The changing climate of climate change economics

Petterson Molina Vale
p.m.vale@usp.br
Post-doctoral Researcher, Department of Economics, USP-RP, Brazil

Abstract

Climate change economics is now four decades old. Much of what it has achieved as a field of academic enquiry can be linked back to issues of integrated assessment modelling. This paper shows that the standard approach is going through a major change in scope as of the last five years. The conventional focus on determining optimal mitigation paths based on modelling the social cost of carbon is being enlarged to embrace promising new waves of research. These are: (1) the economics of insurance against catastrophic risks; (2) the economics of trade and climate; and (3) the economics of climate change adaptation. The paper helps to bridge the gap between economics and climate policy by showing that the analytical toolkit of climate change economics has shifted towards more realistic representations of climate policy.

Keywords: climate change, economics, carbon, adaptation, insurance, trade.

Introduction

"Can we control carbon dioxide?"

William Nordhaus's seminal work on the economics of climate change came out in 1975. In the forty years since, economists have approached climate change research from the perspective of integrated assessment modelling. Despite two inflections in the research agenda in 1992 (when William Cline published *The economics of global warming*) and 2006 (with the *Stern Review*), the bulk of the discussion has revolved around technical issues such as intertemporal discounting. As of the last five years, a new wave of scholarly work has come out that is broadening the scope of the debate.

Research on the economics of climate change has seen major shifts in the last five years. This paper presents the most recent literature to show that a narrow focus on integrated assessment modelling, issues of intertemporal discounting, and emissions mitigation is being expanded to include the following waves of research: (1) the economics of insurance against catastrophic risks; (2) the economics of trade and climate, including topics such as border adjustments and carbon leakage; and (3) the economics of climate change adaptation. The paper builds upon and adds to recent surveys that cover particular aspects of the literature (Dell, Jones and Olken, 2014 for identification of the causal link between the climate and the economy; Stern, 2013 for economic models of climate change impacts; Di Falco, 2014 for agriculture and climate change) by providing a more encompassing review and advancing a new perspective on the state of the literature. The recent developments in climate change economics are helping to make it more relevant to policymakers.

As the ideal scenario of globally coordinated climate action becomes less attainable, increased attention is given in the policy arena to bottom-up approaches to climate cooperation. The 2009 Copenhagen climate summit signalled the rupture of a *universalistic* paradigm of action in which global coordination and an international enforcement system are seen as premises for the effective control of climate change. Despite strong political pressure by the public and some heads of state in the month leading to the meeting, results were bleak. A polarization between China and the United States prevented a binding commitment. Global targets were not set, and institutional progress turned out meagre.

In spite of the above, voluntary climate legislation moved forward in countries including China, Brazil, Argentina and other developing nations. In China, the 12th Five-Year Plan, published in 2011, includes targets to reduce the carbon intensity of GDP by 17% from 2005 levels by 2015. Emissions trading systems are also being piloted in provinces such as Guangdong and in municipalities such as Beijing (Nachmani et al., 2014). In Brazil, crucial climate legislation was passed in 2009. Even without formal commitments at the international level, Brazil established a National Climate Policy which provides for reduction of emissions of around 35% of projections for 2020. What is the sense of China and Brazil unilaterally committing to emission reductions at the very moment when the global climate framework was reversing? How to explain such an initiative in the context of a recognized failure of international negotiations?

Action at the national and subnational levels is gaining momentum. Climate policy is increasingly implemented by individual jurisdictions with a view to be subsequently coordinated with other parties at higher geographical scales. Sectorial negotiations, for example in energy, aviation, and forests, are also accelerating. The debate is thus shifting from a rigid universalistic approach to a paradigm of individual action subject to some degree of global coordination. This is what International relations scholars and political scientists have termed a “building blocks” (Falkner, Stephan and Vogler, 2010) or a “polycentric approach” (Ostrom, 2010) (more on this in Section 3).

The first section of this paper provides a short summary of the results of four decades of climate-economy modelling, presenting the controversy around the validity of using aggregated models to determine optimal emission paths. The second section introduces the first trend of the climate change economics literature: assessing the amount of insurance that society must be willing to pay for in order to prevent major climatic disasters. While research in this area is far from establishing a sound methodological basis to deal with the economics of catastrophic, small-risk events, it is reinvigorating the discussion about policy options.

The third section seeks to show that a universalistic approach to climate action—where all countries with significant emissions take binding commitments in a synchronic and coordinated way—has proven unfeasible both theoretically and in practice. This leads to the second trend in research: the economics of trade and climate (Section 4 of the paper). The premise that unilateral action will keep growing is the basis to a mounting interest for issues such as the impact of climate policy on competitiveness and the role of carbon border adjustments on inducing cooperation.

The third and last important trend is the rising interest for the economics of adaptation. While discussions of climate policy were for a long time compartmentalized between mitigation and adaptation, the latter was typically given much less attention. In the fifth section of the paper, the most recent literature on the economics of adaptation is summarized to show that it is paving its way into mainstream analyses. Given the relevance of adaptation strategies especially for developing countries, this should lead to a more fluid dialogue between climate economists and policymakers.

1. Four decades of economic climate modelling

This section presents the most important aspects of climate-economy models before examining the recent debates around their validity as decision tools. Scientific models are representations of reality on a small scale. Economic models take results from biophysical models on climate scenarios and their probability distributions to determine the best course of present action. First, a set of scenarios for the future costs of climate change is calculated: the costs of inaction, or the ‘social cost of carbon’. Second, response costs are calculated, and they come in two main forms: reduction of emissions, and adaptation (usually calculated independently). Three sets of estimates are thus generated, the results of which are integrated into a cost-benefit framework to estimate the best course of action. Potential gains and losses are weighted up, and an optimal strategy is determined. A *shadow* carbon price is the final output.

What do these standard models tell us?

> "Very little. A plethora of integrated assessment models (IAMs) have been constructed and used to estimate the social cost of carbon (SCC) and evaluate alternative abatement policies. These models have crucial flaws that make them close to useless as tools for policy analysis: certain inputs (e.g. the discount rate) are arbitrary, but have huge effects on the SCC estimates the models produce; the models' descriptions of the impact of climate change are completely ad hoc, with no theoretical or empirical foundation; and the models can tell us nothing about the most important driver of the SCC, the possibility of a catastrophic climate outcome. IAM-based analyses of climate policy create a perception of knowledge and precision, but that perception is illusory and misleading" (Pindyck, 2013a).

The quote above sets the tone of disbelief that is building upon a specific type of economic model that until recently was considered the epitome of the profession: "the social cost framework is under fire", say economists Kenneth Arrow and colleagues (Revesz, 2014).

Robert Pindyck, who was until recently an outsider to climate change economics, criticizes the way these calculations are implemented. He asks a fundamental question (Pindyck, 2013b): what should be the price of carbon?, and replies that no one knows, least of all IAMs. For him, the best that can be taken from more than two decades of intense debate around the technicalities of these highly abstract models is a sort of scientific consensus on what the real social cost of carbon may be[1].

Pindyck's position is not intended to lead to scepticism, but rather to direct the efforts of economists to a more pragmatic study of the economics of catastrophic risk management. While this is indeed an area of enquiry that has gained increased attention as shall be discussed in Section 2, the bulk of mainstream economics is still devoted to IAMs. When it comes to quantifying climate action, IAMs are virtually inescapable, as Pindyck himself (2013b) admits. On his side is also Nicholas Stern (2013), who tacitly admits not to know better options than IAMs.

Climate-economy modelling

---

[1] Martin Weitzman (2009, p. 18) argues that "[a]ll of this is naturally unsatisfying and not what economists are used to doing, but in rare situations like climate change where the Dismal Theorem applies we may be deluding ourselves and others with misplaced concreteness if we think that we are able to deliver anything much more precise than this with even the biggest and most-detailed climate-change IAMs as currently constructed and deployed".

William Nordhaus laid the foundational stone of climate change economics well before the first climate conference (Geneva, 1979) and the creation of the IPCC (in 1988). Yet economic models of climate change had to wait until 1992 to gain notoriety with the publication of William Cline's *The economics of global warming*. Climate-economy models such as Nordhaus's DICE (Dynamic Integrated Climate-Economy) then reigned supreme until shortly after the publication of the Stern Report in 2006.

The most salient result of William Nordhaus's climate modelling is the idea that the optimal policy should follow a ramp pattern, where social welfare maximization leads to relatively low investments in the short run, allowing time for the cost of a "backstop technology" to go down, and investments then rise linearly to reach a substantial level in the second half of the current Century (Nordhaus, 2008, p. 98)[2]. This is in sharp contrast with the proposal advanced by the Stern Review, which called for a policy that cut emissions strongly in the short term, with costs up to ten times higher than in Nordhaus's ramp. Why such striking difference between "optimal" policies?

The answer has three components. First, given that the expected impacts of climate change will take place over the next decades and centuries, the models typically work with extremely long timeframes, 600 years in the case of Nordhaus's and infinite in the case of Stern's. This feature of climate models helps to understand Pindyck's position on IAMs. The confidence level of estimates of GDP and greenhouse gas emissions for twenty years is very low. What to say of a horizon of six centuries?

Second, a time discount procedure must inevitably be employed with such timeframes. One dollar next year is worth less than the same amount today, as the capital saved today should grow according to a market interest rate. Likewise, investments made within 100 years cannot be valued the same way as those made today. A standardized procedure needs to be adopted for the values at different points in time to be comparable: intertemporal discounting.

If the intertemporal discount rate is high, the costs and benefits in the distant future are given minor importance in the present. If it is low or zero, the future has relatively high importance. The Stern Review adopted a low discount rate (mostly due to a low 'pure rate of time preference') based on the premise that future generations should be weighed similarly to the present generation. This argument caused considerable controversy, pushing the debate towards the acceptance of at least a declining discount rate (Arrow et al., 2013; Heal and Millner, 2014).

---

[2] The findings of a panel formed in 2013 by the US government to synthesize the results of the main economic-climate models (US Government, 2013) are consistent with Nordhaus's DICE estimates.

Timeframe and discounting procedure are interrelated choices. If an infinite timeframe is adopted, a low discount rate leads to a much higher weight to future generations, to the point where the present generation becomes almost irrelevant. Likewise, if combined with a shorter horizon, higher discount rates virtually eliminate the future generations from the modelling effort.

Finally, the technical debate cannot be detached from ethical considerations concerning the weight that society should attach to those still to be born. Moreover, climate-economy models face serious within-generation distributional issues (Anthof and Tol, 2007). For example: how fair is it that a poor person contributes in equal measure to a rich person to fight climate change? Such important ethical considerations have been discussed elsewhere[3] and will not be further developed. The key idea is that a rigid stance among some economists that decision-making on the climate must be informed by controversial IAMs is starting to be relaxed. The first wave of research that has emerged in this context is what Simon Dietz (2014) has termed "climate change mitigation as catastrophic risk management".

2. The economics of insurance against catastrophic risks

Uncertainty, ecosystem thresholds and catastrophe

This section presents a subfield of climate change economics that is gaining increased attention and bringing fresh air to the study of optimal climate pathways. Research on the economics of insurance against catastrophic risks is commonly based on cost-effectiveness analyses that take policy targets as given and explores optimal carbon prices therein.

Modelling uncertainty is a challenge to climate-economic models. Uncertainty arises when the best possible measure of the odds of an undesired event is a worded qualification. If a probability distribution can be assigned to the event, then uncertainty becomes risk. If, on the other hand, the very event to be modelled is poorly defined, then uncertainty can be qualified as *fundamental*. There are serious doubts about exactly how much warming a given concentration of greenhouse gases in the atmosphere generates (warming potential); about how much a given level of warming impacts the broader climate; about how changes in the climate impact the economy; and about how human well-being is affected by all of the above. The final output of an IAM is subject to the combination of all these layers of uncertainty (Stainforth, 2007).

The role of uncertainty has often been obscured by discussions of intertemporal discounting. Only in the last few years did uncertainty become a central topic in climate

---

[3] See, for example, Pearce (2003), Tol (2005), Hourcade, Ambrosi and Dumas (2009), and Anthof, Hepburn and Tol (2009).

change economics, due in part to the seminal work of Weitzman (2007), but also to earlier precursors such as Kolstad (1994), Tsur and Zemel (1996), and Gjerde et al. (1999). Uncertainty with respect to a single parameter of IAMs, the exponent of the damage function, leads to a variation of 700% in the estimates of the social cost of carbon in Nordhaus's DICE (Vale, 2010), having a greater impact than the discount rate. Moreover, not only the exponential of the function is uncertain but the function itself has little empirical grounding.

A promising area of enquiry in economics stems from the debate above: the possibility of climate-related catastrophes and of critical ecosystem thresholds (tipping points) being surpassed. An ecosystem threshold is a theoretical resilience boundary that, when exceeded, can trigger an irreversible qualitative change in the state of ecosystems, causing large-scale damage. It is by definition a hypothetical event, with little foundation in empirical observation. The notion of climate disasters, on the other hand, is more comprehensive and may involve either well-known events—hurricanes, floods—or the (unknown) consequences of surpassing theoretical thresholds.

A crucial empirical question is whether the economic impact of extreme climatic events has risen and, if so, whether that can be associated with anthropogenic emissions. Asking this is different than asking whether the climate impacts the economy, another important stream of research that has gathered much empirical evidence recently (Dell, Jones and Olken, 2014). There are two main challenges to enquiries on the economic effect of extreme climate events: first, that there is little data on extreme events (given their low frequency); and second, that even with the data at hand a causal link between emissions and economic damage is difficult to isolate. The IPCC made a detailed analysis of existing studies in this area, and found that extreme events have increased in recent decades (IPCC, 2012). The economic damage arising from these events has also increased, but the report admits with high confidence that most of the damage cannot be linked back to anthropogenic climate change, but rather to an increased exposure to extreme events and to the amount of wealth exposed. The same conclusion is reached by a synthesis of 22 published studies on the subject (Bouwer, 2011).

Lemoine and Traeger (2012) advance a model that incorporates ecosystem thresholds. They employ the notion of option cost—the price to pay for the possibility of choosing not to exceed a threshold resilience level. In the case of climate change, the benefit of the option is to mitigate the risk of catastrophes. Thus, for example, in the presence of doubt about whether greenhouse gas concentrations above 450 ppm could unleash extreme events, it would be rational to impose such a ceiling concentration (and the respective option costs) until information about the safety of exceeding that threshold should appear.

The problem, however, is that option costs increase with uncertainty about the thresholds. At present levels of uncertainty, the model suggests that carbon prices would rise by 40% if the possibility of crossing thresholds is internalized.

A more pragmatic solution was suggested by Pindyck (2011), who calls for a *maximin* approach, where the risk of the worst case scenario is minimized. He agrees that quantifying such extreme scenarios is virtually impossible, but argues that if there is a theoretical possibility, however small, of a catastrophe to occur when, for example, the 10 ^{o}C warming threshold is surpassed, then it is reasonable that measures be taken to avoid such level of warming. The problem, he says, is that the weather is not the only source of possible catastrophes. There are numerous other undesirable events that could require the purchase of long-term insurance: the use of nuclear weapons, the dissemination of mega-viruses, etc. If each of these events can justify expensive precautionary action, it follows that society would rationally be willing to spend all of its resources in insurance.

Such was the conclusion reached by Weitzman (2011) in modelling the possibility of extreme climate-related events. He raised the crucial point that the right-hand side of the probability density function of climate damages is intrinsically thick. Since there is no information on situations where global temperatures rose by 10 ^{o}C over pre-industrial levels, the (theoretical) probability distribution of the extreme events that may happen as a consequence of such high warming levels is by nature *fat-tailed*: the probability of occurrence falls less than exponentially with the size of the damage (Pindyck, 2011).

The centre of the distribution—the part that lies near the mean—may be taken as an objective frequency distribution, but the tail is mostly made of ignorance. Given the lack of empirical backing, extreme events are modelled with fat-tailed distributions. But the consequences of assuming one distribution or another are nonnegligible. The standard assumption in a fat-tailed climate damage distribution is that a catastrophic scenario, where a zero consumption situation follows extremely high warming levels, may arise with a high enough probability. In such case, the standard Bayesian analytical framework can yield results that correspond to society spending all of its income on insuring itself against the extreme scenario (Dietz, 2011; Weitzman, 2009). This artefact of the adoption of a fat-tailed probability distribution is known as the *dismal theorem*.

Conventional IAMs focus on average warming scenarios and derive optimal policies mostly from the centre of the damage distributions. An “anti-disaster principle” (Sunstein, 2004), on the other hand, is an alternative to climate-economy models that informs regulation based on the scenarios of highest danger, using the economics of insurance against catastrophic risks. While the validity of the dismal theorem would imply that there is little sense in using the conventional expected utility framework to model climate insurance, the discussion is ongoing and the frontier of climate modelling under extreme events is rapidly being pushed forward[4]. Moreover, this relatively new research avenue is bringing climate change economics closer to the world of policymaking by focusing on the scenarios that create the most distress.

In the next section I briefly discuss the economics of climate cooperation to show that a bottom-up approach, where action is primarily taken by individual states and subsequently coordinated at the global level, is imposing itself in economics as in the real world.

3. A non-universalistic action approach

The economic game of coordination

The atmospheric CO^2 concentration has risen from 375 parts per million (ppm) in 2003 to 396 ppm in 2013 (Scripps Institute, 2014). In face of the generally accepted idea that levels above 400 ppm are dangerous, the figures above suggest a resounding failure of climate policies. Why after two decades of existence of an international treaty aimed at controlling global warming have mitigation policies not succeeded?

This section provides a short summary of the research on cooperation and global coordination to mitigate greenhouse gas emissions, arguing that the institutional model to control climate change inspired by the Montreal Protocol was doomed to failure. Besides being a rare example of success in creating a global environmental regime—for various reasons, including the lack of a cheap and effective decarbonisation technology and the absence of a hegemon country with a stake—the Montreal Protocol cannot be taken as a model for climate action (Keohane and Victor, 2011).

Studies based on game theory have long suggested that climate cooperation between a large number of players is unfeasible (Carraro and Sinisalco, 1992; Barrett, 1994). The attempt to establish a global agreement is based on the simple premise that there is a single atmosphere and emissions in any given country have an equal effect, so there is no point in reducing emissions in country A while they are raised in country B. Yet economic models predict that universal climate agreements, where all or almost all of the relevant parties abide to action, can only lead to one of two equally undesirable outcomes: setting and achieving goals that fall short of the required action (such as in the Kyoto Protocol), or setting ambitious goals that are not satisfied due to lack of sanction power (Barrett, 2006).

The alternative to universalistic institutional arrangements is a polycentric model (Ostrom, 2010). The idea of institutions dealing with public goods in a decentralized way

---

[4] Millner (2013) provides an excellent assessment of the current state of the literature, emphasizing the unavoidable ethical considerations involved. A recent article by Buchholz and Schymura (2012) frames the discussion in terms the ethics of risk aversion assumptions (“the tyranny of catastrophic risks”).

was explored by Ostrom from the 1960s, and seems to have become increasingly important for the study of climate change. Ostrom considers several scales of climate action, from county energy efficiency programs, through the state laws of California and Colorado (United States), to the European carbon trading scheme. For her, as well as for economists such as Nicholas Stern (Hepburn and Stern, 2009) and Scott Barrett (2008), the sum of these polycentric institutions is an important way of tackling climate change. However, she admits that such an approach can only work if all countries integrate some local or regional arrangement.

The work of Finus et al. (2009) makes it clear that smaller-scale agreements between countries with common interests are more feasible than universal agreements. Whereas such regional / sectorial arrangements lead to sub-optimal equilibria—abatement levels being lower than could theoretically be achieved under full cooperation—these possible equilibria are still superior to the situation where each country acts individually[5]. Another recent study confirms that small-scale institutions are much more effective in ensuring cooperation than global institutions (Tavoni, 2013).

The validity of the game-theoretical results could not be more obvious in face of the outcome of the Copenhagen summit. In discussing the apparent failure of global negotiations, international relations scholars Falkner, Stephan and Vogler (2010) argue that the model intended to create a system with global coordination was a miscalculation that lasted 20 years. They call instead for a building blocks approach, and suggest that the Copenhagen summit has indeed established the basis for such type of arrangement. Examples of the "blocks" are the negotiations on forests and REDD (Reducing Emissions from Deforestation and Degradation), the discussions around an adaptation fund, and the heated debate on technology transfer. The idea is that negotiations will increasingly be made on a sectorial basis, tackling specific issues that involve different sets of concerned countries, and that the complexity of the issues negotiated will increase over time, in an evolutionary model not different from the one that describes the GATT / WTO (World Trade Organization) complex.

Economic models have shown that a universal agreement is unfeasible. The more realistic world of second-best solutions—a middle ground between the ideal and the worst-case scenarios—has imposed itself in theory as in practice (Bosetti and Victor, 2011). The analytical framework of climate change economists is being broadened to include institutions built on a disaggregated basis. The next section shows that policies that promote emission reductions despite the lack of global cooperation (through trade, for example) are increasingly addressed by climate change economics.

---

[5] Action by a single country has been shown to have potentially counterproductive results (Hoel, 1991).

4. The economics of trade and climate

Carbon pricing and border adjustments

A first-best climate change mitigation policy is an internationally harmonized carbon tax (Nordhaus, 2008). Based on the tax system, this approach has the crucial benefit of using an institution that is fully embodied in the market system. Although taxes can create deadweight losses and reduce allocative efficiency, they may yield benefits if designed to attenuate major market failures such as greenhouse gas emissions. This is perhaps one of the few ideas that have no opponents in the world of climate change economics (Weitzman, 2013).

A well-known variant is the *cap-and-trade* arrangement. It is also based on imposing a cost on greenhouse gas emissions, but it uses a mechanism of tradable quotas in which a central organization, managed or supervised by the government, distributes allowances. Such schemes already exist in the European Union (EU ETS), in nine states in the United States and Canada (Regional Greenhouse Gas Initiative) as well as in California and the Canadian province of Quebec (California Air Resources Board). Yet they are often criticized for imposing more distortions than a tax and having delivered questionable results in Europe (Giddens, 2009).

It is difficult to establish whether pure taxes are more popular than tradable quotas. Several countries have implemented carbon taxes: Finland, Sweden, Denmark, UK, Norway, Switzerland, Ireland, Costa Rica and Australia, plus the Canadian province of British Columbia and the City of Boulder (USA). Institutional designs are highly heterogeneous as they adapt to the specific contexts of each location (OECD, 2013). Some schemes are in fact more appropriately categorized as *hybrid* approaches (Hepburn, 2006), where certain aspects of each of the pure pricing approaches—taxes and quotas—are adopted. The goal, however, is always the same: to impose a cost on carbon emissions.

The structure that was implemented in Australia, for example, imposed pre-established prices for the tonne of carbon emitted, but at the same time distributed emission quotas that initially could not be traded. Companies emitting above their allowance were subject to a price 30% higher for any additional emission. From 2015, the regulator would allow the price to float and companies to market quotas. In addition, the government had implemented a tax recycling scheme, reducing the fiscal burden on the poorest to avoid them being harmed by the carbon price[6].

---

[6] The carbon pricing scheme was repealed by the Senate in July 2014.

The carbon pricing systems that have emerged across the world are not internationally coordinated. Instead, each jurisdiction has unilaterally adopted the most convenient domestic measures (Bosetti and Victor, 2011). Moreover, the emission reductions achieved are negligible. Hence the attractiveness of a harmonized tax, which would prevent carbon emissions from being leaked from regulated to unregulated markets. Yet the universalistic route appears to be impracticable in the current context. As shown by McKibbin et al. (2011), the Copenhagen summit opened up the political path for countries to take unilateral mitigation goals that can be measured in the scale that best suits each jurisdiction. Although the signed document was not legally binding, the political weight of the leaders who personally tailored the agreement has weakened a universalistic trajectory (Green, 2014; Helm, 2012; Weitzman, 2013).

Climate change economic policy is increasingly about how unilateral policies interact with international trade. In this respect, one stream of research investigates the effects on the competitiveness of the regulated countries, notably in terms of increased imports of carbon-intensive products and delocalization of companies to *pollution havens*. A second branch of the literature studies the effects of different mechanisms of *border carbon adjustment*—import taxes and / or subsidies to the export of carbon-intensive products—aimed at harmonizing the price of carbon in a world where a limited number of countries implement regulation[7].

At the firm level, a popular idea is that well-designed regulation can lead to technological innovation and enhanced competitiveness (the 'Porter hypothesis', by Porter and van der Linde, 1995). The empirical evidence regarding this theory, however, is mixed (Ambec et al., 2013). At the country level, recent studies suggest negligible losses even with unilateral policies. For example, Aldy and Pizer (2011) estimate a 1% drop in production in the regulated sectors if a \$ 15 fee is imposed on the tonne of CO^2 in the United States. For the case of Europe, Barker et al. (2007) estimate a small, and possibly negative, leakage of carbon emissions from six countries that have implemented carbon taxes to other European countries. They conclude that technological spillovers from regulated to non-regulated countries may have lowered emissions in both groups. A similar conclusion was reached by Branger et al. (2013) who found that a European carbon tax would have no effect on imports of iron and cement.

Contrariwise, a comprehensive model that studies the impact of environmental regulation in foreign countries on domestic value added shows strong evidence of a pollution haven effect in which non-regulated countries benefit from trade (Feddersen, 2013). More interesting, however, is the conclusion that the production shift resulting from

---

[7] A related line of research asks whether trade is good for the environment. See, for example, Coperland and Taylor (1994; 2013) and Frankel and Rose (2005).

the imposition of environmental regulation is strongly conditioned by the transport cost structure, which follows regionalized patterns, so the harmonization of regulations between neighbouring countries could solve most of the problem. Even if the unilateral imposition of a cost on emissions can lead to economic losses, coordination at the regional level may be sufficient to eliminate that cost.

Research on the potential trade barriers to be imposed by countries that adopt unilateral actions is burgeoning. Imposing a tax on carbon imports corresponds to taxing consumption instead of production of carbon-intensive products. Helm et al. (2012) argue that imposing such a tax could be a game changer in climate negotiations, as the most affected countries—China, Russia and middle-income nations, whose exports have a high carbon content—would be forced to respond. For Helm and colleagues, countries or regions wishing to pursue leadership in climate policy have three options: maintain the current system of unilateral policies and risk a loss of competitiveness until an agreement is reached in 2020; accept that the current regime is ineffective and grant exemptions to their own exporters to avoid losses; or impose trade barriers based on carbon trading.

The latter strategy was followed by the European Union when including aviation in its tradable quota system in 2012. There was immediate protest from the United States, China and other countries, as all flights passing through the European Union would have been taxed, even if originating in other countries. This led to a diplomatic dispute that ultimately pushed the International Civil Aviation Organization to discuss the creation of a global structure of taxation of carbon emissions from 2020. Given the relative success of the move, the European Union already has plans to repeat it to the shipping industry (*ibid*.).

Carbon border tax adjustments have been found to reduce the negative spillovers that follow the adoption of regulation by clubs of countries, such as in the Kyoto Protocol (Demailly and Quirion, 2006), but also to cause a GDP loss due to administrative costs that can potentially overweight gains (McKibbin and Wilcoxen, 2008; Manders and Veenendaal, 2008). While the evidence is again mixed, it may well be that when political costs are put into the equation border tax adjustments become an ineffective solution.

Climate policy has been increasingly created from the bottom up, with countries defining their strategies first and, in a second stage, creating international coordination platforms. Whether or not the climate policy agenda will be merged with the trade agenda should largely depend on the reaction of the WTO to the matter of tariff restrictions on carbon content (Fischer and Fox, 2012). Given the failure of negotiations under the UNFCCC, the climate may become another front of trade disputes in the near future.

5. The economics of adaptation

Adaptation as development

Climate change adaptation is the process of building climate-resilient socioeconomic systems. Simply defined, resilience means *ability to recover*, and it alludes to the capacity of the climate system to return to its original state without suffering severe changes in response to extreme events. By building resilient systems to climatic conditions humans were able to colonize the planet and settle in the harshest environments. Such ability to respond to environmental changes is essential for survival, with or without anthropogenic climate change.

The bulk of economic studies, however, downplay the capacity of families, businesses and communities to develop solutions to address climate change (Hallegatte et al., 2011). But the scenario is changing. Adaptation has entered the UNFCCC agenda through the adaptation fund, the green fund, and national adaptation plans (Fankhauser and Burton, 2011). The recognition that the climate will not stop changing (especially due to anthropogenic warming), and that an important part of the solution is to continue developing structures and institutions that promote the coexistence with these changes, starts to emerge (Nature, 2013).

Climate adaptation encloses two important aspects. First, it has an eminently local character. Unlike mitigation, which ultimately deals with a spatially homogeneous object—greenhouse gas emissions being physically the same everywhere—adaptation depends crucially on how climate changes materialize across space and the economy, and how families and businesses are affected. This implies that adaptation is less subject to free riding behaviour than mitigation, and that if one country invests in adaptation the others are less likely to invest in mitigation. Smaller countries are thus predicted to favour adaptation more than bigger ones (Antweiller, 2011). This, however, depends crucially on relative costs as well as on the complementarity between adaptation and mitigation. For a sufficiently high cost to adaptation, Buob and Stephan (2011) find that poor countries will engage solely in mitigation even without cooperative behaviour. If, on the other hand, adaptation reduces the marginal impact of emissions, then international cooperation is more likely, implying that some forms of adaptation could be conducive to climate cooperation (Marrouch and Chaudhuri, 2011).

Second, climate adaptation strategies overlap in many cases with other development goals, including poverty reduction and health improvement. To the extent that adapting to climate change can also boost development, adaptation can yield a bonus of political legitimacy. The idea of "adaptation as development" has been raised in the context of political ecology (Ayers and Foresyth, 2009; Ayers and Dodman, 2010), but economic studies also suggest that adaptation can serve larger goals (Fankhauser, 2010a; Fankhauser and McDermott, 2014). For example, analysing agriculture in Ethiopia, Di Falco et al. (2011) found a causal link between climate change adaptation (including new crop varieties and soil conservation measures) and food security. Adaptation strategies were also found to increase crop yields if adopted in isolation, and to be even more effective when implemented in conjunction with other agricultural practices such as water conservation methods (Di Falco and Veronesi, 2013).

Adaptation is being brought to the centre of climate policy debates (Petherick, 2012). Studies on the economics of adaptation have hitherto focused on agriculture-related issues (Hertel and Lobell, 2014 provide a current synthesis of the literature), as food production is where adaptation measures are the most obvious and straightforward. But adaptation is now starting to be considered by economists more widely as an inescapable component of the policy mix to face global warming (De Zeeuwn and Zemel, 2012; Zemel, 2015).

For example, studies on the global costs of adaptation yield estimates ranging between $ 25 billion a year and $ 100 billion for the period 2015-2030. These figures reflect the cost of adapting to a 2-3^{o} C warming over the next 20 years, with costs for higher temperatures expected to rise exponentially (Fankhauser, 2010b). Disaggregated estimates yield higher figures for individual countries, with the costs only for the U.S potentially amounting to tenths to hundreds of billions of dollars (Sussman et al., 2014). These numbers, however, are purely cost-effectiveness estimates. Millner and Dietz (2015) model the balance between investment in productive and adaptive capital, the first being investment that raises output but is not resilient to climate change and the latter being climate-resilient investment (that is less productive in the absence of climate change). They employ a standard Ramsey-Cass-Koopmans Nordhaus-type formulation to find that it is always rational to grow the adaptive sector faster, even though, calibrating the model to data from Sub-Saharan Africa, investment in adaptation does not exceed 1% of the economy.

If adaptation is complementary to mitigation, costs will depend on the mitigation level, except for the most catastrophic scenarios where there is no room for adaptation (Agrawala et al., 2011). For the most likely warming levels adaptation has the greatest potential for damage reduction and it may therefore absorb more resources than mitigation (Bosello et al., 2010). If the total cost of adaptation may be as high as that of mitigation, how are these costs to be born, especially in the context of a non-universalistic climate approach?

There are two partial answers to this question. Adaptation to climate change involves the transfer of resources to the most affected countries, and within these, to the most affected communities. This should require climate cooperation. Contrary to mitigation, however, close-to-full participation is not essential. Free-riding is a fundamental problem for mitigation because by not reducing emissions non-participant countries are counter-balancing the abatement efforts from others (the leakage problem, as in Hoel, 1991 and Elofsson, 2007). This is arguably less relevant for adaptation. A limited number of nations may be able to fund adaptation efforts in the countries most in need even if others free ride. Secondly, when seen as increased resilience adaptation overlaps with development, bearing two implications. From an operational point of view, there exists a network of institutions and organizations dedicated to implementing development projects in the South that can be mobilized for the adaptation effort. From a political point of view, climate policy can gain legitimacy by being seen as an integral part of development policy.

Conclusion and policy implications

Three major research trends have broadened the scope of climate change economics as of the last five years. First, the study of the economic implications of potential climate catastrophes resulting from very high warming levels. This is an important change of direction as the standard models focused almost exclusively on lower warming bands, mostly due to methodological limitations for the analysis of scenarios that fall far apart from the mean of the probability distribution. The second trend is the study of carbon border adjustments—taxing the carbon content embedded in imported goods. Research in this area has been particularly fruitful in the last few years as unilateral climate initiatives by nations and sub-national entities has proliferated, and with them the worry that regulation would crowd out competitiveness. The third stream that opens up is the study of the economics of adaptation to climate change, which includes issues such as costs and benefits of adaptation and the identification of overlaps between climate action and development objectives. This has to do with the increased recognition that optimal mitigation policies are impracticable and that second-best solutions must be envisaged.

Does it matter for policy? The centrality of adaptation is indeed one of the policy measures proposed by Dieter Helm, an economist at Oxford University, in his book *The carbon crunch* (2012). His policy appraisal is a good illustration of the trends in economic thinking on climate change that were stressed in this paper. Besides giving a central role to adaptation, Helm calls for a carbon pricing system with border adjustments. However, instead of defining the optimal mitigation path and carbon price based on standard climate-economy models, the proposed pricing system would work on the premise that it is not possible to determine "correct" prices, setting instead a “low” starting price. The system would be designed to ensure a rising price in the long run. But given the challenges of a global climate agreement, how could such a pricing system be implemented? For Helm, the doldrums of negotiations could be broken by forcing the merge between the climate change and the trade agendas: the unilateral imposition of carbon border adjustments (possibly by the European Union) would push hesitating countries to respond.

The post-Copenhagen period has imposed a reversal upon climate policy whose scale is still to be appreciated. The essence of this change is the recognition that universally coordinated climate policy in the style of the Montreal Protocol is not practicable, and what should come up is a system in which decisions are taken in a decentralized, but not necessarily uncoordinated, way. The imposition of trade barriers based on carbon content is consistent with this approach, as it would drive the negotiations to a sectorial basis. In addition, the orthodoxy of emissions mitigation is being replaced by a policy mix that includes adaptation and mitigation of the risk of the worst case scenario. The focus on adaptation gives climate policy a local and regional character—polycentric—while minimizing the risk of a catastrophe relies on globally coordinated action.

References

Agrawala, Shardul, Francesco Bosello, Carlo Carraro, Kelly De Bruin, Enrica De Cian, Rob Dellink, and Elisa Lanzi. 2011. "Plan or react? Analysis of adaptation costs and benefits using integrated assessment models." *Climate Change Economics* 2 (03):175-208.

Aldy, Joseph, and William Pizer. 2011. The competitiveness impacts of climate change mitigation policies. National Bureau of Economic Research.

Ambec, Stefan, Mark Cohen, Stewart Elgie, and Paul Lanoie. 2013. "The Porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness?." *Review of Environmental Economics and Policy* 0 (0): 1-22.

Anthoff, David, Cameron Hepburn, and Richard Tol. 2009. "Equity weighting and the marginal damage costs of climate change." *Ecological Economics* 68 (3): 836-849.

Anthoff, David, and Richard Tol. 2007. On international equity weights and national decision making on climate change. In *Fondazione Eni Enrico Mattei Working Papers*.

Arrow, Kenneth, Maureen Cropper, Christian Gollier, Ben Groom, Geoffrey Heal, R Newell, William Nordhaus, Robert Pindyck, William Pizer, and P Portney. 2013. "Determining benefits and costs for future generations." *Science* 341 (6144):349-350.

Ayers, Jessica, and David Dodman. 2010. "Climate change adaptation and development I the state of the debate." *Progress in Development Studies* 10 (2):161-168.

Ayers, Jessica, and Tim Forsyth. 2009. "Community-based adaptation to climate change." *Environment: science and policy for sustainable development* 51 (4):22-31.

Barker, Terry, Sudhir Junankar, Hector Pollitt, and Philip Summerton. 2007. "Carbon leakage from unilateral environmental tax reforms in Europe, 1995–2005." *Energy Policy* 35 (12):6281-6292.

Barrett, Scott. 1994. "Self-enforcing international environmental agreements." *Oxford Economic Papers* 46 (Special Issue on Environmental Economics (Oct., 1994)):878-894.

Barrett, Scott. 2006. "Climate Treaties and "Breakthrough" Technologies." *American Economic Review* 96 (2):22-25.

Barrett, Scott. 2008. "Climate treaties and the imperative of enforcement." *Oxford Review of Economic Policy* 24 (2):239-258.

Bosello, Francesco, Carlo Carraro, and Enrica De Cian. 2010. "Climate policy and the optimal balance between mitigation, adaptation and unavoided damage." *Climate Change Economics* 1 (02):71-92.

Bosetti, Valentina, and David Victor. 2011. "Politics and Economics of Second-Best Regulation of Greenhouse Gases: The Importance of Regulatory Credibility." *Energy Journal* 32 (1).

Bouwer, Laurens. 2011. "Have disaster losses increased due to anthropogenic climate change?" *Bulletin of the American Meteorological Society* 92 (1).

Branger, Frédéric, Philippe Quirion, and Julien Chevallier. 2013. Carbon leakage and competitiveness of cement and steel industries under the EU ETS: much ado about nothing. CIRED Working Paper Series.

Carraro, Carlo, and Domenico Siniscalco. 1992. "The international dimension of environmental policy." *European Economic Review* 36 (2): 379-387.

Cline, William. 1992. *The economics of global warming*. Washington, D.C.: Peterson Institute.

De Zeeuw, Aart, and Amos Zemel. 2012. "Regime shifts and uncertainty in pollution control." *Journal of Economic Dynamics and Control* 36 (7): 939-950.

Copeland, Brian, and Scott Taylor. 1994. “North-South trade and the environment.” *The Quarterly Journal of Economics* 109 (3): 755-787.

Copeland, Brian, and Scott Taylor. 2013. *Trade and the Environment: Theory and Evidence: Theory and Evidence*. Princeton University Press.

Dell, Melissa, Benjamin Jones, and Benjamin Olken. 2014. "What Do We Learn from the Weather? The New Climate-Economy Literature." *Journal of Economic Literature* 52 (3): 740-98.

Demailly, Damien, and Philippe Quirion. 2006. "CO2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation." *Climate Policy* 6 (1): 93-113.

Di Falco, Salvatore. 2014. "Adaptation to climate change in Sub-Saharan agriculture: assessing the evidence and rethinking the drivers." *European Review of Agricultural Economics* 41 (3): 405-430.

Di Falco, Salvatore, and Marcella Veronesi. 2013. "How Can African Agriculture Adapt to Climate Change? A Counterfactual Analysis from Ethiopia." *Land Economics* 89 (4):743-766.

Di Falco, Salvatore, Marcella Veronesi, and Mahmud Yesuf. 2011. "Does adaptation to climate change provide food security? A micro-perspective from Ethiopia." *American Journal of Agricultural Economics* 93 (3):829-846.

Dietz, Simon. 2011. "High impact, low probability? An empirical analysis of risk in the economics of climate change." *Climatic Change* 108 (3):519-541.

Dietz, Simon. 2014. "Climate change mitigation as catastrophic risk management." *Environment: science and policy for sustainable development* 56 (6):28-36.

Elofsson, Katarina. 2007. "Cost uncertainty and unilateral abatement." *Environmental and Resource Economics* 36 (2): 143-162.

Falkner, Robert, Hannes Stephan, and John Vogler. 2010. "International climate policy after Copenhagen: Towards a ‘building blocks’ approach." *Global Policy* 1 (3):252-262.

Fankhauser, Samuel. 2010a. "Market and Policy Driven Adaptation." In *Smart Solutions to Climate Change*. Cambridge: Cambridge University Press.

Fankhauser, Samuel. 2010b. "The costs of adaptation." *Wiley interdisciplinary reviews: climate change* 1 (1):23-30.

Fankhauser, Samuel, and Ian Burton. 2011. "Spending adaptation money wisely." *Climate Policy* 11 (3):1037-1049.

Fankhauser, Samuel, and Thomas McDermott. 2014. "Understanding the adaptation deficit: why are poor countries more vulnerable to climate events than rich countries?" *Global Environmental Change* 27:9-18.

Feddersen, John. 2013. Pollution Havens: Does Third Country Environmental Policy Matter?

Finus, Michael, M Elena Saiz, and Eligius Hendrix. 2009. "An empirical test of new developments in coalition theory for the design of international environmental agreements." *Environment and Development Economics* 14 (1):117.

Fischer, Carolyn, and Alan Fox. 2012. "Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates." *Journal of Environmental Economics and Management* 64 (2):199-216.

Frankel, Jeffrey, and Andrew Rose. 2005. “Is trade good or bad for the environment? Sorting out the causality.” *The Revierw of Economics and Statistics* 87 (1): 85-91.

Giddens, Anthony. 2009. *The politics of climate change*. Cambridge, UK: Polity.

Gjerde, Jon, Sverre Grepperud, and Snorre Kverndokk. 1999. "Optimal climate policy under the possibility of a catastrophe." *Resource and Energy Economics* 21 (3): 289-317.

Green, Fergus. 2014. "This time it's different": the prospects for an effective climate agreement in Paris 2015. In *Grantham Research Institute on Climate Change and the Environment*. London, UK: London School of Economics.

Heal, Geoffrey, and Antony Millner. 2014. "Agreeing to disagree on climate policy." *Proceedings of the National Academy of Sciences* 111 (10):3695-3698.

Helm, Dieter. 2012. *The Carbon Crunch*: Yale University Press.

Helm, Dieter, Cameron Hepburn, and Giovanni Ruta. 2012. "Trade, climate change, and the political game theory of border carbon adjustments." *Oxford review of economic policy* 28 (2):368-394.

Hepburn, Cameron. 2006. "Regulating by prices, quantities or both: an update and an overview." *Oxford review of economic policy* 22 (2):226-247.

Hepburn, Cameron, and Nicholas Stern. 2009. "The global deal on climate change." In *The economics and politics of climate change*, edited by Dieter Helm and Cameron Hepburn, 36-57. Oxford: Oxford University Press.

Hertel, Thomas, and David Lobell. 2014. "Agricultural adaptation to climate change in rich and poor countries: Current modeling practice and potential for empirical contributions." *Energy Economics*.

Hoel, Michael. 1991. "Global environmental problems: the effects of unilateral actions taken by one country." *Journal of Environmental Economics and Management* 20 (1): 55-70.

Hourcade, Jean-Charles, Philippe Ambrosi and Patrice Dumas. 2009. “Beyond the Stern review: lessons from a risky venture at the limits of the cost-benefit analysis.” *Ecological Economics* 68 (10): 2479 – 2484.

IPCC. 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the intergovernmental panel on climate change*: Cambridge: Cambridge University Press.

Keohane, Robert, and David Victor. 2011. "The regime complex for climate change." *Perspectives on politics* 9 (01):7-23.

Kolstad, Charles. 1994. "George Bush versus Al Gore: Irreversibilities in greenhouse gas accumulation and emission control investment." Energy Policy 22 (9): 771-778.

Lemoine, Derek, and Christian Traeger. 2012. Tipping points and ambiguity in the economics of climate change. National Bureau of Economic Research.

Manders, Ton, and Paul Veenendaal. 2008. *Border tax adjustment and the EU-ETS, a quantitative assessment*. No. 171. CPB Netherlands Bureau for Economic Policy Analysis.

McKibbin, Warwick, Adele Morris, and Peter Wilcoxen. 2011. "Comparing climate commitments: a model-based analysis of the Copenhagen Accord." *Climate Change Economics* 2 (02):79-103.

McKibbin, Warwick, and Peter Wicoxen. 2008. "The economic and environmental effects of border tax adjustments for climate policy [with comments]." Brookings Trade Forum. Brookings Institution Press, 2008/2009.

Nachmany, Michael, Sam Fankhauser, Terry Townshend, Murray Collins, Tucker Landesman, Adam Matthews, Carolina Pavese, Katharina Rietig, Philip Schleifer, and Joana Setzer. 2014. The GLOBE Climate Legislation Study: A Review of Climate Change Legislation in 66 Countries. In *GLOBE International and the Grantham Research Institute*. London, UK: London School of Economics.

Nature Climate change editorial. 2013. "Adapting to a changing climate." *Nature Clim. Change* 3 (11):939-939. doi: 10.1038/nclimate2048.

Nordhaus, William. 2008. *A question of balance: Weighing the options on global warming policies*. New Haven: Yale University Press.

OECD. 2013. Climate and carbon. Aligning prices and policies. OECD Publishing.

Ostrom, Elinor. 2010. "Beyond markets and states: polycentric governance of complex economic systems." *The American Economic Review* 100 (3):641-672.

Pearce, David. 2003. “The social cost of carbon and its policy implications.” *Oxford Review of Economic Policy* 19 (3): 362 – 384.

Pindyck, Robert. 2011. "Fat tails, thin tails, and climate change policy." *Review of Environmental Economics and Policy* 5 (2):258-274.

Pindyck, Robert. 2013a. Climate Change Policy: What do the models tell us? : National Bureau of Economic Research.

Pindyck, Robert. 2013b. "Pricing carbon when we don’t know the right price." *Regulation* 36 (2):43-46.

Porter, Michael, and Claas Van der Linde. 1995. "Toward a new conception of the environment-competitiveness relationship." *The journal of economic perspectives* 9 (4): 97-118.

Revesz, Richard, Peter Howard, Kenneth Arrow, Lawrence Goulder, Robert Kopp, Michael Livermore, Michael Oppenheimer, and Thomas Sterner. 2014. "Global warming: Improve economic models of climate change." *Nature* 508 (7495):173-175.

Scripps, Institute. 2014. Atmospheric CO2.

Stainforth, David, Miles Allen, Edward Tredger, and Leonard Smith. 2007. "Confidence, uncertainty and decision-support relevance in climate predictions." *Philosophical*

Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365 (1857):2145-2161.

Stern, Nicholas, ed. 2006. *Stern Review: The economics of climate change*. Vol. 30. London: HM treasury London.

Stern, Nicholas. 2013. "The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models." *Journal of Economic Literature* 51 (3):838-859.

Sunstein, Cass. 2004. "Cost-benefit analysis and the environment." *U Chicago Law & Economics, Olin Working Paper* (227).

Tavoni, Alessandro. 2013. "Game theory: Building up cooperation." *Nature Climate Change* 3 (9):782-783.

Tol, Richard. 2005. “The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties.” *Energy Policy* 33: 2064 – 2074.

Tsur, Yacov, and Amos Zemel. 1996. "Accounting for global warming risks: resource management under event uncertainty." *Journal of Economic Dynamics and Control* 20 (6): 1289-1305.

US government. 2013. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis—Under Executive Order 12866. edited by Interagency Working Group on Social Cost of Carbon.

Vale, Petterson Molina. 2010. "Economia das mudanças climáticas: uma avaliação dos principais modelos." Master’s dissertation, Economics Institute, UNICAMP, Brazil.

Weitzman, Martin. 2007. "Role of uncertainty in the economics of catastrophic climate change." *AEI-Brookings Joint Center Working Paper* 07-11.

Weitzman, Martin. 2009. "On modeling and interpreting the economics of catastrophic climate change." *The Review of Economics and Statistics* 91 (1):1-19.

Weitzman, Martin. 2011. "Fat-tailed uncertainty in the economics of catastrophic climate change." *Review of Environmental Economics and Policy* 5 (2):275-292.

Weitzman, Martin. 2013. Can Negotiating a Uniform Carbon Price Help to Internalize the Global Warming Externality? : National Bureau of Economic Research.

Zemel, Amos. 2015. "Adaptation, mitigation and risk: An analytic approach." *Journal of Economic Dynamics and Control* 51: 133-147.