Environmental Regulation

Climate Change: Pricing Carbon

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Introduction

Introduction

Humanity's large self-deception

- Today, Humanity's attitude can be described by the followings:
    - "It's just natural climate change"!
    - "When we understand all the physics, we can stop it".
    - "Somebody else has to lower their emissions".
- However, the climate clock is running: what is the remaining time? And to quote John Muir, "When one tugs at a single thing in nature, he finds it attached to the rest of the world."

Figure 1: Humanity's attitute toward Climate Change.

Introduction

We don't know the full implications of an eventual 6° C temperature change. We can't know. It's a blind planetary gamble. Devastating home fires, car crashes, and other personal catastrophes are almost always much less likely than 10 percent. And still, people take out insurance to cover against these remote possibilities, or are even required to do so by laws that hope to avoid pushing these costs onto society. Risks like this on a planetary scale should not – and must not – be pushed onto society.

Climate Shock, The Economic Consequences of a Hotter Planet
G. Wagner and M. Weitzman (2015)

Climate change and risk management

- Climate Policy is an interesting exercise in risk management, and insurance analogy is an appealing metaphor. However, when it comes to details, it is not quite right.
- In general, when we insure, we sell a risk that we bear to someone else who was not bearing it and who now assumes it. Insurance companies then effectively annihilate it through risk pooling and the law of large numbers.
- The insurance analogy does not apply when the planet is at risk: there isn't anyone else who is not exposed to whom we can sell our risk.
- Insurers are very disturbed by the prospect of climate change, as it threatens them with correlated risks and probabilities of risks are not known, in contrast to conventional property and casualty risks whose characteristics are well-documented.
- Focusing on the most likely outcomes under climate change lulls us into a false sense of security! Climate has... Domino effects with many irreversible processes.

The scientific importance of catastrophes and disasters

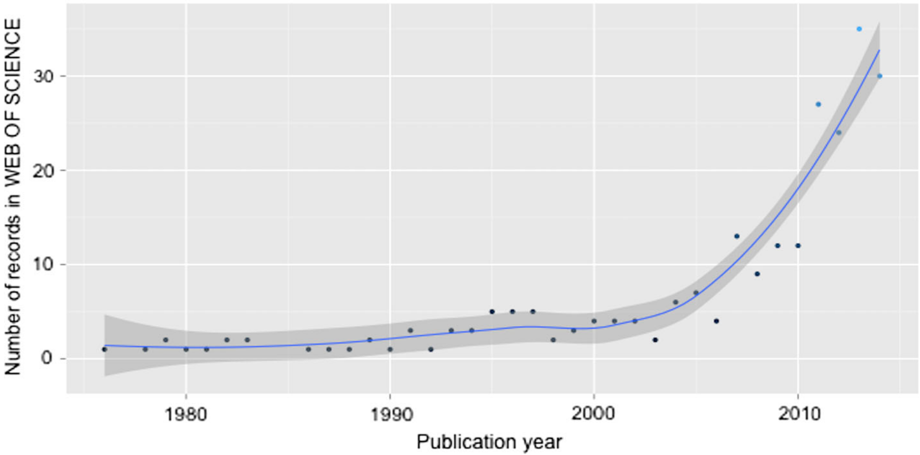


Figure 2: Economic papers on catastrophes and disasters (including man-made environmental threats), 1974-2014. Source: Rheinberger and Treich (2017).

Cumulative Climate Hazards

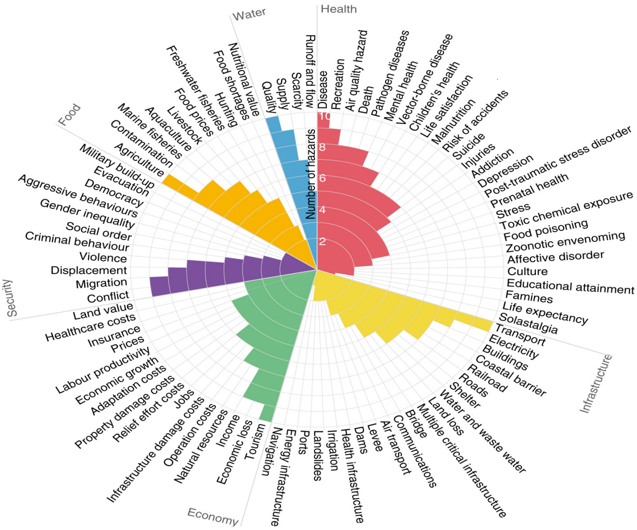


Figure 3: Observed climate hazards based on 3280 papers (Mora et al., 2018).

Questions

- Climate change can be considered as **mother of all externalities**. Carbon-free solutions seem **expensive**. GHG mitigation is an international **public good** without international governance. In addition, there is a very serious **free riding** problem!
- In light of these characteristics, climate change is an important problem and needs new way of thinking:
  - what are the best **instruments** for basic control/negotiation tools?
  - where does the global warming public goods problem now stand? Spirit of Kyoto and beyond: **Pledge and Review**!
    - Essentially quantity based instrument.
    - Breakdown of top-down approach and current emphasis on bottoms-up approaches. Is current volunteerism enough?
- Climate change appears to public as relatively remote distant-future problem. Not yet felt at grassroots level. But are perceived climate-change catastrophes in some sense endogenous/inevitable?
- Let us all **keep powder dry**! Opportunities for comprehensive solutions may arise!

Road Map

- Some useful definitions and facts.
- Human activities and climate change.
- The Social Cost of Carbon.
- The Economic analysis of climate change.
- Policy options.
- A Simple Pollution Tax Model.
- Conclusion
- Selected References

Some Useful Definitions and Facts

Early theories on Greenhouse Gases (GHGs)

- The concept of the GHG effect was first proposed in the 1820s, by the French mathematician and physicist J. **Fourier** (1768–1830). He showed that the Earth should be much cooler than it is, given the amount of energy it receives from the sun. He proposed that the Earth's atmosphere might provide an **insulating effect**, retaining some of the heat that would otherwise be reemitted into space.
- Later, the GHG effect was shown in a research laboratory by 1859, but it was not quantified until 1896. S. **Arrhenius** (1859–1927) established a linear relationship between CO_2 concentrations in the atmosphere and the globe's average surface temperature. He proposed that the rapid emission of CO_2 resulting from fossil fuel combustion tied to industrialization could eventually lead to a small increase in global temperatures.
- In 1979, the Charney Report (US National Academy of Sciences) established a linear relationship between **Radiative Forcing** (RF) and near-surface air temperature.

Some definitions

- **Definition**: *Climate* is the average **weather patterns** over a longer period of time. It covers statistics about the weather. *Climate change* is a significant change in weather patterns, glaciers, sea level rise, etc.
- **Definition**: *Climate Sensitivity* is the **global equilibrium surface temperature** response to a specified changes in *Radiative Forcing* caused by a doubling of atmospheric CO_2 concentrations:

$$S^a = \frac{\Delta T}{\Delta R_{[CO_2]}}$$

  where *a* refers to actuo, for present-day. ΔT represents global mean near-surface temperature response measured with respect to the additional radiative heat flux change due to changes in atmospheric GHG concentrations, in particular CO_2, $\Delta R_{[CO_2]}$.
- **Definition**: *Radiative Forcing* is one of the most used **metrics** to examine how various drivers contribute to climate change. It is the net change in the energy balance of the Earth system due to some imposed perturbations.

Where am I coming from?

- Climate change has deep structural uncertainties and an inability to exclude catastrophes. Potentially unlimited downside liability.
- The point is, when we put climate change in the perspective of a longer period of time, we find that it has happened many times before!
- Further, policy debates cover different issues:
  - the importance of risk and uncertainties: **analytic foundations**, and many large and irreversible processes!
  - models do not provide precise forecasts: **assumptions** and **timing** (long braking distance)!
  - models embody a relationship between temperature and economic damage: **implications** (global domino effects) and estimations (social costs and distribution)!
  - **discounting** and risk aversion affect the results: effects (longer period of time)?

Where am I coming from?

- To figure it out, go over *Keeling Curve*, *Antarctic Ice Core Record*, *Climate Sensitivity*.
- Based on IPCC 5th Assessment Report (AR5) description of climate sensitivity probabilities:

ppm CO_2e	450	500	550	600	650	700	750	800
Median ΔT	1.8°	2.2°	2.5°	2.7°	3.2°	3.4°	3.7°	3.9°
$\Pr[\Delta T \geq 6^\circ]$	.3%	1.2%	3%	5%	8%	11%	14%	17%

- The "most likely" range for the equilibrium climate sensitivity is in the region of $[1.5^\circ, 4^\circ]$, but some highly-reputed climate models give a chance of at least 15% that it is no less than 6°C.
- Irreversibility:
    - 70% of atmospheric (CO_2–280) remains after 100 years;
    - 40% of atmospheric (CO_2-280) remains after 1000 years.

Stabilization and commitment to warming

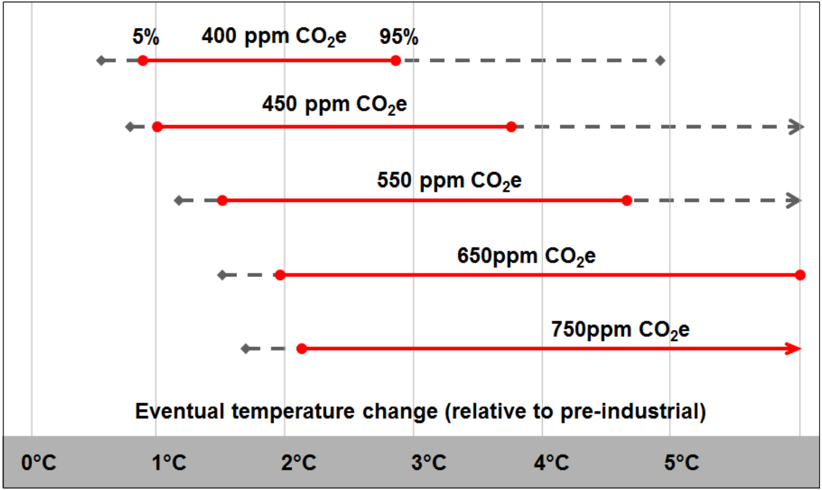


Figure 4: The relationship between the level of GHG stabilization and eventual temperature change.

Antarctic Ice Record of Carbon Dioxide and Temps

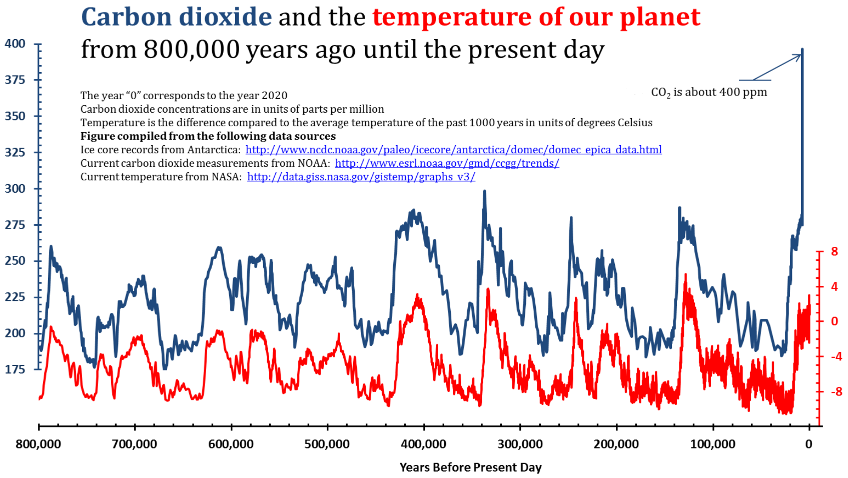


Figure 5: CO_2 concentration measurements 800K years ago.

The Keeling Curve

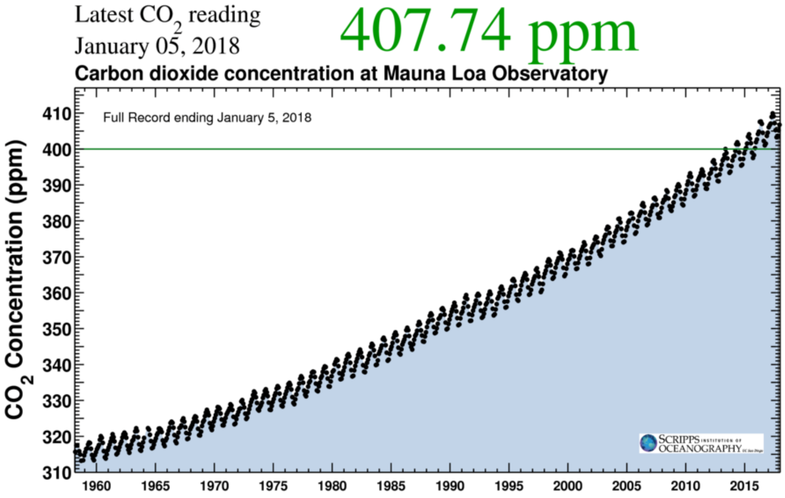


Figure 6: Rising Carbon Dioxide Levels (Scripps Institution of Oceanography).

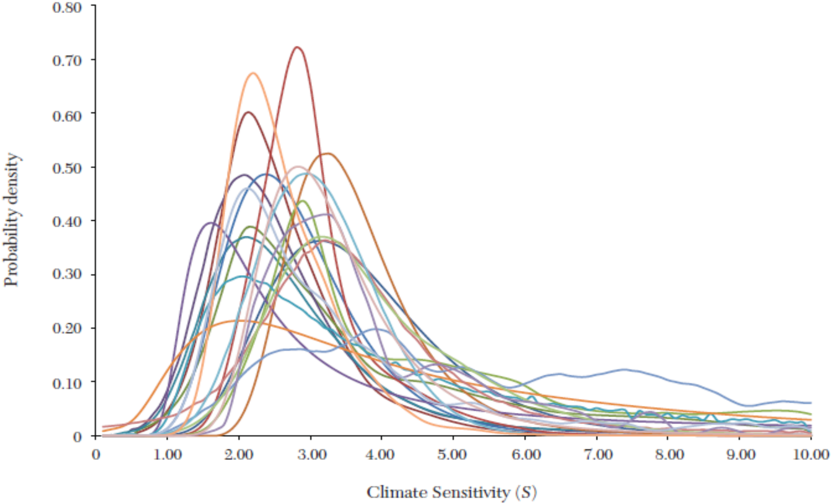


Figure 7: Estimates of the probability for climate sentitivity. Source: Heal (2017).

Climate Sensitivity

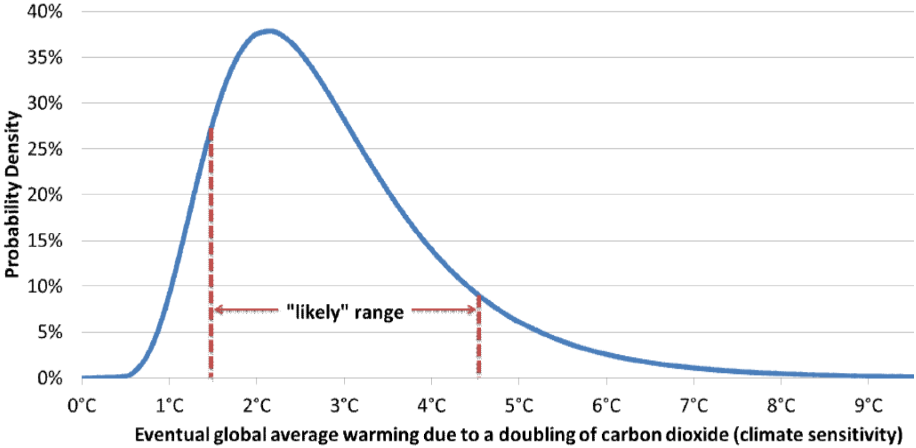


Figure 8: Probability distribution of climate sensitivity according to IPCC.

Schematic possible future trajectories

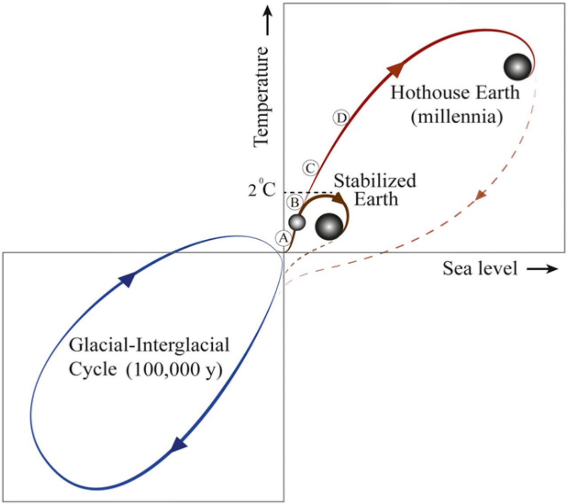


Figure 9: Possible future pathways of the climate against the background of the typical glacial-interglacial cycles. Source: Steffen et al. (2018).

And potential consequences...

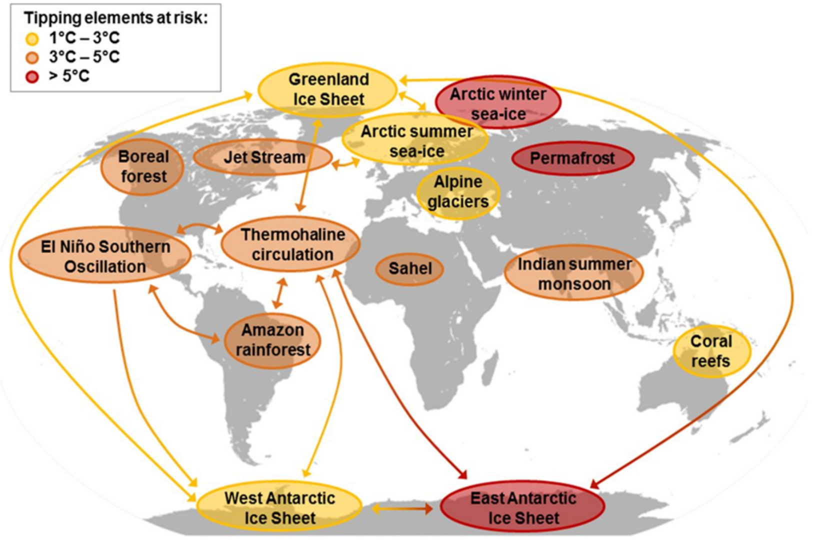


Figure 10: Global map of potential cascades. Source: Steffen et al. (2018).

And potential consequences...

- Self-reinforcing feedbacks could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilization of the climate at intermediate temperature rises and cause continued warming on a "Hothouse Earth" pathway even as human emissions are reduced!
- Crossing the threshold would lead to a much higher global average temperature than any intergacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene $\Rightarrow$ the resulting trajectory would likely cause **serious disruptions** to ecosystems, society, and economies!
- The unique solution: **collective human action** is requiered to steer the Earth Sytem away from a potential threshold and stabilize it in a habitable interglacial-like state. Such global action includes: decarbonization of the global economy, enhancement of biosphere carbon sinks, behavioral changes, technological innovations, new governance arrangements, and transformed social values.

Human Activities and Climate Change

Global emissions and human activities

- During the last decades, human activities have greatly increased the atmospheric stock of GHGs, the most important of which, by far, is CO_2. The IPCC, which embodies the mainstream of climate science, showed that the major contributors to modern climate change are CO_2 and GHG emissions from burning **fossil fuels**, which come from human-based activities in industry, agriculture, and technology.
- The IPCC also highlights that we are currently at atmospheric concentrations of CO_2 that were last seen over 3 million years ago: a **doubling** of atmospheric CO_2 concentrations implies a near-surface warming of $[2, 4.5^\circ]$.
- Since **uncertainty** cannot be banished from the issue of global warming, the IPCC publishes projections of climate change based on **four** Representative Concentration Pathways (RCPs) for emissions and land use up to 2100: RCP2.6 scenario designed to represent very low GHG concentration levels; RCP4.5 and RCP6 are stabilization scenarios; and RCP8.5 represents rising Radiative Forcing.

Economic activities and climate change

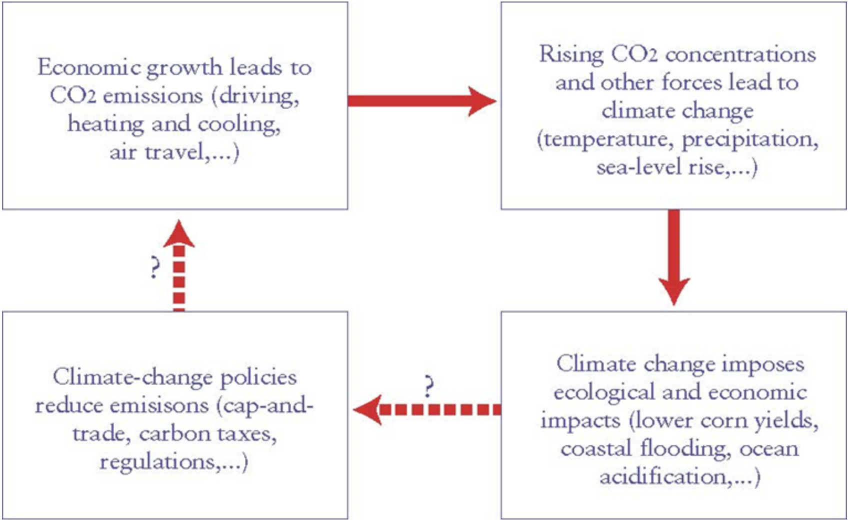


Figure 11: The circular flow of global warming science, impacts, and policy.

In 2017, CO_2 emissions from fossil fuels and industry are projected to grow by 2.0% (+0.8 to +3.0%).
This follows three years of nearly no growth (2014-2016)

The plateau of last year was not peak emissions after all...

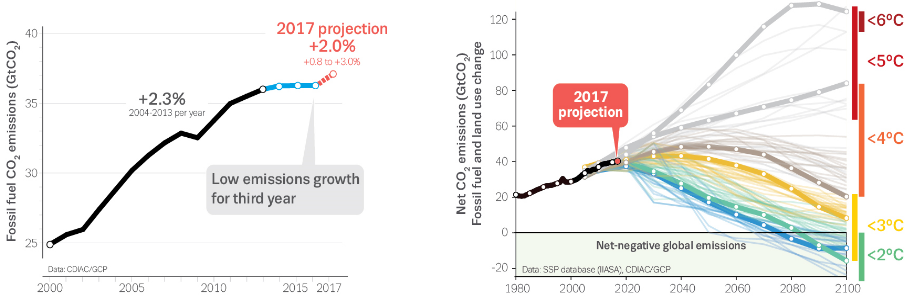


Figure 12: Fossil fuel CO_2 emissions.

Global Carbon Budget 2017

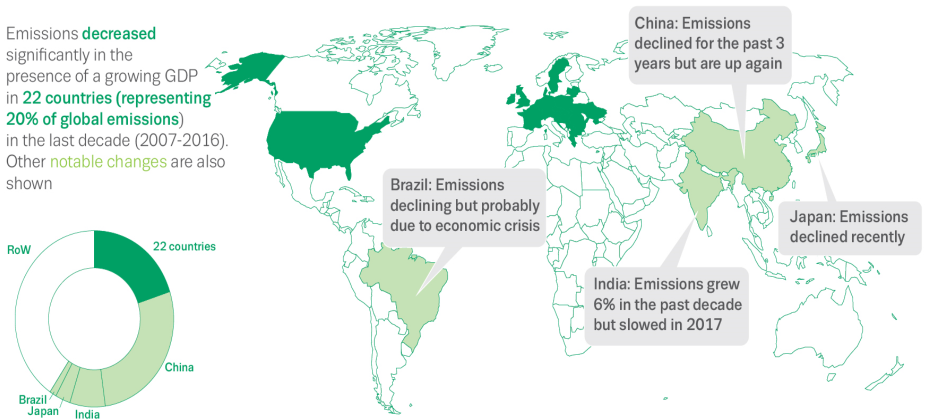


Figure 13: Fossil fuel emissions in different countries.

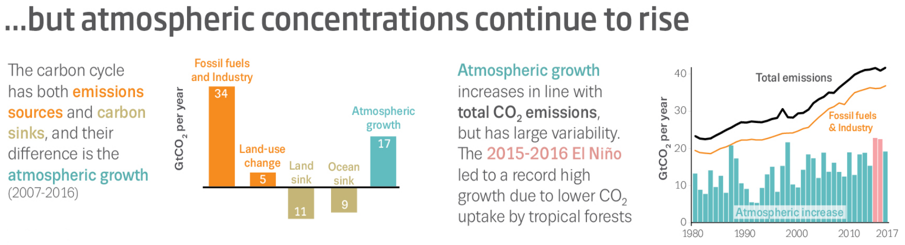


Figure 14: Atmospheric CO_2 concentrations.

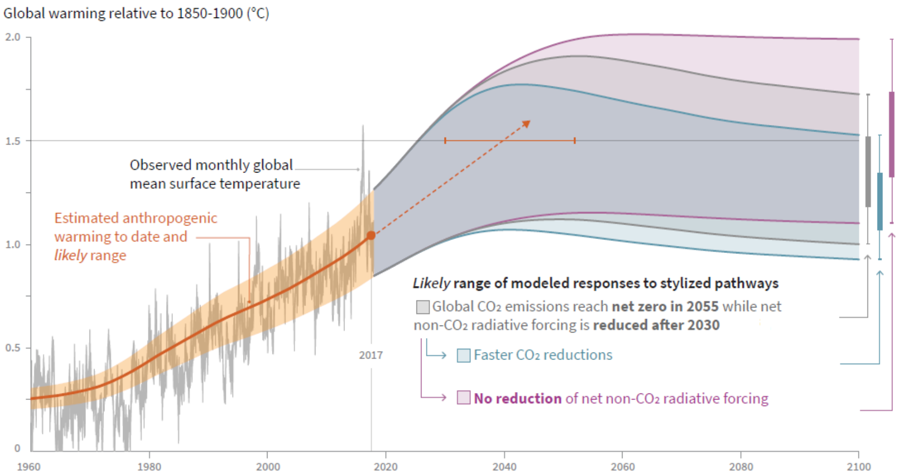


Figure 15: Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways. Source: IPCC (2018).

Forecasts to 2100

- In a recent study, Raftery et al. (2017) used a country-specific version of **Kaya's identity** to develop a statistically based probabilistic forecast of CO_2 emissions and temperature change to 2100. The Kaya identity is a specific modified version of the **IPAT equation**:

$$\text{Impact} = \text{Population} \times \text{Affluence} \times \text{Technology}$$

  It expresses future emissions levels in a country as a product of three components: Population, GDP per capita, and Carbon Intensity, the latter being the CO_2 emissions per unit of GDP.
- The **bottom line** from this study is that the **likely range** of global temperature increase is $[2.0, 4.9^\circ]$, with a median of 3.2°C. This simply means that **Paris targets** clearly could not be met.

Different Forecasts to 2100

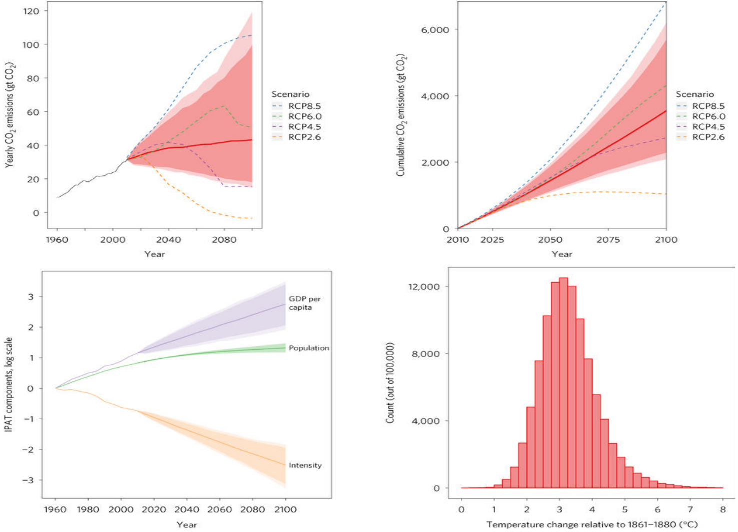


Figure 16: Probabilistic forcasts to 2100. Source: Raftery et al. (2017).

Different Forecasts to 2100

- This figure shows the predictive distributions of future world CO_2 emissions, by year and cumulatively, as well as of the Kaya components:
  - (a) CO_2 emissions by year;
  - (b) Cumulative CO_2 emissions by year;
  - (c) Logarithm of the components of the Kaya identity by year, normalized to zero in 1960;
  - (d) Histogram of the predictive distribution of the global mean temperature increase relative to 1861–1880.
- In (a) and (b), the solid line is the predictive median, the heavily shaded zone is the likely range (90% interval), the lightly shaded zone is the 95% interval, and the IPCC RCP scenarios are the dashed lines.
- There is a 5% chance of less than 2 °C warming, and a 1% chance of less than 1.5 °C.

Predictive Distributions to 2030 for Leading Countries

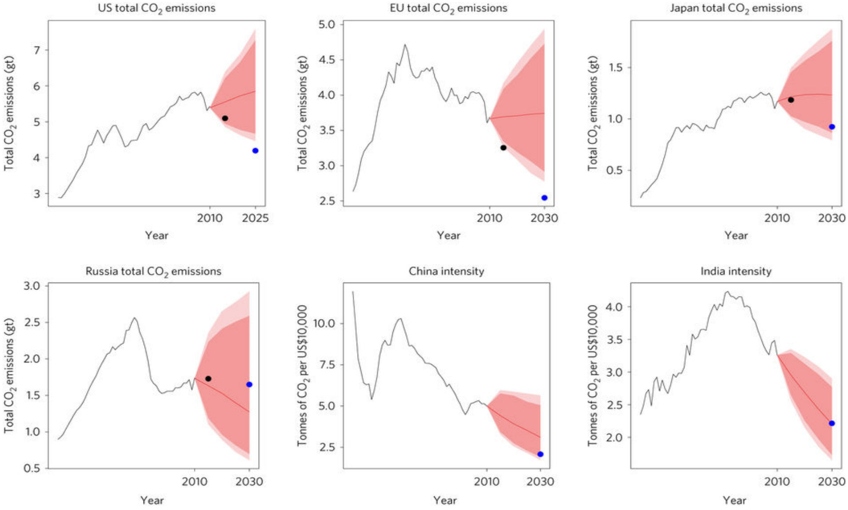


Figure 17: Probabilistic emissions forecasts. Source: Raftery et al. (2017).

Predictive Distributions to 2030 for Leading Countries

- In each panel of this figure, the large black dot shows the preliminary estimate of CO_2 emissions for 2015, while the large blue dot shows the Paris Agreement targets for 2030 (2025 for the US).
- These targets are well within the predictive intervals for Russia and India, towards the lower end but within the intervals for Japan and China, and well below the lower bounds for the USA and the EU.
- The analysis of the preliminary report emissions for 2015 points that the EU and the US alone were to meet their targets under the Paris Agreement. However, achieving the goal of less than 1.5 °C warming will require **carbon intensity** to decline much faster than in the recent past.
- The Paris Agreement's target of net zero emissions in the second half of the twenty-first century is, unfortunately, **extremely unlikely to be reached**.

The Social Cost of Carbon (SCC)

Climate change is not a delusion

- Although the mismatch between rising GHG emissions and not-rising temperatures over short periods is among the **biggest puzzles** in climate science, that does not mean climate change is a **delusion**. We all need to accept the reality of global warming and the urgent need to do something about it.
- Further, climate change does not yet tell the **full story**! Climate sensitivity describes what happens when concentrations of CO_2 in the atmosphere double. What if CO_2 concentrations more than double?
- Climate change is a **planetary**, **long-term**, **irreversible**, and **uncertain externality** and is difficult to solve. In addition, the **fickleness** of human nature and the limits of our understanding are at the **core** of the climate policy dilemma.
- The risk of catastrophic climate effects stresses the importance of drawing public attention to climate change and bringing the world to action on the issue. This justifies **more aggressive** and very **urgent policies** in the near future to limit GHG emissions.

The Concept of SCC

- The SCC is a **central concept** for understanding and implementing climate change policies. It has become an important tool in the determination of **regulatory policies** that involve GHG emissions.
- The most **general definition** of SCC is the **marginal damage** generated by an additional ton of carbon. Like the shadow price of carbon, the SCC also depends on the future socioeconomic evolutions, and on the **future pathway** of carbon emissions. In particular:
  - The SCC is the **economic cost** generated by an **additional ton** of carbon dioxide emissions or its equivalent (CO_2e), starting from the **optimal emission pathways**.
  - The SCC can be defined as the **benefits from decreasing emissions** by one ton of carbon, starting from the current trend scenario (business as usual scenario).
- In a more **precise definition**, it is the change in the **discounted value of economic welfare** from an additional unit of CO_2e emissions.

The Concept of SCC

- The literature review reveals a wide range of SCC estimates, which shows how deep the uncertainties remain on the value of SCC.
- A major source of uncertainty is linked to econometric estimates and the choice of the functional forms of the damage function.
- Further, estimates of the SCC are necessarily **complex** because:
  - They involve the full range of nonlinear **impacts** from emissions, through the **carbon cycle** and **climate change**, and including economic **damages** from climate change.
  - They also depend on the **tripping point risks**, which is not scientifically precisely known.
  - There are missing categories of impacts, such as ocean warming and acidification.
- Other drivers of the discrepancies in SCC estimates is the socioeconomic module: the SCC highly depends on the future **socioeconomic** evolutions (mitigation costs and future technologies), and on the future **pathway** of carbon emissions.

The DICE Model

- Nordhaus (2017) defined a general model of the economics of global warming, known as the Dynamic Integrated model of Climate and the Economy (**DICE**). This model views climate change in the framework of economic **growth theory**.
- In a **standard neoclassical** optimal **growth model**, society invests in **capital goods**, thereby reducing consumption today, to increase consumption in the future. The DICE model modifies the growth model to include **climate investments**, which are analogous to capital investments in the standard model.
- The model contains all elements from economics through climate change to **damages** in a form that attempts to represent simplified best practice in each area. Starting from the **optimal emission pathways**, running the model yields the SCC which heavily depends on the future. In particular, the SCC depends on **mitigation costs** and technological change.

The DICE Model

- The model optimizes a **social welfare function**, $\mathcal{W}$, which is the **discounted** sum of the population-weighted utility of **per capita consumption**:

$$\max \mathcal{W} \equiv \sum_{t=1}^{T\max} \mathcal{V}\left[c\left(t\right), \mathcal{L}\left(t\right)\right] \mathcal{R}\left(t\right) = \sum_{t=1}^{T\max} \mathcal{U}\left[c\left(t\right)\right] \mathcal{L}\left(t\right) \mathcal{R}\left(t\right)$$

where,

- $\mathcal{V}\left(\cdot\right)$ is the instantaneous social welfare function,
- $\mathcal{U}\left(\cdot\right) \equiv \frac{c^{1-\alpha}}{1-\alpha}$ is the utility function which has a constant elasticity with respect to per capita consumption,
- $c\left(t\right)$ is per capita consumption,
- α is a generational inequality aversion,
- $\mathcal{L}\left(t\right)$ is population,
- $\mathcal{R}\left(t\right) \equiv \left(1+\rho\right)^{-t}$ is the discount factor on welfare,
- ρ is the pure rate of social time preference or **generational discount rate** on welfare.

The DICE Model

- Under these specifications, we can estimate the **net output** which is gross output reduced by damages, $\Omega(t)$, and mitigation costs,:

$$\mathcal{Q}(t) \equiv \Omega(t)\left[1 - \Lambda(t)\right]\mathcal{Y}(t)$$

  - $\mathcal{Q}(t)$ is output net of **damages** and **abatement**,
  - $\mathcal{Y}(t)$ is **gross output**, which is a Cobb-Douglas function of capital, labor, and technology,
  - $\Lambda(t)$ represents the abatement cost function.

- Total output is divided between total consumption and total gross investment. Labor is proportional to population, whereas capital accumulates according to an optimized savings rate.

Global vs. Strategic SCC

- Most estimates of SCC are global. From one country's own perspective:
  - part of this SCC is "selfish" because emission reductions in one country reduce impacts in this same country, and should be accounted for even in a self-interest cost-benefit analysis,
  - part is "universal" and refers to the climate public goods. The share varies in different countries.
- Note that, seeking the one right estimate of the global SCC fails to recognize strategic incentives on the part of countries (Weitzman 2016, Kotchen 2016).
- For instance, Nordhaus' analysis estimates that the SCC is \$31 per ton of CO_2 in 2010 US\$ for the current period (2015). This means that the real SCC grows at 3% per year over the period to 2050.
- According to Stern (2013): 5% of GDP for climate damage versus 1% of GDP for mitigation costs. This depends on the case for action.
- In the presence of nonlinear climate change impacts or tipping point risks, the value of the SCC is different (Ackerman and Stanton, 2012).

Air Pollution: the EU Consequences

- The World Health Organization (WHO) classifies air pollution as the biggest environmental risk to health. For instance, in the EU,
  - Air pollution causes more than 1000 premature deaths on average each day, which is 10 times the number of victims by road accidents;
  - Up to 96% of EU citizens living in urban areas were exposed to levels of air pollutants considered by the WHO as damaging to health;
  - The estimated health-related external costs of air pollution are in the range of €330 and €940 billion per year (WHO, 2016)!
- The point is that EU actions to protect human health from air pollution have not delivered the expected impact:
  - EU's air quality standards were set 20 years ago and some of them do not consider the latest scientific evidence on human health impacts;
  - Most Member States still do not comply with air quality standards and were not taking enough effective actions to improve air quality;
  - The Commission faces limitations in monitoring Member States' environmental performance. Efficient enforcement is needed;
  - Some EU policies do not sufficiently well reflect the importance of improving air quality (such as transport, industry, and agriculture).

The Economic Analysis of Climate Change

Climate change: a tragedy of the commons

- Climate change is a good example of the **tragedy of the commons** as **property rights** to the atmosphere are poorly defined. **Elinor Ostrom**, a political scientist, won the 2009 Nobel Prize in economics for her lifelong studies of **common-pool dilemmas**, one of which is climate change.
- If each country has its own climate, then **self-interested** countries would reach the climate goal. However, since climate change is a global problem, a country abating its emissions receives only a tiny fraction of the benefits, yet incurs the full cost of its abatement!
- Thus, climate **externalities** simply cause a **global free-rider problem**. Self-interested agents have little incentive to curtail emissions of GHGs: if some nations that emit sit back and rely on others' efforts, the incentives for anyone to act are weakened.
- To save the commons, the users of such commons must **cooperate**. That requires **trust**, and trust requires a **reciprocal agreement**.

Climate change: a simple cooperation game

- Let's consider a group of $i \in I = \{1, \ldots, 10\}$ completely **selfish** agents in a climate game and show how **negotiation design** matters by changing **rules**.
- To this end, we suppose that each player has \$10, some or all of which the players may simultaneously **pledge** to a common pot. Voluntary pledges are enforced: a referee makes sure they honor their pledges.
- Each dollar (for carbon abatement) placed in the pot will be doubled (by climate benefits) and distributed evenly to all players. So, for any dollar placed in the pot, 20 cents will be returned to each player.
- In the first game we assume the **individual** commitment game in which all pledges are independent of those of others. In the second, we consider the **common** commitment game: the pledge is a commitment to reciprocally match the minimum pledge of others.

Individual commitment game

- All pledges are made independently and the referee makes sure each contributes exactly what he or she pledges. Having said that, this involves enforcement. However, enforcement is weaker.
- This is the classic **public-goods game**: the rational strategy for the narrowly self-interested player is to contribute **nothing** because this makes an agent better off no matter the others do.
- The result is the famous **tragedy of the commons**: cooperation does not occur (all pledge \$0), except perhaps on the part of a few commited altruists, who correctly note that if only everyone cooperated, everyone would be better off.

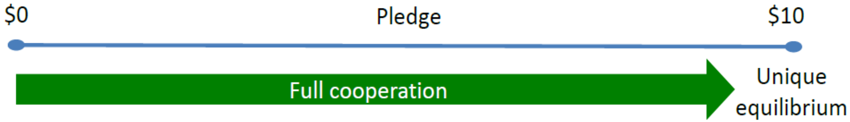
Common commitment game

- In this game, the rule is that the referee interprets a pledge of $\$x$ to mean a player will contribute up to $\$x$, but only as much as the lowest pledge. Unlike before, the referee will not enforce contributions greater than the **lowest pledge**.
- This is a "I will if you will" reciprocal agreement : each player is free to pledge from $0 to $10 and no one is forced to contribute more than his or her pledge.
- This changes everything: pledging $0 will mean simply keeping your $10, whereas pledging $10 could result in ending up with anything between $10 (if the lowest pledge is $0) and $20 if the lowest pledge is $10), depending on what others pledge.
- "I will if you will" may promote **cooperation** and protects against free-riding: selfish behavior has changed from "contribute nothing" to "contribute everything".

Common commitment game

- Main result: full cooperation and all pledge \$10.

	Player $j \in I, j \neq i$	
Player $i \in I$	0	10
0	$(10; 10)$	$(10; 10)$
10	$(10; 10)$	$(20; 20)$



- The story does not stop at this point! The final outcome dramatically depends on enforcement power, the design of the negotiations, and players' political will.

Economics of climate change

- Over forty years of empirical and theoretical literature confirms that no single action, no single country can resolve the problem of this global common on its own. Based on hundreds of field studies, Ostrom (2010) showed that insufficient reciprocity leads to a **downward cascade**.
- **Pledge-and-review** was invented for the United Nations Framework Convention on Climate Change (UNFCCC) by Japan in 1991, and it hasn't changed much since then (Kyoto, Copenhagen, Cancun).
- In December 2015, the Paris Climate Change Agreement (PCCA) formulated an ambitious global climate goal, and adopted like under the last Conferences of the Parties (COP), a **pledge-and-review approach** to cutting global carbon emissions.
- Such pledge-and-review approach does not work if the collective goal is not translated into a reciprocal, enforced common climate commitment (Mackay et al. 2015). Even under **kyoto Protocol,** Japan, Russia, Canada, and New Zealand left the agreement.

Pledge and Review approach

- Under such approach, countries have pledged almost anything, and now they will review it like in the past. By the end, we know well that without a binding agreement based on a reciprocal, common climate commitment with reliable monitoring efforts, countries will just act in their narrow self-interest. And then, there may be more pledges and more reviews!
- Research papers show that the dynamic of a pledge-and-review does not actually work and that quite the opposite will happen. Under Kyoto countries picked commitments levels relative to 1990. Within the EU, these ranged from a 30% cut to a 40% increase.
- It is time today to find another path, otherwise humanity will be always trapped in the wrong way of thinking to deal with the challenges associated with climate change. This requires governments, citizens, and firms to work collaboratively to reduce GHG emissions, a task that needs further information on companies' emissions levels, risks, and reduction opportunities.

COP 21, The Paris Agreement

- **COP-21**, 195 nations sign the Paris Agreement, providing for worldwide voluntary actions by individual countries (Intended Nationally Determined Contributions, INDC's).
- **Principle**: a country promises to reduce its emissions by amounts that will be revised later. This will, theoretically, enable an upward spiral of ambition over time.
- No one can offer any proof that the Paris Agreement will be a **miracle** $\Rightarrow$ lack of reciprocity!

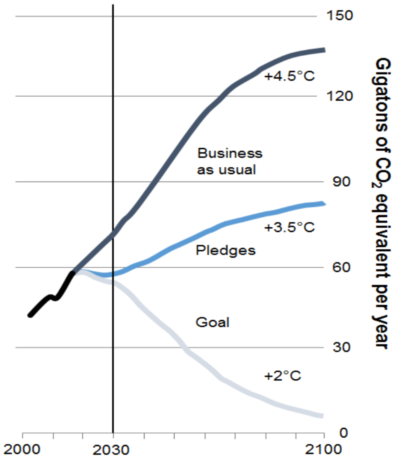


Figure 18: Business as Usual, Paris Pledges, and 2°C Path.

Policy Options

Policy Options

The climate system is an angry beast and we are poking it with sticks.

Wallace Broecker

Climate change is the biggest market failure the world has ever seen.

Nicolas Stern

Urgent Need to Carbon Pricing

- It is well-known that, if the market is left to operate freely, GHG emissions will be excessive, since all players in the marketplace, i.e. firms, households, etc., have insufficient incentives to reduce emissions.
- In the absence of environmental policy, the social cost of pollution largely exceeds the private cost because of negative externalities.
- The costs of climate impacts, including public health and damage costs of heatwaves, flooding, heavy downpours, and droughts, are borne by taxpayers and by individuals who are directly affected, but are not taken into account in decisions made by producers or consumers of carbon-intensive goods.
- As such, it is highly recommended to place a price on CO_2, i.e. a monetary value on GHGs, so far excluded from consideration in international negotiations. Emitting carbon becomes more expensive, and economic agents seek ways to use more environmentally friendly technologies and products.

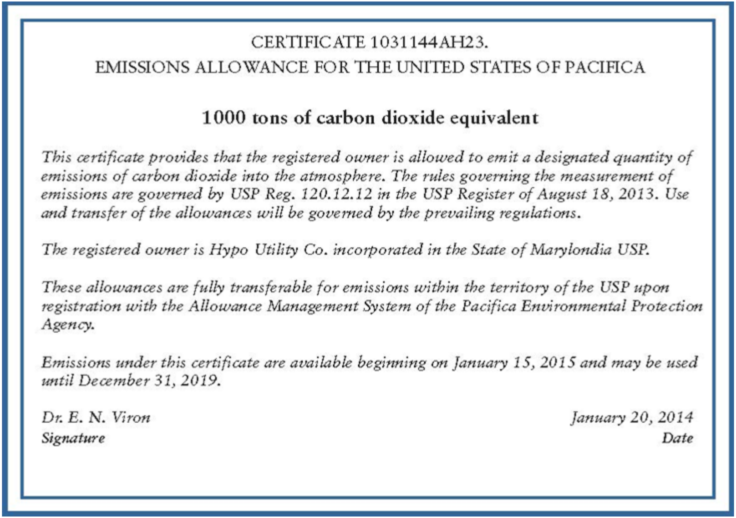
Pricing Programs

- Carbon pricing programs can be implemented through legal regulatory actions in which the government would mandate how much individual entities could emit or what technologies they should use:
  - **Technology-Push Subsidies**: the idea is to subsidize R&D in carbon-reducing energy sources. This is justified by external benefits of energy sources. It can work within other policy instruments.
  - **Direct regulation (standards)**: public authorities determine best methods to reduce GHGs, require use of those methods, and punishes non-compliers. This type of regulation is very costly.
- Carbon pricing programs can be achieved through **incentive-based strategies** or market-based instruments:
  - **Cap and Trade** (US Clean Air Act, 1970's).
  - **Carbon Tax** (Sweden).
- More than one approach is likely necessary. Some economists recommend a **hybrid system** that may offer a third path to deal with climate change and other global threats.

Cap and Trade scheme

- Public authorities set a limit on aggregate emissions during some period and would require regulated entities to hold rights, or allowances, to the emissions permitted under that cap.
  - Determine the desired reduction in CO_2 emissions (20%, 30%?).
  - Identify all major sources of CO_2 (e.g., power plants).
  - Issue each source a permit for each unit of allowed CO_2 emissions.
  - Monitor CO_2 emissions from each identified source.
- The system then allows market forces to set a price on emissions, either directly through government auctioning of allowances and/or through trades of allowances in organized or informal markets:
  - If an emitter generates more CO_2 than allowed, then it must purchase permits (to avoid fines), otherwise it may sell permits.
- Expected savings by adopting such policy instrument:
  - Reduce compliance costs by 50% across the economy if implemented only in industrialized countries.
  - Reduce costs by 75% if also implemented in developing countries.
  - Unregulated CO_2 emitters may voluntarily join such programs.

Cap and Trade scheme



CERTIFICATE 1031144AH23.
EMISSIONS ALLOWANCE FOR THE UNITED STATES OF PACIFICA

1000 tons of carbon dioxide equivalent

This certificate provides that the registered owner is allowed to emit a designated quantity of emissions of carbon dioxide into the atmosphere. The rules governing the measurement of emissions are governed by USP Reg. 120.12.12 in the USP Register of August 18, 2013. Use and transfer of the allowances will be governed by the prevailing regulations.

The registered owner is Hypo Utility Co. incorporated in the State of Marylondia USP.

These allowances are fully transferable for emissions within the territory of the USP upon registration with the Allowance Management System of the Pacifica Environmental Protection Agency.

Emissions under this certificate are available beginning on January 15, 2015 and may be used until December 31, 2019.

Dr. E. N. Viron — *January 20, 2014*
Signature — *Date*

Figure 19: Whimsical certificate for emissions allowance for the U.S. of Pacifica.

Carbon Tax

- A carbon tax such as fossil-fuel taxes directly sets a price on each ton of CO_2 emitted, which then determines the level of emissions. For instance, the tax reflects the carbon content of the fuel.
- Carbon tax gives all entities an appropriate incentive to cut back on their emissions whenever doing so would cost less than paying the tax. The reduced quality of pollution depends on the chosen level of the tax:
  - if the tax level is too low, economic agents are likely to opt for paying the tax and continuing to pollute, over and above what is socially optimal;
  - too high, the costs will rise higher than necessary to reduce emissions, impacting economic conditions, e.g. profits, jobs and consumers.
- Carbon tax also encourages abatement, and gives incentives to innovate. Further, it is easy to administer as the bulk of fossil fuels are sold on international commodities markets.
- Same level of expected economic savings as Cap and Trade.

Cap and Trade or Carbon Tax

- Designed well, carbon taxes and CAT with auctioned allowances have exactly the same outcomes under certain idealized conditions. They can deliver on the main aim of a robust carbon pricing program, which is to help cut emissions cost-effectively in line with climate goals.
- In addition, both provide dynamic incentives for the adoption and diffusion of cheaper and better pollution control technologies.
- However, in reality, they differ in many ways. In light of climate change and other global related threats, the comparison of taxes and quotas remains an important policy question and is not a debate that is likely to end any time soon!
- For instance, Gollier and Tirole (2015) favor an international CAT agreement to implement whereas Cramton et al. (2015) and Weitzman (2009, 2014) among others prefer instead a global carbon tax to curb emissions.
- Note that the implementation of both instruments at a global level would require complex international institution.

Cap and Trade or Carbon Tax

- Cap and Trade scheme has many advantages:
  - quantities and targets are determined by regulators,
  - less of a financial burden on sources if permits are given for free initially (grandfathering).
- However, all workable forms of CAT did not come even remotely close to accomplishing their central purpose and different questions remain:
  - the level of pollution (target) to be permitted over time,
  - how the initial allocation of permits will be set (political brawling),
  - Cap and Trade systems are vulnerable to uncertainties (macroeconomic conditions and other disturbances),
  - the price volatility associated with Cap and Trade systems may reduce or delay long-term green investments,
  - in less well-governed countries, this instrument is an open invitation to corruption (even in Europe).
- The price of the EU ETS from 2006 to 2012 declined sharply during the financial crisis and at the end of 2012, when the future of global climate-change agreements was in doubt.

Cap and Trade scheme

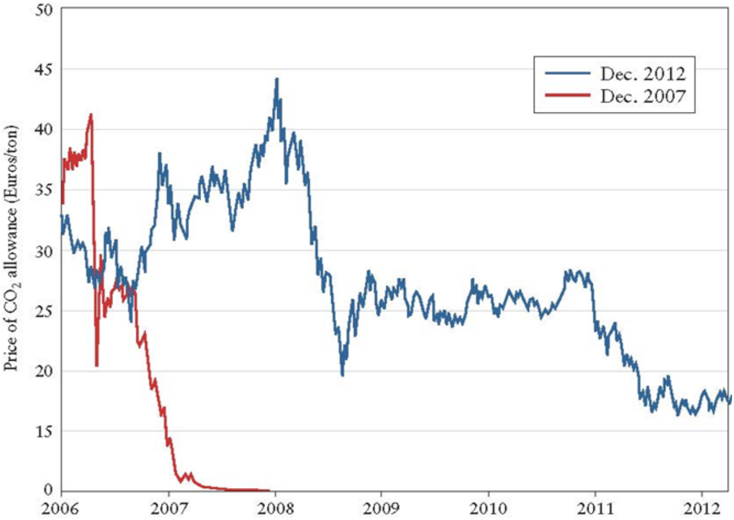
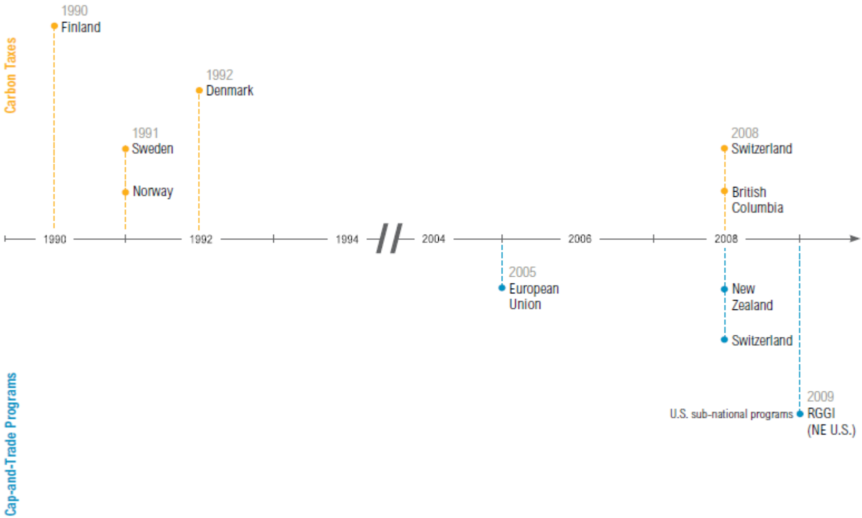


Figure 20: The market price of CO2 under the European Trading Scheme.

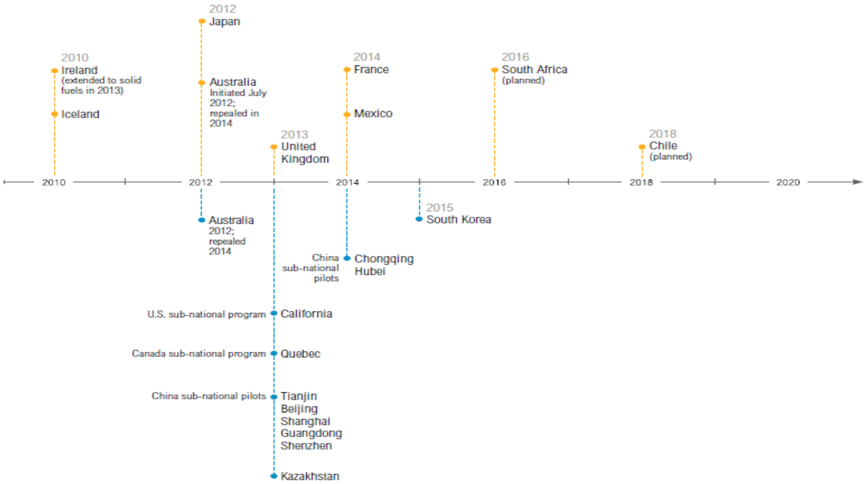
Cap and Trade or Carbon Tax

- Given the uncertainties involved with the issue of climate change, there remains a high potential for a wider use of environmental taxes to slow down global warming.
- On the basis of economic models of climate change, carbon taxes outperform tradable permits, both theoretically and in numerical simulations.
- The efficiency advantage of a tax is likely to be quite large. Specifically, available research suggests that in the near term, the net benefits of a tax could be roughly five times greater than the net benefits of an inflexible cap.
- Further advantages of Carbon Tax:
  - Revenues are earned.
  - Used to reduce income taxes or to finance R&D in clean energy technologies.

Cap and Trade and Carbon Tax Around the World



Cap and Trade and Carbon Tax Around the World



A Simple Pollution Tax Model

Cournot mechanism for pollution control

- Let's consider a simple pollution control model.
- Assumptions:
  - Set of n players emitting an homogeneous pollutant.
  - Each player sells its output q_i at a price p on a competitive market.
  - Production cost is given by $C_i(q_i, e_i)$ with:

$$\frac{\partial C_i}{\partial q_i}(\cdot) > 0; \frac{\partial^2 C_i}{\partial q_i^2}(\cdot) > 0; \quad (1)$$

$$\frac{\partial C_i}{\partial e_i}(\cdot) < 0; \frac{\partial^2 C_i}{\partial e_i^2}(\cdot) > 0 \quad (2)$$

  - Total emissions:

$$\xi = \sum_{i=1}^{n} e_i = \xi_{-i} + e_i \quad (3)$$

The regulator's program

- The social planner has the task to maximize:

$$\max \mathcal{W} = \sum_{i=1}^{n} \left[pq_i - C_i\left(q_i, e_i\right)\right] - \mathcal{D}\left(\xi\right), \text{ with } \frac{\partial \mathcal{D}}{\partial \xi} >, \frac{\partial^2 \mathcal{D}}{\partial \xi^2} > 0 \quad (4)$$

- The first order conditions are:

$$\begin{cases} \frac{\partial \mathcal{W}}{\partial q_i} = p - \frac{\partial C_i}{\partial q_i}\left(\cdot\right) = 0 \\ \frac{\partial \mathcal{W}}{\partial e_i} = -\frac{\partial C_i}{\partial e_i}\left(\cdot\right) - \frac{\partial \mathcal{D}}{\partial \xi}\frac{\partial \xi}{\partial e_i} = 0 \end{cases}, \text{ with } \frac{\partial \xi}{\partial e_i} = 1. \quad (5)$$

- The optimal size of the group:

$$\mathcal{W}\left(n\right) - \mathcal{W}\left(n-1\right) = 0 \text{ and } \mathcal{W}\left(n+1\right) - \mathcal{W}\left(n\right) < 0 \quad (6)$$

- Optimum: $\left(\left\{q_i^*, e_i^*\right\}, n^*\right)$,
$pq_n - C_n\left(q_n, e_n\right) - \left(\mathcal{D}\left(\xi\right) - \mathcal{D}\left(\xi_{-n}\right)\right) = 0$

The optimal policy

- Define the tax as $T_i = \mathcal{D}(\xi) - \mathcal{D}(\xi_{-i})$. The program of each player:

$$\max \pi_i = pq_i - C_i(q_i, e_i) - (\mathcal{D}(\xi) - \mathcal{D}(\xi_{-i})) \tag{7}$$

- The first order condition for each player:

$$\begin{cases} \frac{\partial \pi_i}{\partial q_i} = p - \frac{\partial C_i}{\partial q_i}(q_i^*, e_i^*) = 0 \\ \frac{\partial \pi_i}{\partial e_i} = -\frac{\partial C_i}{\partial e_i}(q_i^*, e_i^*) - \frac{\partial D}{\partial e_i}(\xi_{-i}^* + e_i^*) = 0 \end{cases} \tag{8}$$

- The optimal size of the group:

$$pq_n^* - C_n(q_n^*, e_n^*) - (\mathcal{D}(\xi^*) - \mathcal{D}(\xi_{-n}^*)) = 0 \tag{9}$$

- Results and implications:
  - Such a tax policy allows to obtain the long term socially optimal level of output and pollution.
  - The fiscal burden for the sector is always lower than in the case of a pigouvian approach under perfect information.

The Swedish Carbon Tax

- In 1991, Sweden adopted a tax reform (with the participation of all political parties and stakeholders including business representatives, experts and the public). This reform is based on:
    - Reduced and simplified labor taxes;
    - Value Added Tax on energy;
    - Carbon Tax introduced at a low level combined with approximately 50% cuts in energy tax rates;
    - Certain investment state aid measures.
- The Swedish environmental tax has gradually been increased to reach over 120 euros in 2018, and generates considerable revenues for the general budget per year.
- It has led to the phasing out of fossil fuels used by households and businesses, which means considerable reductions in GHG emissions and an increase in the use of green technologies and energy.

What does the Swedish public think?

- Swedes, like any other people worldwilde, do not love to pay tax, but the Carbon tax is generally accepted.
  - General environmental concerns, both from households and firms;
  - Start at low tax levels, raise gradually;
  - Ensure that feasible options are available (bio fuels, district heating, public transport, housing isolation, etc.);
  - "Polluter Pays Principle" means "Money Talks"!
  - Over 25 years of carbon taxation show good environmental effects, meaning that pollution from fossil fuels is not essential to economic success and growth.
- Further, such environmental tax is easy to administer with low administrative costs for public authorities and businesses $\Rightarrow$ good experience to share at a global level but exact design need to take account of national conditions.

Conclusion

Conclusion

"If we make the bet to be environmentally unsafe and if the future proves us right, then nothing is gained but the bet, and we lose everything if the bet goes bad.

If we made the bet to be environmentally friendly and if we lose the bet, then we do not lose anything, and if we win, then we win everything".

Michel Serres, a French Philosopher.

Conclusion

- William Nordhaus (2013) used the term *Casino* to describe humankind's relationship with the environment. According to Nordhaus, human activities, especially in the developing global economy, should be thought of as **rolling the climate change dice**, the results of which could be surprising and perilous.
- Paul Krugman, in reviewing Nordhaus' *The Climate Casino* book, used the term **Gambling With Civilization** (The New York Review, November 7, 2013).
- During the last few decades, the facts show that we have made an immensely **dangerous bet**. Will we win the bet? The question is simply **nonsensical** because, if the bet goes bad, we don't have another chance to play!
- Climate change is not a **delusion**. An effective and clear public policy is urgently needed to curb GHG emissions, otherwise, if the planet continues to get warmer, humanity will catch a **deadly fever**.

Conclusion

- Environmental and resources economists sounded the **alarm bell** long time ago: the economic system we adopted during the last century is on an **unsustainable path**.
- The question is, are they **one-handed** to deal with environmental externalities? In other words, are they able to provide consensus opinion on environmental issues without saying "on the other hand"?
- Although they have come under increasing criticism from both outside and inside the profession due to the large number of empirical anomalies and failures, the majority of economists give the genuflection to the virtues of **market-based instruments** and make crystal clear the need to place a substantial immediate price on carbon, and gradually raising that price in the near future.
- **Carbon pricing** is a **risk management instrument** and an essential component of any serious solution to global warming. Further, other policy instruments are broadening our repertoire of the antidote for the most of the environment' **ills**, such as **disclosure programs**.

Conclusion

- Thus, if we accept that we inhabit a world with serious and severe environmental problems, then changes that affect those problems have to be undertaken.
- In the last few decades, there have been important advances in understanding the **climate change science**. Some advances have been made in understanding and formalizing climate-economy linkages. However, many questions and gaps remain.
- The point of environmental regulation is to accomplish deep and structural changes in the economic and ecological behavior of individuals, households, firms, and institutions in order to curtail environmentally and ecologically undesirable effects.
- Hence, it is reasonable that policy makers view environmental-related issues through the lens of environmental economists and consider the argument in favor of the use of market-based instrument in environmental regulation.

Conclusion

- The policy options, i.e. carbon tax or a trading system combined with some other programs, differ in their potential to reduce emissions efficiently, to be implemented with relatively low administrative costs, and to create incentives for emissions reductions that are consistent with incentives in other countries.
- However, the environmental effectiveness and the efficiency of economic instruments could be improved further if they are well designed and implemented.
- Since the environment remains high on public and political agenda around the world, it would be reasonable to assume that, sooner or later, public authorities will impose taxes on GHG emissions, which will present a challenge for each industry and each country.
- Disclosure programs may be part of a policy direction to balance "overreaction" with "inexcusable inaction" and to narrow the gap between our current efforts and our enormous needs to achieve some strategic aspects of international climate agreements.

Conclusion

- The idea of an internationally harmonized but nationally retained carbon tax inspires today more and more some intellectual and political respect:
  - wisely combined with **mandatory disclosure programs**, a carbon tax which affects all sectors of the economy, would be the most efficient incentive-based option for reducing the global effects of GHG emissions;
  - well coordinated among major emitting countries, it would help minimize the cost of achieving a global target for climate change by providing **consistent incentives** for reducing emissions around the world.
- However, taxing every ton of CO_2 emitted is not an easy task:
  - it is difficult to compute the social cost of carbon,
  - implementing an international carbon tax is likely to be complicated to administer because it could be perceived as too large an infringement on sovereignty,
  - or there are returns to scope in tax collection (Metcalf and Weisbach, 2009).

Conclusion

- The point is that advances in international climate change negotiation require strong and sustained **political will**. Unfortunately, given the current legal and political situation of the US, governed today by **climate science denial** President, any form of **global cooperation** involving this country is now in doubt.
- D. Trump, President of one of the biggest polluter in the world, continues to reject **mainstream climate science**. His administration engineered with quiet efficiency a dizzying reversal of clean air and water regulations implemented by Barack Obama's administration.
- Further, his decision to withdraw the US from the Paris Agreement, and to dismantle of major environmental policies could bring about a global knock-on effect, pushing the world toward harsh nationalism and reduced international cooperation climate change policies.
- Thus, any proposal to put a substantial and steadily rising price on carbon as a policy instrument is not going anywhere anytime soon!

Conclusion

"Success is the ability to go from failure to failure without loss of enthusiasm".

Winston Churchill.

Conclusion

Climate change: do nothing, do a little, do a lot, or just drink a glass of wine... and you?

Climate change matters...

Figure 21: In a divided world, we all lose. However, many small steps count... they all add up!

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