UK) and New York (NY): Cambridge University Press.

IPCC. 2007a. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, In: Pachauri RK, Reisinger A, editors. *Core Writing*

- Team, IPCC, Geneva, Switzerland, 104 pp; [cited 2010 mar 31]. Available from: http://www.ipcc.ch/publications_and_data/ar4/syr/en/frontmatter.html.
- IPCC. 2007b. Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avery KB, Tignor M, Miller Jr, HL, editors. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge (UK) and New York (NY): Cambridge University Press.
- IPCC. 2007c. Summary for Policymakers, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1–18; [cited 2010 mar 31]. Available from: <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf>.
- Jaeger CC, Krause J, Haas A, Klein R, Hasselmann K. 2008. A method for computing the fraction of attributable risk related to climate damages. *Risk Anal.* 28(4):815–823.
- Johnson S. 2007. The rise of sovereign wealth funds. *Finance and Dev.* 44(3):56–57.
- Kalaugher L. 2009. Climate Change Congress: Scientists and prime minister go head to head; [cited 2009 May 28]. Available from: <http://environmentalresearchweb.org/blog/2009/03/climate-change-congress-scient.html>.
- Keller K, Kim S-R, Baehr J, Bradford DF, Oppenheimer M. 2007. What is the economic value of information about climate thresholds? In: Schlesinger M, Kheshgi H, Smith J, De La Chesnaye F, Reilly JM, Wilson T, Kolstad C, editors. Human-induced climate change: an interdisciplinary assessment. Cambridge (UK): Cambridge University Press.
- Keller K, Yohe G, Schlesinger M. 2008. Managing the risks of climate thresholds: uncertainties and information needs. *Clim Change.* 91(1/2):5–10.
- Kunreuther HC. 1998. Insurability conditions and the supply of coverage. In: Kunreuther HC, Roth Sr, RJ, editors. *Paying the price: the status and role of insurance against natural disasters in the United States*. Washington (DC): Joseph Henry Press.
- Lenton TM, Held H, Kriegler E, Hall JW, Lucht, W, Rahmstorf S, Schellnhuber HJ. 2008. Tipping elements in the Earth's climate system. *Proc Natl Acad Sci USA.* 105(6):1786–1793.
- Lyons G. 2008. State capitalism: the rise of sovereign wealth funds. *Law and Business Review of the Americas* (reprint of 2007 Report produced for Standard Chartered Group). 14(1) D1–D62.
- Maynard T. 2008. Climate change: impacts on insurers and how they can help with adaptation and mitigation. *Geneva Pap Risk Insur-Issues Pract.* 33(1):140–46.
- McLeod S. 2009. Research suggests sea levels rising faster than expected; [cited 2009 Jul. 15]. Available from: <http://www.abc.net.au/lateline/content/2008/s2513635.htm>.
- Meinshausen M, Meinshausen N, Hare W, Raper, SCB, Frieler K, Knutti R, Frame DJ, Allen MR. 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature.* 458:1158–1162.
- Mills E. 2005. Insurance in a climate of change. *Science.* 309(5737):1040–1044.
- Mills E, Lecomte E, Pears A. 2001. US insurance industry perspectives on global climate change. Berkeley (CA): Lawrence Berkeley National Laboratory.
- Munich Re. 2001. Risk transfer to the capital markets – using the capital markets in insurance risk management. Munich, Germany: Munich Re.
- Munich Re. 2008. Risks of change. Topics 2/2008. Munich, Germany: Munich Re.
- Norlen, D, Phelan L. 2002. Reforming ECAs: The story so far. . . . Asian Lab Update. (43); [cited 2009 Oct 15]. Available from: http://www.amrc.org.hk/alu_article/export_credit_agencies/reforming_ecas_the_story_so_far.
- O'Hara BM. 2006. Risk and value: changing perceptions and cultural challenges for the property and casualty industry. *Geneva Pap Risk Insur Issues Pract.* 31:83–87.
- Palmer TN, Räisänen J. 2002. Quantifying the risk of extreme seasonal precipitation events in a changing climate. *Nature.* 415:512–514.
- Parsons C. 2003. Moral hazard in liability insurance. *Geneva Pap Risk Insur Issues Pract.* 28(3):448–471.
- Paterson M. 2001. Risky business: Insurance companies in global warming politics. *Global Environ Polit.* 1(4):18–42.
- Phelan L, Henderson-Sellers A, Taplin R. 2009a. From weather hazards to managing climate risks: insurance resources for earth system governance. Perth, Australia: CSIRO.
- Phelan L, Henderson-Sellers A, Taplin R. Forthcoming. Reflexive mitigation of the Earth's economy: A viable strategy for insurance systems. In: Leal Filho W, editor. *The Economic, Social and Political Elements of Climate Change*. Berlin (Germany): Springer Verlag.
- Phelan L, Taplin R, Albrecht G. 2008. A powerful agent of long-term socio-ecological governance? The global insurance industry as a driver for greenhouse mitigation and adaptation. Berlin, Germany: Environmental Policy Research Centre, Freie Universität Berlin.
- Point Carbon. 2009. Carbon 2009 – emission trading coming home. Oslo, Norway: Point Carbon.
- Rubin HW. 2008. Dictionary of insurance terms. Hauppauge (NY): Barrons Education Series Inc.
- Schär C, Jendritzky G. 2004. Hot news from summer 2003. *Nature.* 432:559–560.
- Schellnhuber HJ, Cramer W, Nakicenovic N, Wigley T, Yohe G, editors. 2006. *Avoiding dangerous climate change*, Cambridge (UK) & New York (NY): Cambridge University Press.
- Schiro JJ. 2006. External forces impacting the insurance industry: threats from regulation. *Geneva Pap Risk Insur Issues Pract.* 31:25–30.
- Schneider SH. 2003. Abrupt non-linear climate change, irreversibility and surprise (ENV/EPOC/GSP(2003)13/FINAL). Paris, France: Organisation for Economic Cooperation & Development.
- Serio GV. 2006. External forces shaping the future of the insurance industry. *Geneva Pap. Risk Insur Issues Pract.* 31:31–37.
- Six JP. 2005. Alternative instruments for financing long-tail (liability) risks. In: The 27th Liability Regimes Conference, A European perspective on global developments, Working Paper No. 295 of Études et dossiers: Working Paper Series of the Geneva Association, Geneva (Switzerland): The Geneva Association, p. 11–16.
- Solomon S, Plattner G-K, Knutti R, Friedlingstein P. 2009. Irreversible climate change due to carbon dioxide emissions. *Proc Natl Acad Sci USA.* 106(6):1704–1709.
- Stanton EA, Ackerman F. 2008. Out of the shadows: what's behind DEFRA's new approach to the price of carbon. Somerville (MA): Stockholm Environment Institute – US Center.
- Steffen W, Sanderson A, Tyson P, Jäger J, Matson P, Moore III, B, Oldfield F, Richardson K, Schellnhuber HJ, Turner II, BL, Wasson RJ. 2003. *Global change and the Earth system: a planet under pressure*. Berlin & Heidelberg, Germany, & New York (NY): Springer-Verlag.
- Stern N. 2006. *Stern review on the economics of climate change*. Cambridge (UK): Cambridge University Press.
- Stone DA, Allen MR. 2005. The end-to-end attribution problem: from emissions to impacts. *Clim Change.* 71:303–318.
- Stott PA, Stone DA, Allen MR. 2004. Human contribution to the European heatwave of 2003. *Nature.* 432:610–614.

- Supple B. 1984. Insurance in British history. In: Westall OM, editor. The historian and the business of insurance. Manchester (UK): Manchester University Press.
- TERI & IISD. 2006. Designing policies in a world of uncertainty, change, and surprise: adaptive policy-making for agriculture and water resources in the face of climate change. Winnipeg (MB) and New Delhi, India: International Institute for Sustainable Development (IISD) and The Energy and Resources Institute (TERI).
- The Economist*. 2009. Equilibrium; [cited 2010 Mar 31]. Available from: <http://www.economist.com/research/economics/alphabetic.cfm?term=equilibrium#equilibrium>.
- UK Met Office. 2008. Extreme temperatures on the rise (media release 26 March); [cited 2010 Mar 31]. Available from: <http://www.metoffice.gov.uk/corporate/pressoffice/2008/pr20080326.html>.
- United Nations. 1992. United Nations framework convention on climate change. Paris, France: United Nations.
- Walker G. 2007. General principles of catastrophe insurance. Sydney, Australia, unpublished data, 18pp. Available from Aon Re Asia Pacific.
- Washington WM, Knutti R, Meehl GA, Teng H, Tebaldi C, Lawrence D, Buja L, Strand WG. 2009. How much climate change can be avoided by mitigation? *Geophys Res Lett*. 36:L08703, doi: 10.1029/2008GL037074.
- Westall OM, editor. 1984. The historian and the business of insurance, Manchester (UK): Manchester University Press.