Liu Peixin

Asset Pricing

Ph.D. Qualification Examination Companion

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An Ongoing Personal Project

Contents

Chapter 1
Environment

Hong et al. (2020) RFS special issue.

1.1 Integrated Assessment Models

IAMs integrate the climate science models with the economic models. Parson and Fisher-Vanden (1997) summarize the four broad contributions of IAMs: (1) evaluating potential responses to climate change; (2) structuring knowledge and characterizing uncertainty; (3) contributing to broad comparative risk assessment; and (4) contributing to scientific research.

Prominent IAMs include the Dynamic Integrated Climate-Economy (DICE) model in Nordhaus (2008), and its variation, the Regional Integrated Climate-Economy model (RICE) in Nordhaus and Yang (1996), the Climate Framework for Uncertainty, Distribution and Negotiation (FUND) in Tol (2002a,b), and the Policy Analysis of the Greenhouse Effect (PAGE) in Hope (2006). These three IAMs are used by the U.S. Government Interagency Working Group.

But how decision makers deal with a bunch of IAMs? Cherry picking seems a reasonable informal approach. In practice, The IWG runs simulations of selected IAMs, with a range of parameter values, discount rates, and assumptions regarding GHG emissions, to estimate the SCC. Meta-analysis (e.g., Meinshausen et al. (2009), McJeon et al. (2011)) is a more formal and academic approach to compare conclusions from various studies. Another approach is to do some model blending that merge multiple models to generate a single forecast. Tebaldi and Knutti (2007) survey the multi-model ensemble and discuss the difficulties of combining predictions from multiple climate models.

Critiques

Ackerman et al. (2009) identify three principal areas where the standard economic approach is arguably deficient: (1) the discounted utility framework, which attaches less weight to future outcomes; (2) the characterization and monetization of the benefits of mitigation; and (3) the projection of mitigation costs, which rests on assumptions about the pace and nature of technical change. They suggest to reframe the climate policy problem as conducting precautionary actions against catastrophic, low-probability events.

Heal (2017) gives a comprehensive review on the economic characteristics of the climate problem, focusing on the choice of discount rates in the presence of a stock externality, risk and uncertainty/ambiguity, and the role of IAMs in analyzing policy choices. He suggests that IAMs can play a role in providing qualitative understanding of how complex systems behave, but are not accurate enough to provide quantitative insights.

Pindyck (2013) attacks the vulnerability of the parameters and functional forms that IAMs use as central ingredients. For example, key parameters include discount rates (time preference and risk aversion) and climate sensitivity, and the functional forms include social welfare (preferences) and damage functions. He claims that IAMs are of little or no value for evaluating alternative climate policies and estimating the SCC, because those model inputs are too ad hoc.

1.2 Uncertainty in Environmental Problems

Uncertainty is central to environmental problems. Pindyck (2007) counter that for many environmental problems the uncertainties are greater and more crucial to policy design and evaluation. In particular, three important complications arise that are often crucial for environmental policy, but are usually much less important for most other private and public policy decisions.

- Environmental cost and benefit functions tend to be *highly nonlinear*. Furthermore, the precise shapes of the functions are unknown.
- Environmental policies usually involve important *irreversibilities*, and those irreversibilities (of sunk costs and environmental damage) sometimes interact in a complicated way with uncertainty.
- Environmental policies often involve *very long time horizons*. A long time horizon exacerbates the uncertainty over policy costs and benefits and makes discount rate uncertainty much more important.

Heal and Millner (2014b) argue that the choice of discount rate is an ethical primitive and advocate a social choice-based approach in which a diverse set of individual discount rates is aggregated into a "representative" rate. Heal and Millner (2014a) explore uncertainties in the issue of climate change and decompose the sources of uncertainty into *scientific* and *socioeconomic* components. Scientific uncertainty arises from the incomplete knowledge of the climate system. Socioeconomic uncertainty is from the imperfect understanding of the interaction between climate change and human societies. Pindyck (2007) also claims another kind of uncertainty over technological changes that might ameliorate those economic impacts and/or reduce the cost of limiting the environmental damage in the first place.

The UN Intergovernmental Panel on Climate Change, the Third Assessment Report (IPCC-AR3) goes even further and recognizes no less than five stages of uncertainty. Its five categories are uncertainty (1) about emission scenarios, (2) about the responses of the carbon cycle to these emissions, (3) about the sensitivity of the climate to changes in the carbon cycle, (4) about the regional implications of a global climate scenario, and finally (5) about the possible impacts on human societies.

Standard approaches, such as expected utility theory and benefit-cost analysis, are not effective in response to the great uncertainties. Heal and Kriström (2002) call for economic analysis that explicitly incorporates uncertainty. Kunreuther et al. (2013) highlight the value of robust decision-making tools and suggest to broaden the risk-management approach.

Climate Sensitivity

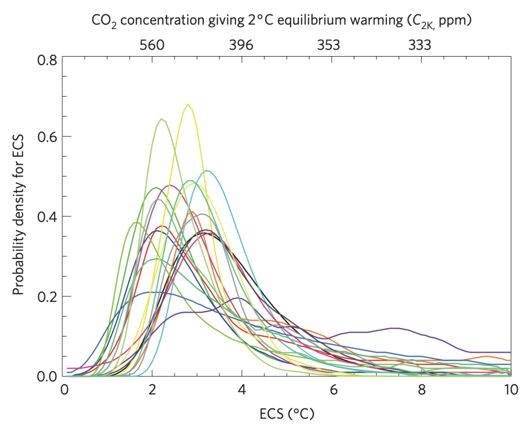

Fig. 1.1 Estimates of the probability distributions for climate sensitivity from various published studies collated by Meinshausen et al. (2009).

Millner et al. (2013) introduce scientific ambiguity into the DICE model and find the effect of ambiguity aversion on welfare is significant. The value of emissions abatement increases as ambiguity aversion increases

Damage Function

Most IAMs relate the temperature increase ΔT to GDP through a "loss function" $L(\Delta T)$. . For example, the Nordhaus (2008) DICE model uses the inverse-quadratic loss function. Weitzman (2009) suggests the exponential-quadratic loss function

$$L(\Delta T) = \frac{1}{1 + \pi_1 \Delta T + \pi_2 (\Delta T)^2} \quad \text{or} \quad L(\Delta T) = \exp\left(-\beta (\Delta T)^2\right)$$

But the damage function is the weakest part of any IAM due to the lack of economic (or other) theoretical support on these functional forms. They are just *arbitrary functions*, made up to describe how GDP goes down when ΔT goes up, as stated in Pindyck (2013). Woodward and Bishop (1997) use the maxmin criterion to study the optimal policy when there is ambiguity about the relationship between temperature change and economic damage.

Some works try to avoid this weakness rather than cope with it. Llavador et al. (2015) pick a framework within which there is no need to model explicitly the damages resulting from climate change. The damage function is replaced by a constraint that no major damage be done. But it is not the only feature of their model that marks it out very sharply from the standard IAMs. They place their IAM not within the normal utilitarian framework, but within what they term a *substabilitarian* framework. To get a glimpse, a pure-sustainability problem is defined as

$$\max \ \Lambda \qquad \text{s.t.} \quad u_t \geq \Lambda \quad t = 1, 2, \ldots$$

The entire model is to maximize the utility of the current generation given recursive preference, subject to not exceeding emissions on RCP 2.6 and not delaying the convergence of developing and developed countries.

Tails

Climate catastrophes are low-probability, high-impact events, and these downsides are nonnegligible. This is the "fat-tail" feature. But distributions with fat tails are ones for which the probabilities of rare events decline relatively slowly as the event moves far away from its central tendency. This means that it can be hard to detect fat-tailed distributions and very hard to know how fat the tails are.

Weitzman (2009) shows that fat tails can come from multiple routes, not only the nature of climate problems, but also the difficulty in learning from finite data (structural uncertainty). Moreover, fat tail of climate phenomenons has real impacts. The fat tail makes standard economic analysis invalid due to unbounded disutility in tails. He proposes a general theory, called "dismal theorem", to assess tail events. A fat-tailed cost-benefit analysis can turn conventional thin-tail-based climate-change policy advice on its head. The catastrophe-insurance aspect of such a fat-tailed unlimited-exposure situation, which can never be fully learned away, can dominate the social-discounting aspect, the pure-risk aspect, and the consumption-smoothing aspect.

In 2001, *Review of Environmental Economics and Policy* assembled a symposium on Fat Tails and the Economics of Climate Change and published three review articles. Nordhaus (2011) provides a detailed examination on the scope and applicability of the dismal theorem. He emphasizes that, though it helps identify when tail events have significances, the dismal theorem holds only under very limited conditions. Pindyck (2011) challenges that the notion of an unbounded marginal utility makes little sense. He also argues that the avoidance of extreme outcome is not the only concern for climate insurance. That is, the entire distribution matters more than just the tails.

Weitzman (2011) takes a defensive position. He restates the dismal theorem in a more intuitive way. The critical question, which tail fatness quantifies, is *how fast* does the probability of a catastrophe decline relative to the welfare impact of the catastrophe. It means that the upper tail of the disutility is a result of *interaction* of all such factors as probabilistic temperature changes, temperature-sensitive damages, utility functions, discounting, and so forth, but not any single factor *alone*.

Tipping Point

1.3 Environmental Policy

Possible policy responses to climate change take two forms: *mitigation*, actions that reduce the flow of greenhouse gases into the atmosphere and, thereby, change the probability distribution over future climate states; and *adaptation*, actions that reduce the damages associated with a given climate state.

Precautionary Principle

Precautionary principle embodies the age-old mantra "better safe than sorry". A representative statement of the *Precautionary principle* is from the Principle 15 of the Rio Declaration, in the context of the 1992 United Nations Earth Summit:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

The Wingspread Statement, formulated at the 1998 Wingspread Conference on the Precautionary Principle, goes even further:

> When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relation- ships are not fully established scientifically.

Kriebel et al. (2001) provides a comprehensive introduction on precautionary principle. Barrieu and Sinclair-Desgagné (2006) develop an intuitive formalization of this rule. Meckling and Allan (2020) portray the evolution of economic ideas in climate policy since its inception in the 1990s.

Ambiguity

Roseta-Palma and Xepapadeas (2004) apply a robust framework to water resource management decisions. Gonzalez (2008) studies a specific policy instrument, the pollution tax, and compares the relative strength of preference (welfare cost) between robust and non-robust policies. Vardas and Xepapadeas (2010) provide robust biodiversity management rules. Funke and Paetz (2011) analyze robust CO_2 abatement policies. Precautionary behaviors emerge when ambiguity is present, but specific implications are dependent on the objective functions, the sources of ambiguity and other model details.

Athanassoglou and Xepapadeas (2012) analyze the robust control of pollution when the government can both decrease emissions and invest in damage control. The result suggests that different policy tools respond to ambiguity in different patterns. Optimal investment in damage control is found to be increasing in ambiguity. Optimal mitigation decisions, however, need not always comport with the precautionary principle. When damage-control investment is both sufficiently cheap and sensitive to ambiguity, damage-control investment and mitigation may act as substitutes.

Irreversibility

Scientific progress is made over time that provides information on the distribution of the intensity of damages. Learning is an intuitive approach to access to the uncertainty. Gollier et al. (2000) investigate the optimality of the precautionary principle based upon the expected utility theory and the Bayes rule of revision of beliefs. They show that earlier prevention efforts takes place despite of future information flow only if prudence is larger than twice absolute risk aversion. However, market forces often do not sustain the implementation of precautionary policies. Gollier and Treich (2003) show that, even when precautionary policies should be adopted in the global economy, these policies may not be selected at the equilibrium of the economy.

However, Lange and Treich (2008) show that the DM's risk preference and payoff function are instrumental in the (Bayesian) expected utility framework. Specifically, uncertainty and learning generally cannot provide a clear argument for stricter abatement of emissions today or their postponement. Thus, they consider a generalization of the expected utility framework that accounts for ambiguity and show that ambiguity typically leads to stricter abatement policies today.

Nishimura and Ozaki (2007) finds that risk and ambiguity have different effects when a firm decides the timing to undertake irreversible investments. Asano (2010) studies the optimal timing of the environmental policy when the government is less confident on the social cost of pollutant. He shows that an increase in ambiguity decreases the optimal timing of adopting an environmental policy, which implies that the government will hasten the adoption of the optimal environmental policy.

1.4 Climate-Sensitive Assets

Dietz and Walker (2019), Dietz and Niehörster (2020): insurance.

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