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Delving into Climate Change Economics

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By quantifying climate change's effects and assessing potential mitigation and adaptation techniques, economists contribute valuable perspectives to political, ecological and social conversations about the planet's future. This Economic Brief summarizes presentations from the Richmond Fed's recent conference on the economics of climate change.

Climate change presents a myriad of economic questions: What innovations might be coming in the energy sector? To what extent will natural disasters and rising sea levels affect local and regional economies? And what are the costs and benefits of carbon taxes and other mitigation and adaptation policies? In November, the Federal Reserve Bank of Richmond hosted a virtual conference on the economics of climate change to discuss these and other topics. Presenters addressed the implications of climate change for infrastructure planning and local economies. They also reviewed ways to measure the social discount rate and the social cost of carbon dioxide emissions, two components of the present and future costs of climate change. Finally, presenters examined adaptation and mitigation policies, including carbon taxes and financial adaptation to climate default risk.

Climate Defaults and Financial Adaptation

Increasing the probability of sovereign debt crises is a significant potential effect of natural disasters, especially in less financially developed countries. Unfortunately, many of those countries are also the most vulnerable to climate change.[1] Toan Phan and Felipe Schwartzman of the Richmond Fed presented a theoretical and quantitative framework that analyzes a country's "climate default" risk — which captures the relationship between its risk of facing climate-related natural disasters and its risk of facing sovereign default — and potential tools for financial adaptation.

In their model — calibrated with data from strong cyclones — a natural disaster delivers a shock to the financial system that causes investment to decrease and default risk to increase. This result further decreases investment, creating a vicious cycle. Also, the default risk increases with the frequency of, and damage caused by, the disasters. Thus, to the extent that climate change intensifies and increases the frequency of natural disasters, it raises the probability of sovereign default in developing economies with high climate change vulnerability.

In light of this prognosis, Phan and Schwartzman examined two instruments of financial adaptation: CAT bonds, also known as act-of-God or catastrophe bonds, and disaster insurance. CAT bonds pay bondholders unless a catastrophe occurs, in which case the bonds' issuers are no longer obligated to repay the principal or to pay interest; disaster insurance allows countries to account for disaster risk, even if they default on their debt. Each instrument individually produces a relatively small welfare gain, but the welfare gain from the combination of CAT bonds and disaster insurance is almost 30 percent of the loss that results from an increase in natural disasters. While disaster insurance eases the recovery process, CAT bonds reduce default risk, allowing vulnerable economies to borrow more in the aftermath of a disaster. Phan and Schwartzman's research produces not only a method for analyzing climate default risk and the effects of financial adaptation measures, but also a framework for combining the two analyses.

In Harm's Way? Infrastructure Investments and the Persistence of Coastal Cities

Coastal countries are particularly vulnerable to rising sea levels, yet infrastructure investment in coastal regions shows no sign of abating. In her presentation, Clare Balboni of the Massachusetts Institute of Technology focused on Vietnam — one of the five countries most likely to be affected by climate change — and examined the optimal allocation of infrastructure investments in the country given the prospect of rising sea levels.

Using geographic, economic, transportation and demographic data spanning 2000–10 in more than 500 districts of Vietnam, Balboni developed a dynamic, multiregion spatial equilibrium model to estimate the welfare effects of coastal infrastructure investments under various scenarios of rising sea levels. Her model accounts for roadbuilding's generally positive effects on growth; locational differences in amenities, productivity and trade links; imperfect mobility of goods and workers; and roads' durability. Road investments and rising sea levels have opposite welfare effects: Roadbuilding increases market access, reduces prices and increases wages, while rising sea levels reduce land supply.

Balboni compared the welfare effects of status quo infrastructure investments, which tend to be concentrated in coastal regions, to other potential infrastructure allocations and rising sea level scenarios. She examined four counterfactual road networks: one connecting major administrative centers, another maximizing market potential regardless of the location of coastal zones, a third maximizing market potential outside the five-meter coastal zone (coastal areas with elevations within five meters of sea level) and a fourth maximizing market potential outside the one-meter coastal zone. She also included two sea level scenarios: a one-meter rise over the next century, consistent with the Intergovernmental Panel on Climate Change's Fifth Assessment Report, and no sea level rise.[2] She found that the road network that avoided the one-meter coastal zone and maximized market potential (the network that addressed rising sea levels and connected densely populated regions) had the highest aggregate welfare gain. Even in the absence of rising sea levels, however, she concluded that there are gains to be made from reallocating infrastructure investments away from the coast. Adding rising sea levels to the analysis only strengthens this conclusion.

The Local Economic Impact of Natural Disasters

Turning to impacts on the United States, Brigitte Roth Tran of the Board of Governors of the Federal Reserve System presented work with Daniel J. Wilson of the Federal Reserve Bank of San Francisco on the local economic impact of natural disasters. The prevalence and cost of natural disasters have increased in recent decades, and climate change likely will perpetuate this trend, but the economic impact of disasters is unclear. Some evidence indicates that no economic recovery occurs after a natural disaster or that regions simply recover to trend, while other evidence points to a "creative destruction" effect — a significantly higher level of per-capita income following the disaster. Between these two scenarios is a "build-back-better" pathway that exceeds the preexisting economic trend but does not rise to the level of creative destruction. Tran and Wilson's research supports this build-back-better hypothesis and highlights evidence of differences in outcomes between counties and disaster types.

Tran and Wilson's panel dataset spans 1980–2017 and includes county-level data on damages, per-capita income, employment, average weekly wages, house prices, government aid and U.S. population. Using a panel version of the local projections method, which regresses future outcomes on present variables,[3] to estimate natural disasters' effects on economic outcomes, they found that personal income per capita tended to increase after natural disasters, as predicted by the build-back-better hypothesis.[4] This increase was driven by an increase in employment in the short run and by higher average wages in the long run. Tran also explained that it could be a result of the rebuilding process: If local capital stock improved during post-disaster rebuilding, productivity and per-capita income would increase.

However, not all disasters and counties are the same. Tran and Wilson accounted for this heterogeneity by separating outcomes based on disaster severity and type and by each county's predisaster income and historical experience with disasters. They also estimated spatial spillover effects to determine if economic recovery in one county came at the expense of neighboring counties. In fact, they did find differences when disasters and counties were separated by these criteria. More severe disasters had larger positive effects on personal income but also trended toward different equilibria due to declines in population and home prices in the long run. Moreover, the build-back-better outcome did not follow for all disaster types or county profiles: Income per capita did not increase after floods, severe storms and extreme winter weather, nor did it increase in counties that were inexperienced with disasters. This heterogeneity in economic outcomes emphasizes the need to use caution when extrapolating results.

The Rising Cost of Climate Change: Evidence from the Bond Market

Researchers also are attempting to measure the cost of climate change. Calculating the social cost of CO_2 emissions requires a comparison of present benefits and future costs. The social discount rate (SDR), a measurement of the present value of future damages, captures this comparison. SDRs can either be prescriptive (based on normative judgments of what is morally acceptable)[5] or descriptive (based on real returns from financial markets).[6] Since descriptive SDRs tend to be higher than prescriptive ones, estimates of the social costs of carbon emissions that use descriptive SDRs tend to be lower than those that use prescriptive SDRs. Glenn D. Rudebusch of the Federal Reserve Bank of San Francisco, presenting a joint paper with Michael D. Bauer of the Universität Hamburg, assessed various SDRs using evidence from the bond market. Their work demonstrates that taking the recent secular decline in the steady-state interest rate into account lowers descriptive SDRs closer to prescriptive levels.

The steady-state interest rate has been declining for decades as a result of changes in population, productivity and savings patterns, among other factors. Bauer and Rudebusch showed that this steady-state interest rate anchors the term structure, also known as the yield curve, of discount rates. They focused on risk-free discount rates, which are used for payoffs that are certain or certainty-equivalent, in their analysis. Using a time-series model and data on inflation-adjusted Treasury bond yields, they estimated that the steady-state interest rate fell by between one and two percentage points from 1990 to 2019 for all bond maturities. Because the term structure of SDRs is anchored to the steady-state interest rate, the downward shift in the interest rate implies that the term structure of risk-free SDRs has shifted downward.

This finding has dramatic implications for the social cost of carbon, boosting it by at least 96 percent. Although Bauer and Rudebusch use a 1994 integrated assessment model (IAM) to calculate the social cost of carbon, their findings are robust to other, more recent damage functions. Their results highlight both the importance of macrofinance for climate policy and the possibility of aligning descriptive and prescriptive SDRs.

Estimating a Social Cost of Carbon for Global Energy Consumption

Another approach to measuring the cost of climate change focuses on the negative externalities of carbon dioxide emissions. In other words, CO_2 emissions are costly to "external" groups, people who don't benefit from the economic activity that emits the carbon. According to economist Arthur Pigou, internalizing such externalities requires imposing a tax that lifts the private cost of carbon to match the social cost. However, imposing this tax at the correct level requires policymakers to determine the social cost of carbon. Solomon Hsiang of the University of California at Berkeley and his colleagues at the Climate Impact Lab have taken a step in that direction. Using global data from the International Energy Agency spanning the years 1971–2012 for 146 countries, they have quantified part of the social cost of CO_2 emissions in what Hsiang presented as "the first estimate of the global impact of climate change on total end-use energy consumption."

Since energy consumption varies with income as well as with temperature, accounting for economic development is one of the model's key features. In fact, at the national level, income matters more than temperature for electricity consumption. Building on this relationship and on earlier versions of IAMs, Hsiang and his fellow researchers analyzed 25,000 regions to project the energy impacts of climate change. As one might expect, they found that when temperatures increased, warmer areas used more energy. However, the increase in total electricity consumption varied across regions and energy sources. For example, they projected that total electricity consumption would increase by 2 percent in the United States but 113 percent in India as global temperatures increased. They also predicted that global consumption would decrease for fuels used for purposes other than generating electricity or providing transportation. Again, the results were unequally distributed across countries: They predicted that consumption would fall by 7 percent in the United States and 42 percent in India.

Once they modeled changes in energy consumption as a result of warming, the researchers were able to estimate an empirical damage function for the energy sector that accounted for uncertainty and price growth. They concluded that the partial energy consumption-only social cost of carbon (SCC) — that is, the social cost for the energy sector, not for society as a whole — is negative $1 per ton of carbon dioxide. The negative sign indicates a social benefit of carbon (in terms of energy consumption only) rather than a social cost: In other words, temperature increases result in one dollar of energy savings per ton of carbon dioxide emissions. The nonlinear relationship between income and energy consumption accounts for this outcome: When global temperatures increase, emerging (and warming) countries consume more electricity, but wealthy, cooler countries save even more on other uses of fuel, counteracting the increase in electricity consumption.

Climate Change, Directed Innovation and Energy Transition: The Long-Run Consequences of the Shale Gas Revolution

Since the late 2000s, U.S. natural gas production has skyrocketed, a phenomenon known as the "shale revolution." Since natural gas burns cleaner than coal, the increase in natural gas production has coincided with a decline in carbon dioxide emissions from U.S. electricity generation. However, it also has coincided with a decrease in technological innovation in clean energy production. Lint Barrage of the University of California at Santa Barbara presented on work with Daron Acemoglu of the Massachusetts Institute of Technology, Philippe Aghion of the Collège de France and London School of Economics and David Hémous of the University of Zurich to analyze this decline in clean energy innovation and quantify the shale boom's long-term impact on innovation and the U.S. economy.

These economists developed a model in which production of coal, natural gas and green energy depends on energy inputs, such as power plants and resource extraction. After calibrating the model using parameters from the literature and data on the costs and outputs of U.S. electricity generators, they found that carbon dioxide emissions decreased after the shale boom in the short run. In the long run, however, the model predicts an increase in emissions as a result of the boom's negative effect on clean energy innovation. This is because more technologically advanced sectors tend to attract more scientists, increasing those sectors' profits and advancing their technology still further. Ultimately, this tendency creates a positive feedback cycle in which better technology drives more innovation. Thus, when a one-time increase in natural gas extraction technology — such as the shale revolution — boosts technological advancement in natural gas extraction relative to clean energy, the resulting boom reduces long-run innovation in clean energy technologies.

The degree to which the boom reduces innovation depends on the initial level of clean energy generation technology and the growth rate of the productivity of fossil fuel extraction. A higher initial level of clean energy technology and a lack of growth in fossil fuel extraction technology make an eventual transition to clean energy more likely. Even in this best-case scenario, however, the shale boom still delays the transition. In light of this finding, Barrage and her fellow researchers called for a two-pronged policy approach: a carbon tax to internalize the social cost of carbon dioxide emissions and a subsidy to encourage innovation in clean energy.

The Macroeconomic Impact of Europe's Carbon Taxes

Many other economists also have advocated carbon taxes, but economic theory suggests that carbon taxes will result in a parallel shift downward in GDP with no long-run effect on employment. To test that theory, presenter James H. Stock of Harvard University and Gilbert E. Metcalf of Tufts University examined the macroeconomic impact of European carbon taxes. Their dataset consisted of GDP, population, employment, fuel prices, fuel taxes and emissions from 1985–2018 for the 31 European nations in the Emissions Trading System, in addition to carbon prices for the 15 nations within that group that had adopted carbon taxes at varying levels and in different years.

Using two different econometric approaches — local projections and panel vector autoregression — Stock and Metcalf estimated the cumulative dynamic causal effect of a change in the carbon tax on GDP, employment and emissions. They found that a $40 increase in the carbon tax had neither a long-run nor a short-run effect on GDP, a finding that was robust in both approaches. They also tested whether this finding was a result of revenue recycling (returning revenue from carbon taxes to taxpayers). However, even when they separated revenue-recycling and nonrevenue-recycling countries, they found no statistically significant effect for this practice. While carbon taxes did not have statistically significant effects on GDP or employment in the short or long run, they did reduce emissions by 4 percent to 6 percent in the sectors covered by the tax.

Suboptimal Climate Policy

Formulating optimal climate policy is difficult, but the tools of economics not only allow economists to estimate social discount rates and the social cost of carbon, but also provide opportunities to compare markets under different taxation and regulatory frameworks. In this vein of research, Per Krusell of Stockholm University and his colleagues — John Hassler of Stockholm University, Conny Olovsson of Sveriges Riksbank and Michael Reiter of the Institute for Advanced Studies in Vienna and New York University-Abu Dhabi — compared the costs and benefits of suboptimal climate policy. Instead of trying to determine the right policy, they focused on the consequences of obviously imperfect policies, namely setting carbon taxes much too high or much too low, imposing regional rather than global carbon taxes and doling out green energy subsidies instead of levying carbon taxes. The researchers analyzed these policies using an IAM that differentiates between oil-producing and oil-consuming regions. They calibrated the model with data on energy use and production, total factor productivity and initial capital stock in those regions.

First, they examined the suboptimal policy of enacting carbon taxes that are too high or too low. The results showed that the cost of too-low taxes surpassed the cost of too-high taxes in terms of consumption loss. Next, they compared global and regional taxes, revealing that regional taxation that exempts developing areas results in overall welfare loss. Finally, they showed that subsidies of green energy initiatives are less effective than taxes at combating climate change. Analyzing suboptimal policies in this way sheds light on both the potential contributions of IAMs and the ways that economic tools can inform policy analysis.

Conclusion

As climate change threatens to change individual and national ways of life, it is important for policymakers and researchers to understand its costs and consequences. By quantifying climate change's effects and assessing potential mitigation and adaptation techniques, economists contribute valuable perspectives to the larger political, ecological and social conversations about the planet's future.

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[1] *See Kartik Athreya, "The Risks and Inequities of Climate Change," Opening remarks to the Federal Reserve Bank of Richmond Conference on Climate Change Economics, Nov. 19, 2020.*

[2] *Intergovernmental Panel on Climate Change, "Fifth Assessment Report," 2013.*

[3] *Òscar Jordà, "Estimation and Inference of Impulse Responses by Local Projections," American Economic Review, March 2005, vol. 95, no. 1, pp. 161–182.*

[4] *The researchers note that this finding is not a result of population loss. In other words, it is not due to a shrinking denominator in the per-capita income calculation.*

[5] *For an example of the logic behind prescriptive SDRs, see Nicholas Stern, The Economics of Climate Change: The Stern Review, Cambridge, UK: Cambridge University Press, 2007.*

[6] *William Nordhaus, who won the Nobel Memorial Prize in Economic Sciences in 2018 "for integrating climate change into long-run macroeconomic analysis," favors this approach.*

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