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INTRODUCTION

The Economics of Tipping Points

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This special issue originates from a 2014 workshop on the economics of tipping points organized by the Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences. The aim of the workshop was to bring together a group of experts to take stock on where we stand with research in this area. In this introduction, we will provide some background on the research area and a brief summary of the selected papers.

1 Anecdote

The Beijer Institute organizes workshops for economists and ecologists to meet, to talk to each other, and to work together. At one of these workshops in Gozo, Malta, in 1998, the ecologists Stephen Carpenter and Marten Scheffer presented their shallow lake model. Lakes have the characteristic that at some point, a small additional release of phosphorus on the lake flips the lake quickly from “blue water” into “green soup”. Ecological services such as fresh water, fish and amenities are substantially decreased by the flip. Lowering the release of phosphorus afterwards does not restore the lake immediately. It requires more effort or becomes even impossible. The general conclusion was that these flips have to be prevented. An economist challenged this conclusion: what if the possibility to release phosphorus on the lake is for some reason so beneficial that the net result is positive, even if these negative consequences for the ecological services are taken into account? A new research area was born: the economics of tipping points in ecological systems. Of course, this was not the only starting point. New areas usually pop up at different places in the world, but this event definitely had impact.

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2 Tipping Points

What is a tipping point? A well-known metaphor is the “last straw” that breaks the camel’s back. When a critical load is reached, a minor addition may cause large and abrupt reactions. Formal models that can explain such a phenomenon usually have the following property. When some variable is gradually changed, the state of the system remains in an area with a high level of ecological services. However, at some critical point, a sudden shift occurs to a state in an area with a low level of ecological services. In such a case, the system has moved into another domain of attraction (Folke et al. 2004; Biggs et al. 2012). This is called a regime shift, and the point where it happens is called a tipping point. Turning back the direction of change will not immediately restore the level of ecological services. It is usually required to pass another lower tipping point in order to shift back to the area with a high level of ecological services (hysteresis). It may even be impossible to restore it (irreversibility). Ecologists have developed this type of models that explain very well the phenomena they observe, not only for lakes (Scheffer 1997; Carpenter 2003), but also for insect outbreaks (Ludwig et al. 1978), coral reefs (Bellwood et al. 2004), and many other ecological systems (Scheffer et al. 2001, www.regimeshifts.org).

3 Non-convexities

Economics enters the picture when trade-offs are made between the benefits that are attached to the variables that drive the change on the one hand, and the possible loss in ecological services on the other hand. Tipping points put a challenge to economics. Managing this type of ecological system, or developing policies in social-ecological systems where regime shifts can occur, becomes an economic decision problem with non-convexities and multiple steady states (see Dasgupta and Mäler 2003). Non-convexities are, of course, not new in economics, but the new issues gave a boost to this area. Moreover, optimal control of the ecological systems revived the concept of a Skiba point (1978). When the system is optimally controlled and when there is no uncertainty, sudden flips can be avoided, but this does not mean that the different domains do not play a role anymore. Depending on the initial condition, the optimal trajectory can move either to a regime with high phosphorus and a lower level of ecological services or to a regime with low phosphorus and a higher level of ecological services. Skiba points are points of indifference that divide the initial conditions of the system into areas from where the optimal trajectory moves in one or the other way (Brock and Starrett 2003; Mäler et al. 2003). A lot of research has developed in this field: see, for example, Wagener (2003), Dechert and O’Donnell (2006), Crépin (2007) and Heijdra and Heijnen (2013).

4 Uncertainty

In recent years, the attention has shifted to probabilistic models. It is usually uncertain where or when tipping will occur. This revived the hazard-rate model (Kamien and Schwartz 1971) which gives the probability that at some point in time the system will break down. In order to capture the idea of a regime shift, a break-down is too strong, but a shift in one or more parameters will change the dynamics of the system, so that it is attracted to another undesirable stability domain. Furthermore, in order to capture the idea that the probability for a regime shift to occur is larger when the system is more vulnerable, the hazard rate can depend on the state of the system. In this way, policy can trade off a higher exploitation of resources in the system versus a higher risk of tipping the system (Polasky et al. 2011). The literature using hazard-rate models in environmental economics already started in the earlier literature (e.g., Clarke and Reed 1994; Tsur and Zemel 1996; Gjerde et al. 1999). However, in recent years it really took off, mainly because of the issue of climate change. This is a nice example because the climate system may tip, but there is high uncertainty. Interesting research has developed in analysing tipping points in integrated assessment models for climate change (e.g., Lemoine and Traeger 2014).

5 Sustainability

The concept of sustainable development was defined by the Brundtland Commission as *a development that meets this generation's need without compromising the ability for future generations to meet their needs*. This concept has been formalized by economists using more advanced analytical tools (e.g., Arrow et al. 2003; Weitzman 2009). The main idea is that if genuine savings, i.e. the net value of investments and disinvestments over all relevant capital stocks, can remain non-negative over time, then development becomes sustainable. In other words, future generations would on average enjoy a welfare level at least as high as the present generation. In the literature, the role of non-convexities and tipping points has been taken into account for sustainability measurement (e.g., Aronsson et al. 1998; Arrow et al. 2003; Tsur and Zemel 2006; Walker et al. 2010). This strand of research also addresses the question touched upon in the anecdote above, i.e. how to compare the benefit of releasing phosphorus into the lake and the expected damage to the ecological services caused by crossing the tipping point of the phosphorus stock.

6 Summary of the Papers

The first two papers consider the possibility of climate tipping and focus mostly on theory. Van der Ploeg and de Zeeuw show that optimal policy requires a high carbon tax and adjustments to saving. They calibrate a North-South model, where the economic development in the South is lagging behind and the South is more vulnerable for climate tipping. They show that in the absence of cooperation, the carbon tax in the North is low, and in the South it will start low but become higher in the long run. When the North and the South cooperate, the carbon tax in the North is high, and in the South it will start low (in order to catch up first) and become high in the long run.

Engström and Gars use a similar growth model with possible climate tipping, but they focus on the effect of limited availability of fossil fuels. The literature on the "green paradox" argues that the possible arrival of a substitute will push up the extraction of fossil fuels. Possible climate tipping, that changes the value of the fossil fuels, has a similar effect. On the other hand, increasing the use of fossil fuels increases the risk of climate tipping. Numerically, they show that a higher carbon tax to reduce the risk of climate tipping not necessarily lowers the use of fossil fuels, due to the other effect.

Lontzek, Narita and Wilms integrate climate tipping with resource tipping in the form of forest dieback. Forests provide wood as a resource but also sequestrate carbon and in this way lower the probability of climate tipping. On the other hand, climate change increases the probability of forest dieback. Forest tipping can either affect the size of the forest or the growth rate. The second effect is a structural effect and therefore the impact is much stronger. They use Epstein–Zin preferences in order to disentangle risk aversion and the intertemporal elasticity of substitution. The results indicate that the forest tipping risk does not have a strong effect on climate policy.

Kiseleva focuses on the politics of climate policy. She distinguishes strong sceptics who do not believe in anthropogenic climate change, weak sceptics, who do but who do not believe in potential catastrophes, and science-based politicians, who believe in both. In the last case, climate dynamics has a non-linear term that was used to explain the tipping phenomena in the ecological models, mentioned above. The analysis is an evolutionary game between the three types of policy makers. The main conclusion is that science-based expectations are not crucial to avoid a climate catastrophe. With a sufficiently large number of weak sceptics, emissions are kept sufficiently low.

Li, Villasante and Zhu consider a fishery model where tipping can occur in the growth rate or the carrying capacity. Tipping will result in a substantial loss in value, as compared to a fishery without the tipping risk. The hazard rate is stock-dependent, and close to zero for high levels of the stock. They apply this analysis to a calibrated model for the Argentinean hake fishery. They quantify the values of the fishery in the cases of tipping risk, no tipping risk and ignoring the tipping risk, and determine the corrective tax rates. They show how the tax rate should change in case the stock gets lower, in order to take account of the potential regime shift in the fishery.

Tsur and Zemel have a methodology paper. They developed earlier the so-called L-method, which is a convenient method of identifying the optimal steady state before tipping in a hazard rate model. This method is applicable to a class of problems that fits many issues in environmental and resource economics. They extend the method to a broader class of hazard rates that renders the problem non-autonomous. Moreover, they show that their extended L-method can handle various types of events, such as recurrent events. This will be important for future applications, when research will be extended to multiple sequential tipping points.

Lindahl, Crépin and Schill perform an experiment to investigate the exploitation of a common-pool resource, comparing two treatments. In the first treatment, the resource is subject to the standard logistic-growth dynamics but in the second one, the same non-linear term is added to the resource dynamics that was used to explain the tipping phenomena in the ecological models, mentioned above. They use a framed laboratory experiment. They show that the threat of tipping triggers more communication within the group. This enables commitment for cooperation and knowledge sharing about the resource dynamics, which leads to a better performance. Enjoy!

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References

Aronsson T, Backlund K, Löfgren K-G (1998) Nuclear power, externalities and non-standard Pigouvian taxes. Environ Resour Econ 11(2):177–195

Arrow K, Dasgupta P, Mäler K-G (2003) Evaluating projects and assessing sustainable development in imperfect economies. Environ Resour Econ 26(4):647–685

Bellwood D, Hughes T, Folke C, Nyström M (2004) Confronting the coral reef crisis. Nature 429:827–833

Biggs R, Blenckner T, Folke C, Gordon L, Norström A, Nyström M, Peterson G (2012) Regime shifts. In: Hastings A, Gross L (eds) Encyclopedia in theoretical ecology. University of California Press, Berkeley and Los Angeles, pp 609–616

Brock W, Starrett D (2003) Managing systems with non-convex positive feedback. Environ Resour Econ 26(4):575–602
Carpenter S (2003) Regime shifts in lake ecosystems: pattern and variation. International Ecology Institute, Oldendorf/Luhe
Clarke H, Reed W (1994) Consumption/pollution tradeoffs in an environment vulnerable to pollution-related catastrophic collapse. J Econ Dyn Control 18(5):991–1010
Crépin A-S (2007) Using fast and slow processes to manage resources with thresholds. Environ Resour Econ 36(2):191–213
Dasgupta P, Mäler K-G (eds) (2003) The economics of non-convex ecosystems. Environ Resour Econ 26(4):499–691
Dechert W, O'Donnell S (2006) The stochastic lake game: a numerical solution. J Econ Dyn Control 30(9–10):1569–1587
Folke C, Carpenter S, Walker B, Scheffer M, Elmquist T, Gunderson L, Holling C (2004) Regime shifts, resilience, and biodiversity in ecosystem management. Annu Rev of Ecol Evol Syst 35:557–581
Gjerde J, Grepperud S, Kverndokk S (1999) Optimal climate policy under the possibility of a catastrophe. Resour Energy Econ 21(3–4):289–317
Heijdra B, Heijnen P (2013) Environmental abatement and the macroeconomy in the presence of ecological thresholds. Environ Resour Econ 55(1):47–70
Kamien M, Schwartz N (1971) Optimal maintenance and sale age for a machine subject to failure. Manag Sci 17(8):B495–504
Lemoine D, Traeger C (2014) Watch your step: optimal policy in a tipping climate. Am Econ J Econ Policy 6(1):137–166
Ludwig D, Jones D, Holling C (1978) Qualitative analysis of insect outbreak systems: the spruce budworm and forest. J Anim Ecol 47:315–332
Mäler K-G, Xepapadeas A, de Zeeuw A (2003) The economics of shallow lakes. Environ Resour Econ 26(4):603–624
Polasky S, de Zeeuw A, Wagener F (2011) Optimal management with potential regime shifts. J Environ Econ Manag 62(2):229–240
Scheffer M (1997) Ecology of shallow lakes. Chapman and Hall, London
Scheffer M, Carpenter S, Foley J, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. Nature 413(6856):591–596
Skiba A (1978) Optimal growth with a convex–concave production function. Econometrica 46(3):527–539
Tsur Y, Zemel A (1996) Accounting for global warming risks: resource management under event uncertainty. J Econ Dyn Control 20(6–7):1289–1305
Tsur Y, Zemel A (2006) Welfare measurement under threats of environmental catastrophes. J Environ Econ Manag 52(1):421–429
Wagener F (2003) Skiba points and heteroclinic bifurcations, with applications to the shallow lake system. J Econ Dyn Control 27(9):1533–1561
Walker B, Pearson L, Harris M, Mäler K-G, Li C-Z, Biggs R, Baynes T (2010) Incorporating resilience in the assessment of inclusive wealth: an example from South East Australia. Environ Resour Econ 45(2):183–202
Weitzman M (2009) Income, wealth, and the maximum principle. Harvard University Press, Cambridge