CENTRE FOR ECONOMIC POLICY RESEARCH

CEPR CLIMATE CHANGE

CEPR/EAERE Webinar on Climate Policy: Carbon Pricing Under Uncertainty

3 April 2023 - 5:00-6:30 PM (Frankfurt/Paris/Amsterdam) – Online

The optimal price of CO_2 remains a highly debated question among economists, in particular given the deep uncertainties surrounding the costs and benefits of decarbonization. In this 12th CEPR/EAERE Webinar: Carbon Pricing Under Uncertainty, on April 3, 2023, from 05:00-06:30 PM (CET), we asked four experts to address the issue of how to take account of these uncertainties in the determination of efficient CO_2 prices (or "value" for cost-benefit analysis) in the present and future.

Frédéric Cherbonnier (Sciences Po Toulouse & Toulouse School of Economics) & Aude Pommeret (France Stratégie & Université Savoie Mont Blanc) gave a presentation on Carbon Pricing and Stress Discounting, Derek Lemoine (University of Arizona, NBER, Climate Change RPN Associate Fellow) on Components of the Social Cost of Carbon under Uncertainty and Billy Pizer (Resources for the Future) on The Social Cost of Greenhouse Gases: Recent RFF Research, Recent EPA Estimates, and the Stochastic Discounting Approach.

The roundtable and Q&A session with the audience was moderated by Christian Gollier (Toulouse School of Economics, EAERE, CEPR & Climate Change RPN Leader).

Key Points of the Webinar

- **Carbon pricing and stress discounting**
    - **Carbon pricing and Cost Benefit Analysis**

Conducting a cost and benefit analysis allows one to compute the social value creation of an investment. Considering a project's impact on CO_2 emissions aims to identify the marginal (negative) impact of 1 ton of CO_2 (tCO_2) emitted at a given time on consumption. It translates into a marginal impact on the utility of a representative consumer, which is the product of the marginal utility of consumption times the marginal damage. Taking the example of a project, whose only consequence is to reduce emissions, the CO_2 impact on the project's Net Present Value (NPV) equals the marginal utility multiplied by the volume of emissions at time t and the marginal damage occurring later, including a discount rate with a pure preference for time, and divided by the marginal utility of consumption today, in order to get a monetary equivalent. When *t* equals 0 and with an emissions reduction of 1 tCO_2, this calculation leads to today's Social Cost of Carbon (SCC). Public administrations determine an official SCC - usually defined as the monetary equivalent, at time *t*, of damages induced by 1 tCO_2 emitted at the same time - and, when *t* does not equal 0, an official Social Discount Rate (SDR) is determined to get the Net Present Value (NPV) of the avoided damage. However, SCC and SDR often do not result in mutually consistent evaluations. An example can be found when looking at the optimal speed of CO_2 emission reduction. In France in 2019, the official SCC had an increasing rate of 10%, while the SDR was about 3%, meaning that the value of avoiding 1 tCO_2 today was 7% lower than the value of avoiding 1 tCO_2 next year. Such values constitute an incentive to procrastinate. The situation in the U.S. shows the opposite result: the SCC growth rate was about 1% in 2022, while the SDR was around 2%, meaning that the present value of CO_2 emissions is decreasing over time, thus encouraging t action. It should also be noted that, even when the two parameters are consistently defined, the CO_2 impact on project NPV is only correct if the volume of CO_2 emission reduction is certain.

Risk adjusted Social Discount Rate

To properly account for benefits which are uncertain, one must focus on the risk adjusted SDR. The classical approach to compute the NPV of a project yielding net uncertain benefits is to compute the discounted sum of the expected benefits. As the project has marginal impacts on consumption, the present value should also be the discounted sum using a pure preference for time of the expectations of the product benefits when discounting, while evaluating using marginal consumption. These two present values shall be equivalent, leading to the SDR.

The risk-free rate is given, under specific assumptions (constant relative aversion, consumption follows a geometric Brownian motion) by the extended Ramsey Rule. A risk premium, following a consumption-based asset pricing model, is then added. It depends on both a systematic risk premium, and on whether the benefits of the project are correlated with aggregated consumption in the economy, which can be defined as the elasticity of the net social benefit of the project to a change in aggregate consumption. A large elasticity means that the project gains value in times of growth and helps to reinforce macroeconomic risk (*e.g.,* transportation projects). On the contrary, a negative elasticity means that the project has an insurance value (*e.g.,* hospital, nuclear wastes deep repository). The project will deliver high benefits in case the economy is not going well, and low benefits in the reverse situation. The elasticity is, however, complex to set. One of the only countries using a discount rate dependent on it is France. In the absence of existing sectorial estimations, it is supposed to be equal to 1. The UK keeps a constant SDR of 3.5% in general, except for with projects related to health, for which it is set at 1,5%.

Stress discounting: basic example without climate risk

To account for the uncertainties of the benefits of the project, Cherbonnier, Gollier & Pommeret

(2023)[1] propose a new method the idea of insurance value. An asset's value is equal to the expectation of its contingent NPV over the multiple states of nature that characterize this asset. For each state of nature, one needs to use the Ramsey rule to discount the flow of net benefits under certainty. This approach gives the exact value if one considers all possibles states of nature. A good approximation can be obtained by reducing the uncertainty to a few discrete numbers of state of nature, considering for instance a "business as usual" and a "stressed" (Barro type catastrophe) scenario. The calibration of parameters is left to the evaluator. A benchmarking purpose consistent with the main characteristics of the yield curve is proposed in the paper. It is provided by the complex discounting method corresponding to the project analyst's view of the world, Martin's cumulants method, which allows one to also consider the possibility of catastrophe in the economy.

Comparing present values obtained using different elasticity values, we observe that the insurance value does not show up with the UK method, for a real project with a negative elasticity, hence leading to a very low present value. On the contrary, the French methodology puts weight on the different values of the elasticity leading to an overestimated present value of projects that have an insurance value.

- **Stress-discounting with climate risk**

When the climate dimension is explicit in the considered project, the first step of the methodology consists in choosing a description of the economy and the climate. The DICE model is here slightly modified and enriched to consider the two main sources of uncertainty, which are climate sensitivity - corresponding to how much the temperature of the planet increases if the concentration of CO_2 in the atmosphere is multiplied by two, - and growth. A low sensitivity corresponds to 2.62°C, and a high one to 5,7 °C, while good and bad economic scenarios correspond to increases and drops in GDP. In the second step, 4 different scenarios are combined: no negative shocks, climate shock, economic shock and both shocks. The third step consists of checking the method's efficiency.

Considering the example of a mitigation project preventing the emissions of 1 tCO_2/year for 50 years, the stress discounting method gives a very close result to the Monte Carlo simulations used as a benchmark. In terms of contributions of each scenario, about 75% of the project's value comes from catastrophic scenarios, while the biggest contribution comes from the economic shock. The contribution from the very low probability scenario is very significant.

In terms of benchmarking, comparing the present carbon value given by the method versus given by the Montecarlo Simulation, stress-discounting gives a relatively good approximation of the estimation based on Montecarlo simulations with both elasticity equalling 1 and 0. In comparison, using a no-risk adjusted discounted carbon value, when the elasticity is equal to 1, the carbon value is strongly overestimated on the long horizon.

[1] Cherbonnier Fréderic, Gollier Christian, Pommeret Aude. (2023). Stress discounting. *Memeo*.

Components of the Social Cost of Carbon under Uncertainty

Multiple layers of fundamental uncertainties are related to climate changes questions, including about future emissions, warming evolution and its drivers, generated damages, and their impact on the economy, as well as about future technological consumption. Uncertainties are thus critical to climate pricing. Yet, conventional Integrated Assessment Models (IAM) used in the past 30 years struggle to incorporate them. A Monte Carlo analysis of these models, conducted by running different parameter possibilities, can inform us about the spread of outcomes, but does not indicate how policy choices should account for uncertainty. A literature on recursive or dynamic programming versions of IAMs, which rapidly grew in the past 13 years, accounts on the other hand for optimal active learning. It is, however, computationally demanding models and potential black boxes for applied policy analysis.

Channels of uncertainties affecting the SCC

Following Lemoine (2021)[2], uncertainty affects the SCC through several channels: a precautionary savings channel and an insurance channel, which can be broken into a damage scaling one and a growth insurance one. The sign and the degree of **the precautionary channel** depends on whether agents are prudent. Assuming prudent agents, uncertainty about future consumption increases the willingness to save today, moving consumption from the safer to the riskier period. In a climate perspective, this would mean reducing emissions in a form of savings for the future. Climate and economic uncertainties make future consumption (or its equivalent) uncertain and increases desired emission reductions, as well as the SCC. Under a discount rate interpretation, they reduce the risk-free discount rate to be applied to any future payoff, including climate change investments and emission reduction, as for instance the value of new technology that might appear.
The insurance channel is harder to sign and has ambiguous effects on the SCC. The value of emission reductions indeed increases if and only if reducing emissions hedges future uncertainties. The question is thus to determine if today's emission reductions will benefit the future more in cases in which the future turns out to be relatively poor – corresponding to a good hedge and an increasing SCC – or relatively rich – corresponding to a bad hedge and a decreasing SCC. The discount rate is thus adjusted for the risk specifically for climate investment. Risk-adjusted discount rates for climate damages are below the risk-free rate if and only if emission reductions give a good hedge.

There are thus conflicting elements at stake in the insurance channel: on the one hand, the **damage scaling channel** reduces the SCC. While warming reduces consumption multiplicatively, the losses are greater when you are already rich, making mechanical emission reductions a bad hedge. On the other hand, the **growth insurance channel** increases the SCC. Additional emission reductions increase the growth rate of consumption, and not just the level of consumption loss, by more when relatively poor or

[2] Lemoine Derek. (2021). The Climate Risk Premium: How Uncertainty Affects the Social Cost of Carbon. *JAERE,* 8/1, 27-57.

rich. In this case, under conventional preferences and specifications, emissions reductions are a good hedge. The insurance channel thus cannot be signed. However, the precautionary savings channel, which works to raise the SCC, dominates the negative damage scaling channel under conventional preferences. With the growth insurance channel being always positive, it leads to a net effect increasing the SCC. It is thus critical that calculations include both precautionary and insurance adjustments.

Approaches limitations and recommendations

A calculation examining the correlation between climate damages and consumption, as a way of signalling the effect of uncertainty, can be considered incorrect as the marginal effect of emissions on damages is needed as well as the precautionary savings channels. Similarly, accounting for the effect of uncertainty by calculating certainty-equivalent losses from emissions and aggregating using standard (Ramsey) discount rates is questionable. The precautionary channel reduces the discount rate should use to aggregate certainty equivalents, which capture the insurance effect, but not how the equivalents are affects by uncertainty as well. This adjustment depends on uncertain consumption outcomes, so should be determined within the same model. More guidelines for evaluators to measure these certainty-equivalent benefits would be useful.

On the other hand, a possible calculation consists in calculating in each scenario climate damages and using that scenario's growth rate of consumption to determine the risk-free discount rate via Ramsey's rule. Aggregations over time within and across each scenario allow one to determine the expected value of reducing emissions. It is critical that the discount rate vary by scenario in order not to miss the precautionary effect. Another approach is to, in each scenario, calculate the marginal utility loss from climate change and the discount at a pure rate of time preference to then aggregate over time and with different scenarios. This method allows one to make the utility function explicit.

Damage uncertainty is likely to be the most important element to consider because of its deeply uncertain nature and as it constitutes the direct marginal loss from emissions. In terms of recommendations, there is thus a need to converge on distribution to use for damages that accounts for full uncertainty and not just sampling (regression) uncertainty. Finally, it would also be recommended to define SCC calculations' best practices. Their definition raises the following questions: which uncertainties are critical to include, and which are optional? What requirements must distributions meet? Which numerical methods are acceptable? How do we report the components of the effects of uncertainty?

The Social Cost of Greenhouse Gases (GHGs): Recent RFF Research, Recent EPA Estimates, and the Stochastic Discounting Approach

A modular framework for calculating the SCC

The calculation of SCC can be thought of as four modules: first, the **socio-economic module** considers projections of emissions, income, and population. Emissions projections are key to driving the second module on **climate,** which include figuring out temperature change, sea level rise and ocean acidification upon which a pulse of CO_2 is layered to figure the marginal damage from 1t CO_2 emission. The third module is the **damage** one. It requires the level of economic activity and population to draw a baseline distribution of outcome, as well as a scenario including a pulse of CO_2 to statistically represent the uncertainty (including climate, damages and socioeconomic uncertainties in emissions and economic activity). The last module is **discounting**, such as discounting the pulsed and un-pulsed damages to identify the discounted marginal damage. In each of these uncertain states, the level of economic growth is used to determine the discount rate though the Ramsey formula.

- **Evidence supporting a higher SCC**

Considering the Socio-Economic module, **Resources for the Future's (RFF)**'s realised projections on population[3] use stochastic demographic models, while global CO_2 emission scenarios were derived from expert elicitation to reflect policy and historical patterns, as well as specialists' thoughts on future scenarios. The economic growth scenario was determined through a combination of country-level econometric growth projections up to the year 2300 and was constrained by using expert uncertainty from RFF Economic Growth Survey. As a result, the range of uncertainty about future economic growth appears as much wider than previous projections and statistical models suggested it. In particular, very high (>4%) and low (<0%) long-run growth are viewed as highly unlikely, but possible. In the climate module, the response of the climate system is represented by the FaIR climate model, which captures both the equilibrium climate sensitivity and the speed to get to the equilibrium.

Regarding damage functions, the proposed methodology of the **U.S. Environmental Protection Agency (EPA)[4],** equally weighs 3 sets of functions from the Climate Impact Lab's DSCIM Sectoral Damages, the RFF/UC-Berkeley GIVE sectoral damages and the Howard & Sterner Meta Analysis. The first two are based on specific econometric models of estimated temperature damage relationships. The damage functions, which each come with uncertainty, highlight damage scenarios that do not display the kind of dramatic damages on the economy one could expect, with cases up to 20% loss of GDP.

The **stochastic discounting approach**'s idea is to have a discount rate that varies by state of nature based on the growth rate in a particular state of nature. Asset pricing theory states that the appropriate

[3] Rennert Kevin, Errickson Frank, Prest Brian C., Rennels Lisa, Newell Richard G, Pizer William, Kingdon Cora, Wingenroth Jordan, Cooke Roger, Parthum Bryan, Smith David, Cromar Kevin, Diaz Delavane, C. Moore Frances, K. Müller Ulrich, Plevin Richard J., Raftery Adrian E., Ševčíková Hana, Sheets Hannah, Stock James H., Tan Tammy, Watson Mark, Wong Tony E., Anthoff David. (2022). Comprehensive evidence implies a higher social cost of CO_2. *Nature,* 610, 687-692.

[4] U.S. Environmental Protection Agency (September 2022). Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review": EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances.

discount rate varies with uncertain consumption growth. Accordingly, the discount rate in the period *t*, for a given growth rate, depends on the rate of pure time preference and the elasticity of the marginal utility of consumption varying across the compounded growth rate to time *t* in each of the uncertain states. Simulating all these parameters simultaneously allows one to estimate damages in each scenario and an appropriate discount rate in that same scenario to capture all the precautionary futures that need to be included in the SCC. The consumption in the future state is going to include both the stochastic growth up to that state, as well as the actual baseline climate damage in that state. Values need to be calibrated for the discounted process at the rate of pure time preference and with an elasticity of the marginal utility of consumption. To do so, Newell, Pizer and Prest (2022 JAERE)[5] took the risk-free rate that would come out of a stochastic discounting formula and chose the values matching the risk-free term structure of Bauer & Rudebusch's work (2021)[6] for different calibrated, near-term discount rates. Depending on different rates, different calibrated values are found. A 2% discount rate, which is the central case the U.S. government is currently moving towards, leads to a rate of pure time preference of 0.2% and an elasticity of the marginal utility of consumption of 1.24%. The EPA report presents different near-term discount rate scenarios associated with different climate functions (DSIM, GIVE and meta-analysis). At a 2% discount rate, the different SCCs coming out of these different models are between $190 and $200 per tCO2. Going forward in time, the SCC gets higher at a half percent, thus rising less than the discount rate. Considering these results, $200 tCO2 resolved the emission reduction question and argues for net zero emissions. The remaining question is how quickly it is possible to get there.

[5] Newell Richard G., Pizer William A., Prest Brian C. (2022). A Discounting Rule for the Social Cost of Carbon. *JAERE,* 9/5, 1017-1046.

[6] Bauer Michael D., Rudebusch Glenn D. (2021). The Rising Cost of Climate Change: Evidence from the Bond Market. *The Review of Economics and Statistics*, 1–45.