How Economics Can Tackle the 'Wicked Problem' of Climate Change

By Joseph Stiglitz, Scott Barrett, and Noah Kaufman

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ABSTRACT

Addressing the harmful effects of climate change requires an understanding of economic tradeoffs, the politics of policymaking, and the strategy of diplomacy. While early prescriptions for climate solutions focused on idealistic "optimal" policies and all-encompassing global treaties, a more nuanced and realistic vision for climate progress has emerged. As befits a "wicked problem," a wide range of policies and insights from across scientific disciplines are needed to promote collective action, reduce emissions, and help the world achieve a more sustainable future.

INTRODUCTION

Climate change is a "wicked problem" that cannot be easily or quickly solved but rather must be addressed by a variety of interventions over an extended period of time. Earth scientists study the processes that drive and are affected by climate change. Engineers pursue technical solutions. But addressing climate change requires much more. It requires an understanding of economic tradeoffs, the politics of policymaking, and the strategies of interstate diplomacy.

This report focuses on how the field of economics can contribute to climate solutions, informed by the insights of other disciplines. It addresses three central questions:

First, *what should be the goal of climate change policy?* Obviously, we should act, but how? Should our targets focus on temperature increases (e.g. capping it at two degrees Celsius) and emissions (e.g. net-zero greenhouse gas emissions), as in the 2015 Paris Climate Agreement? Should we attempt to "optimize" our response by maximizing the net benefits of alternative actions? Global in scope, the answers to these normative questions depend on our understanding of the science of climate change and the panoply of changes that an increase in atmospheric greenhouse gasses might induce, including the possibility of non-linear relationships between accumulating greenhouse gasses and incurring damage to society. They depend on the technological options for limiting climate change, some of which have yet to be fully realized. They depend on the degree to which we choose to prioritize the well-being of people who live in different places, under different circumstances, and at different points in time. In our second section, we demonstrate how previous attempts to estimate "optimal" climate pathways have systematically underestimated the benefits and overestimated the costs of emissions reductions, while a risk-management approach can provide policymakers with the information needed to minimize intolerable climate risks.

Second, *how should our goals be achieved?* Carbon prices are enormously valuable, but are insufficient by themselves for addressing the problem. A decades-long transformation to a net-zero emissions economy requires a broad portfolio of policies to overcome a wide range of barriers to emissions reductions. For example, the mass rollout of electric vehicles (EVs) depends on the availability of charging stations, while the supply of charging stations depends on expected demand for EVs — the classic "chicken and egg" problem that will only be solved with a multifaceted and well-coordinated policy strategy.

In our third section, we describe how the labeling of carbon prices as "optimal" or "first-best" climate policy distorts policy discussions and policy evaluations. Economists can help policymakers design and implement rapid, cost-effective, and equitable decarbonization strategies, but only if they confront the complex set of barriers facing different emissions sources and recognize carbon prices as just one of many important policy tools.

Finally, *how can we achieve international cooperation that increases the chances of meeting the goals already agreed upon?* Unilateral actions on climate change by individual states will not accomplish much. Cooperation is essential. The most recent major climate treaty, the Paris Agreement, sets the collective goal of keeping global mean temperature well below two degrees Celsius relative to the pre-industrial level and asks parties to pledge "nationally determined contributions" towards meeting this goal. Unfortunately, these pledges are purely voluntary and, even if the pledges made thus far are met, they will fall short of meeting the collective goal. As befits a “wicked problem,” the way to address climate change may not be exclusively through a single treaty, but through a variety of targeted interventions that find leverage for achieving collective action. One critical source of leverage is international trade. Indeed, outside of the framework of the Paris Agreement, countries have successfully leveraged trade to phase down the emissions of hydrofluorocarbons, a powerful greenhouse gas.

It has been over 30 years since the world agreed to address the dangerous risks of climate change. Perhaps not surprisingly, early prescriptions for climate solutions focused on idealistic “optimal” policies and all-encompassing global treaties. In recent years, a more nuanced and realistic vision for climate progress has emerged that combines the answers to the three questions posed above and involves a variety of mutually reinforcing domestic policies and international agreements. This report describes how the tools of economics, when combined with insights from other disciplines, can help policymakers address tradeoffs, implement climate policies that are both equitable and cost-effective, and help the world achieve a more sustainable future.

WHAT SHOULD BE THE GOAL OF CLIMATE CHANGE POLICY?

Climate change is here. We’re feeling it, whether in the smoke of forest fires wafting down from Canada in America’s East Coast, or threatening homes in the West. The changes to the climate are overwhelmingly “anthropogenic,” i.e. man-made — we did it to ourselves, not intentionally of course, but as a result of the greenhouse gasses that we’ve been pouring into the atmosphere since the beginning of the industrial age some 250 years ago.[1]

We often summarize climate change in terms of its effect on the average global temperature — an increase of a few degrees centigrade. The number seems small, but the effects on the climate are large, including not only the occurrences of extreme temperatures and weather events — droughts, floods, hurricanes, freezing vortexes — but also further knock-on effects, such as increases in sea levels that destroy some low-lying island states and force hundreds of millions of people, many of them very poor, to move. But to where? Migration is already a problem, and further climate change will exacerbate the challenge enormously.[2] Large portions of our cities, particularly those located on the coast, will also have to be relocated at enormous cost — money that could well have been spent elsewhere. While some joke that the drowning of Wall Street will be one of the many side benefits, Wall Street won’t die — it will relocate to higher ground, and someone will have to pay the costs. The temperature changes — not seen for millions of years — will destroy biodiversity at a pace never seen before, but at the same time expose us to new diseases for which we have not developed resistance.

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We can say with certainty that climate change will have large effects and pose great costs. We can be certain, too, about the uncertainty. When countries signed the United Nations Framework Convention on Climate Change back in 1992, the signatories knew international action was needed to forestall the "dangerous human interference with the climate system," but they did not fully understand the nature and magnitude of the threat.[3] And that likely remains true today, despite the advances in our knowledge and the extreme climate-related events that are already occurring. Matters could get much worse as temperatures rise.

Recognizing the extreme risks of climate change — and our ability to mitigate these risks at a relatively low cost if policies are well-designed — is central to developing appropriate policy responses. The scientific community — now joined by the political community around the world — has agreed we *must* limit temperature increases to limit the risks of climate change. Specifically, the Paris Agreement codified a global goal to limit global average temperature increases to well below two degrees (relative to the pre-industrial level).

However, steep challenges remain. Naysayers with varying levels of good faith push back against doing more to address the risks of climate change. Unsurprisingly, these naysayers include those who profit from selling greenhouse gas-intensive products, because they see taking action as threatening to their livelihoods.

A surprising source of fodder for the climate action naysayers has come from a group of economists who use models that generate so-called "optimal" pathways by attempting to balance the benefits and costs of climate action. While these models can be calibrated to show virtually any result, the versions that have received the most attention show that the "optimal" level of action would be to allow the earth to warm between three to four degrees Celsius by 2100 — a level of warming that most scientists say is truly frightening.[4] Recent updates to the model suggest an optimal warming of 2.7 degrees in 2100.[5]

This level of warming is still high. Researchers at Columbia and elsewhere have investigated these models, called Integrated Assessment Models (or IAMs) because they integrate environmental effects with economics, something that all good models do. The assumptions ingrained in these models about the environment, the economy, and how they interact are badly flawed.

The benefits of climate actions are estimated by attempting to tally the climate damages that are avoided by action. However, while climate change is a threat multiplier that will affect societies in countless ways, damage estimates focus on the few effects of climate change that are easiest to capture. Many or most categories of climate damage — migration, conflict, ocean acidification, biodiversity loss, etc. — are not included in state-of-the-art models.[6]

The damages that are included in the IAMs may be seriously underestimated because the methodology undervalues the people who will be most harmed by climate change. For example, the models usually ignore distributional concerns, which are highly relevant to policy responses because climate change has the greatest impact on the poor, who have the fewest resources to protect themselves.[7]

Future generations will also be disproportionately harmed by climate change, and they are typically undervalued in IAMs as well. Indeed, a critical assumption in the IAMs is how future benefits are "discounted." A dollar today is worth more than a dollar 100 years from now, but how much more? And how do we value the reduced risk of a climate catastrophe confronting our grandchildren? Most climate damage estimates implicitly undervalue future generations by discounting future benefits using market rates of return, which are determined largely by the preferences of individuals today over consumption at different points during their lifetimes — thus failing to grapple with the ethical issues raised by taking on risks that will be borne by future generations.[8]

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More reasonably, and more ethically, we should value our children and grandchildren as much as we value ourselves. Consider a situation where climate change's effects turn out to be particularly severe, which is a realistic possibility that most IAMs ignore. Incomes of future generations will be reduced as a result — but they will have to spend a lot to repair the damage and to adapt to the new climate, at precisely those times when they are least able to do so. *Doing something* about climate change reduces risk. Like an insurance policy, we are willing to pay a lot upfront to avoid the possibility of horrific outcomes later on.

In addition to undervaluing the benefits of action, the IAMs do not provide useful estimates of the costs of climate action, in part due to the extreme difficulty of forecasting technological innovation over centuries. The models also assume that markets are perfectly efficient, or that they would be efficient if only we could get the price of carbon right — the only distortion is caused by greenhouse gas pollution. But, as we discuss further in the next section, research over the past 50 years has highlighted the multiple inefficiencies in market economies that serve as barriers to emissions reductions — imperfections of competition, of information, of absent markets, and ill-informed or less-than-rational individuals. Models that attempt to solve all of these challenges by focusing only on a single market failure will inevitably produce distorted estimates of the costs of climate action and wrong policy prescriptions, including the primacy of the use of the carbon price.

To be sure, the most recent studies have produced enormous improvements over earlier versions of IAMs. For example, an analysis by Danny Bressler of Columbia University shows a seven-fold increase in climate damages from incorporating an estimate of human mortality caused by temperature increases.[9] The latest estimates from the U.S. Environmental Protection Agency now includes damages from temperature-related mortality.[10] However, even the state-of-the-art estimates of climate damages are plagued by the same limitations noted earlier.

Given the problems with the benefits and cost estimates, it should not be surprising that the results of the IAMs are not robust — small changes in the assumptions lead to large changes in prescriptions. Reasonable and even relatively modest changes to the assumptions using these models support a target that is consistent with the Paris Agreement's aim of keeping global mean temperature change well below two degrees Celsius.[11]

The bottom line is that US government scientists were correct to label climate change as a "risk management challenge for society."[12] All decision making is made under degrees of risk and uncertainty, taking into account what we know and what we don't know. Advances in decision theory have provided some, but limited, guidance on how best to respond to these risks and uncertainties. When both are large—as they are here—it is particularly misguided to sweep them aside. The best we can do is to use the most robust available science and economics to help us chart a course for emissions reductions that reduce risks to more acceptable levels—a "guardrail" approach to addressing large and uncertain climate risks.[13]

Climate science points to a helpful target: net-zero emissions of carbon dioxide at the global level, which means any remaining emissions are balanced by the carbon dioxide that is absorbed by natural "sinks" (i.e. plants) or engineered removals. Surface temperatures will continue to increase until net-zero emissions are achieved, so, while reasonable people may disagree on how fast we need to achieve net-zero emissions or the responsibilities of an individual country, everyone should be able to agree that net-zero is a useful policy goal.

Indeed, the mantra of "getting to net-zero" emissions has been taken up by the climate policy community around the world. Given the primacy of the uncertainties, it is natural that the international community has focused its attention on identifying a time for getting to net zero and, with it, an associated temperature change and risk profile on which to focus. The further into the future the economy gets to net zero, the more risk the world faces. Using this kind of risk analysis, the advanced countries have settled on 2050, whereas the developing countries have settled on 2060. Many experts in advanced countries believe 2060 confronts the world with too much risk, whereas many in developing countries believe 2050 confronts them with too much costs. This is a remarkable convergence. If the judgments of the advanced countries are correct, the resources are available to induce developing countries to join in their efforts to reach net zero by 2050. With risk dominating the decision process, economists can therefore move past the notion that developing "optimal" climate change policies focusing on inter-temporal allocations is particularly useful. And we are some distance away for adequate models to fully incorporate risk and uncertainty. Fortunately, there is much more important work for economists to do in helping policymakers design and implement strategies to chart rapid, equitable, and low-cost pathways to net-zero emissions.

> **"The further into the future the economy gets to net zero, the more risk the world faces.**

COST-EFFECTIVE CLIMATE POLICIES

Carbon prices are immensely valuable policy instruments. They bring many benefits, which include encouraging cost-effective emissions reductions, helping to harmonize policies with climate goals, and enlisting all of society's efforts in reducing carbon emissions: if everyone faces the consequences of higher prices associated with carbon emissions, then everyone has an incentive to reduce those emissions.[14] Critics often miss the mark by attributing to carbon prices the weak ambition of virtually all climate policies to date, and by neglecting how carbon pricing revenue can address distributional concerns that arise in the transition.

Unfortunately, it is common practice to take this admiration a step too far by labeling carbon prices as "optimal" or "first-best" climate policies. By implication, other climate policies are relegated to "second-best" status, meaning they deserve consideration only due to political constraints that inhibit optimal policymaking.

This section explains the misconception of carbon prices as the first-best climate policy instrument and the problems caused by this misconception. Carbon prices are just one important element of a strategy to reduce greenhouse gas emissions substantially over decades at the lowest possible cost. Suggesting otherwise distorts policy discussions by discounting the importance of other policies. It also leads to unhelpful economic evaluations of climate policies, which often rely on the mistaken assumption that a carbon price and real-world policies — such as the recent Inflation Reduction Act — are substitutable methods of encouraging emissions reductions, with the latter being unambiguously inferior.

Climate Economics 101 teaches us that cost-effective mitigation requires all emitters to face the same cost to reduce another ton of emissions.[15] Putting a price on carbon accomplishes that goal by charging emitters the same fee per ton, thus encouraging only emissions reductions that can be achieved at a cost lower than the carbon price. Alternative policies, including measures that encourage changes in particular sectors or technologies, will inevitably be more costly because they fail to focus on the low-cost emissions reduction opportunities.

Let's observe two assumptions baked into this framework. First, the focus is on *marginal* changes; in other words, the question is how relatively *small, near-term* reductions in emissions can be achieved at the lowest cost. Second, the framework treats all emissions identically, thus assuming no useful knowledge about different emissions sources or alternatives. Neither assumption is reasonable to apply to the challenges of decarbonization.

Consider the following thought experiment of teachers put in two different situations. In the first scenario, the teachers are told to administer a test during the first week of school and asked to incentivize students to try their best, even though most will fail. Not knowing anything about the individual students, teachers may design a uniform incentive, like a promise of less homework for those who pass the test — just as a carbon tax provides a uniform financial incentive to reduce emissions.

Now consider a second situation: teachers are given the full school year and told that *all* students must pass the test. These teachers will get to know their students over the year and design detailed, individualized strategies to gradually overcome the variety of hurdles that the students face.

This second situation is far more analogous to the challenges of decarbonization. As described in the prior section, policymakers have appropriately focused on achieving net-zero emissions over many decades, which will require *transformational* changes to economies rather than the small and near-term changes contemplated by the Climate Econ 101 framework. Like individual students, emissions sources are far from homogenous. A cost-effective policy portfolio includes not only price signals but also measures to support the development of infrastructure, institutions, alternative technologies and regulations.

Let's take two emissions sources as examples. In the electricity sector, substantial emissions reductions can be achieved relatively easily — including with a carbon price — due to the high costs of coal-fired electricity. Nevertheless, the full decarbonization of electricity systems is an enormous challenge.[16] Thousands of new electricity-generating projects are waiting years to be connected to power grids due to inefficient permitting processes and insufficient transmission lines; consumers are not provided with proper incentives to reduce their demand for electricity when supply is most scarce; promising technologies to complement wind and solar energy have not yet been demonstrated at commercial scale.[17] To be sure, making high-carbon electricity exorbitantly expensive is one pathway to zero emissions electricity — perhaps with carbon prices rising to $400 per ton or higher, according to a recent Stanford Energy Modeling Forum study. To be sure, however, a lower-cost approach would combine lower carbon price with measures to tackle these additional barriers.[18]

Eliminating emissions from heating homes and businesses presents very different challenges due to the need to replace millions of furnaces and boilers. Raising the costs of heating is unlikely to reduce emissions much — how many of us even know how much we pay per unit of heating, let alone are willing to replace expensive appliances? A carbon price that raises the cost of heating *and* electricity is especially problematic for encouraging consumers to purchase electric heat pumps, which are arguably the most promising low-carbon alternative for space heating. A cost-effective policy portfolio may include a combination of financial incentives, innovation in technologies, regulations, and integrated solutions to meet the heating and cooling needs of buildings, infrastructure to support heat distribution systems, and standards that help overcome status quo biases of manufacturers, installers, and consumers of heating equipment.[19]

Neither example suggests that a well-designed carbon price is a bad idea. The point is that the simplistic Climate Econ 101 framework is neither theoretically correct in the presence of multiple market failures nor practically useful given the complex challenges of the pathway to near-zero emissions. Particularly as clean energy technologies improve, and we increasingly observe low-carbon technologies competing favorably on costs with carbon-intensive alternatives, the low price of fossil fuels may not even be the largest barrier to decarbonization, let alone the only barrier.[20]

A rejoinder to this critique is that *of course* the Climate Econ 101 framework is oversimplified — *that's what 101 means!* Climate economists understand the need for a range of policy tools to address climate risks. Indeed, economists have produced a wealth of important scholarship on a wide range of policies, including measures to overcome barriers to innovation, network externalities, energy efficiency, and other inhibitors of low-cost climate action.

But this lets economists off the hook too easily. References to carbon prices as first-best or optimal climate policy are commonly found not only in our introductory textbooks but also in our journal articles and public policy discussions.[21] One prominent example: in 2019, thousands of economists, including 28 Nobel Laureates, signed a public statement declaring carbon prices "the most cost-effective lever to reduce carbon emissions," with no mention of its proper role alongside a portfolio of policies.[22]

Economists with sway in policy discussions have perhaps spilled more ink on carbon pricing than all other decarbonization policies combined. This disproportionate focus distorts policy discussions. Influential policymakers and lobbying groups rationalize their opposition to other important climate policies by referencing their support for carbon prices—they naturally claim they are the ones listening to the economists rather than resorting to "second best" approaches.[23]

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The simplistic Climate Econ 101 framework also inhibits proper evaluations of climate policies. Consider the Inflation Reduction Act of 2022 (IRA), legislation meant to decarbonize the American economy with spending-focused measures including tax credits, grants, and loans. Helping policymakers understand the cost-effectiveness (or lack thereof) of landmark climate legislation like the IRA is among the most important responsibilities of a climate policy-focused economist.

A cost-effectiveness analysis must compare policies *that achieve similar outcomes*.[24] Instead, economic evaluations of IRA have followed the Climate Econ 101 framework by comparing the IRA to a carbon price. However, the IRA and a carbon price do not achieve similar outcomes. According to one prominent study, a carbon price would reduce near-term emissions at a small fraction of the cost of the electricity tax credits in the IRA, but the resulting 2030 electricity grid has over 30 percent more uncontrolled fossil fuels under the carbon price.[25] That's because the carbon price aims for the lowest-cost emissions reductions in a given year—which results in large shifts from coal to natural gas fuel—while the IRA subsidies are focused on the long-term transformational goal of a carbon-free grid.

Another prominent report estimates the costs of reducing carbon dioxide emissions under IRA at $52 per ton over 10 years.[26] However, a large portion of the IRA spending is focused on goals beyond 10 years. For example, innovation-focused spending primarily intends to improve technologies for future use, while subsidies for electric vehicles aim to jumpstart the multi-decade turnover of the automobile fleet with a large emissions payoff not expected until future decades, when electricity grids are cleaner than today.

A relevant IRA comparison would be to a policy that would have resulted in the same long-term reduction in emissions—and even that is not sufficient without accounting for the differences in distributional consequences and risks associated with the two policies, as well as the host of market failures that inhibit the transition to net zero. For example, in a world with imperfect capital markets, providing loans for "green investments" may be a highly efficient way of reducing carbon emissions; for, in a tailored way, it is simultaneously (partially) correcting two market failures.

Surely there are portfolios of climate policies that could achieve similar outcomes as the IRA for much lower costs. Indeed, a rigorous analysis that highlights the potential for more economically efficient climate policies is an important end in itself, and also a means to building momentum for the future climate policies that will be required to achieve net-zero emissions.

More broadly, economists can play a critical role in helping policymakers design and evaluate policies to achieve more rapid, efficient, and equitable decarbonization pathways. The transformation to net-zero economies will ask policymakers to balance a host of critically important tradeoffs: How should we prioritize innovation compared to the deployment of existing technologies? How can we balance the importance of resilient supply chains versus minimizing costs to consumers? What is the right balance among emissions prices, regulations, and subsidies? Moreover, public policy *has* to address the multiple ways that public investments and regulations shape the economy (e.g. zoning laws and public investments in technology, basic research, infrastructure, and education).

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Like the teachers who need *all* of their students to learn the material, a framework that requires transformational change is more complicated than a framework with a narrow focus on near-term incremental change. For the sake of accurate analysis and policy relevance, climate economists have no choice but to embrace this challenge and move beyond the over-simplistic Climate Econ 101 framework.

HOW TO ACHIEVE MORE INTERNATIONAL COOPERATION?

Enormous diplomatic effort has been devoted to climate change. And, yet, despite over thirty years of negotiations, a slew of treaties, protocols, and agreements (including the Framework Convention, the Kyoto Protocol, and the Paris Agreement), and 27 Conferences of the Parties — popularly known as COPs — CO_2 concentrations are much higher now than they were at the start of negotiations.

We still need diplomacy. The incentives to address climate change unilaterally are weak. No single country can stabilize the climate on its own. All countries must work together to do this. Previous diplomacy may have taken the wrong approach to achieving collective action. By changing the approach, diplomacy can achieve much more.

In adopting the Framework Convention in 1992, all countries agreed that they must act collectively to avoid "dangerous" interference with the climate system.[27] The Kyoto Protocol, adopted in 1997, sought to reduce the emissions of only a subset of countries by just five percent over five years. Kyoto's ambition was modest. It was meant to be a first step. And, yet, Kyoto collapsed. The protocol failed because countries couldn't figure out how to enforce the agreement. After negotiating Kyoto, the United States failed to join it. Canada joined Kyoto but later withdrew from the agreement. Other countries — including Japan and Russia — participated but later declined to join a successor to Kyoto (the Doha Amendment).

In Copenhagen in 2009, diplomacy shifted. It was there that countries agreed on a global temperature change goal for the first time. There they also agreed that every country should pledge the form of a domestic emission reduction target aimed at helping to meet the collective goal. In Paris, countries tightened up their earlier collective goal and declared "nationally determined contributions" towards meeting it. Though countries are united in their support for the collective goal, their nationally determined contributions, when added up and extrapolated into the future, fall far short of being able to meet the goal established. More troubling still, it can't be assumed that the pledges made in Paris and at subsequent conferences will even be achieved. By design, compliance with these pledges is voluntary.

With voluntary compliance, a country pays no penalty for falling short of meeting its pledge. The problem only grows as pledges become more ambitious — as they must if the temperature change goal is to be met. More ambitious pledges are more costly to achieve. Each country may be willing to pay the costs of contributing its fair share to meeting the collective goal, but this willingness is likely to depend on whether each country believes that *others* will meet *their* pledges and whether, as a consequence, *their collective goal will be achieved*. In a laboratory experiment conducted by one of us in advance of the Paris conference, players were put in a situation very much like the one facing the countries gathered in Paris. The experiment showed that the design of the Paris Agreement changed what players said (i.e. their pledges) but had little effect on what they did (i.e. their actual emission levels).[28] In short, Paris is an improvement on the approach tried previously, but it isn't enough.

How do we do better? We can learn from how similar problems have been addressed successfully in the past. Two case histories stand out. The first is the Montreal Protocol, a treaty aimed at protecting the stratospheric ozone layer. Thanks to this treaty, adopted in 1987, emissions of ozone-depleting substances — mainly, chlorofluorocarbons, or CFCs — have been eliminated worldwide. Indeed, scientists are confident that, because of this treaty, the ozone layer will return to its pre-1980 level by around 2050–2060. The second treaty, known as "MARPOL," has prevented deliberate releases of oil by tankers into the seas, and was later revised to prevent accidental oil spills due to tanker collisions. These two UN treaties have worked.

Like the climate agreements, Montreal asks countries to reduce their emissions. However, unlike the climate agreements, Montreal links this obligation to trade. In particular, the protocol forbids participating countries from trading with non-participating countries in CFCs and products containing CFCs. Linkage to international trade creates a positive feedback effect (in economists' jargon, "increasing returns"): as more countries agree to participate, more of the others want to participate. This is because, once a majority of countries, accounting for a majority of world trade, participate, the others lose by having to trade in a smaller market. If their loss in the gains from trade is high relative to their cost savings for not having to phase out CFCs, they will want to join. Trade linkage thus transforms the game. Once a critical mass of countries has participated, all want to participate. In contrast to Paris, Montreal's obligations are legally binding. In contrast to Kyoto, enforcement of Montreal is "built-in."

MARPOL is both different from and similar to Montreal. It is different in that, rather than asking countries to reduce their releases of oil into the sea, MARPOL imposes a technical standard for oil tankers, requiring separate onboard storage for oil and ballast water, and double hulls to prevent accidental spills. MARPOL is similar to Montreal in that it creates a positive feedback effect. Countries wanting to protect their coasts from oil pollution have an incentive to restrict port access to ships that adopt the new standard. As more ports restrict entry, more ships want to meet the standard; and as more ships meet the standard, more ports want to restrict entry. Again, once a critical mass of ports has restricted access, and once a critical mass of tankers has adopted the new standard, all ports and shipping companies want to meet the new standard. Today, over 99 percent of oil is shipped in this way, virtually eliminating the major source of marine oil pollution. Like Montreal, enforcement of MARPOL is "built-in."

Possibly the best climate agreement so far was adopted less than a year after Paris. This treaty, the Kigali Amendment to the Montreal Protocol, phases down hydrofluorocarbons, or HFCs. HFCs were developed to substitute for CFCs. HFCs don't destroy stratospheric ozone, but they are a powerful greenhouse gas. This is what makes Kigali a climate treaty rather than an ozone treaty. The Kyoto Protocol tried but failed to limit HFCs. What is better about Kigali? Like Montreal, Kigali incorporates a trade measure designed to create a positive feedback effect once a critical threshold for participation has been met. Again, enforcement of Kigali is "built-in." Remarkably, Kigali was ratified by the US Senate in September 2022 by a vote of 69 to 27.[29] Why would 21 Republican senators, including Mitch McConnell, vote in favor of a binding treaty for addressing climate change? One key reason is the threshold effect of participation. The design of this treaty made it in the interests of the US to ratify it.

Republican support may also have been influenced by the support for ratification expressed by industry leaders, including executives from Dow Chemical, Honeywell, Chemours, and Fujitsu.[30] To them, ratification was a matter of competitiveness. They did not want to be shut out of other markets or to fall behind the global rush for innovation. Though support like this is to be welcomed, the support of entrenched interests should not drive negotiations. Transformations often reward new entrants, not old incumbents. And incumbents that expect to lose from change will fight against it, and fight effectively. Research by Kyle Meng and Ashwin Rode shows that — dollar for dollar — lobbying by the losers from climate policy change is more effective than lobbying by the winners.[31] Strategies for getting legislation passed and treaties ratified need to navigate these obstacles and openings.

The trade measures in the Montreal Protocol are a stick, but Montreal (and, thus, Kigali) also incorporates a carrot: assistance for developing countries to pay for the "agreed incremental costs" of their compliance. The combination means that developing countries are worse off for not joining, provided the treaty enters into force and trade restrictions are imposed against non-parties by parties representing a bigger share of the global market, and no worse off for joining irrespective of the participation level, relative to a world in which no action was taken on HFCs. This kind of exchange is not only mutually beneficial (all countries, including developing countries, gain from the protection of the ozone layer), but assuages concerns developing countries have about equity.

Once the logic behind these successes is understood, we can apply it to other sectors. Here is an example: Smelting of aluminum results in emissions of CO_2 and PFCs, another greenhouse gas that Kyoto tried, but failed, to phase down. Replacing the carbon anode used today with an inert anode can eliminate these process emissions. An aluminum treaty should require that parties both switch to the inert anode (an effective low-implementation cost-regulatory measure) *and* import aluminum only from other parties to this agreement. The result, once again, should create a positive feedback-effect, once critical mass is achieved.

Voluntary international agreements can reinforce the Paris Agreement by focusing on technology development and adoption. Mission Innovation is a coalition of 22 countries that funds R&D to lower the cost of reducing CO_2 emissions in particular sectors, making take-up of new fuels and technologies more attractive for all countries. For example, Mission Innovation is identifying the best substitute for heavy fuel oil in international shipping, undertaking R&D to lower this technology's costs, and making the new fuel available at the world's ten largest ports. It is too soon to say whether ten ports will suffice to tip behavior globally, but the logic behind this approach is consistent with the successful approaches mentioned above. So long as Mission Innovation encourages enough countries to switch, it will make it in the interests of all the others to switch. A world in which world trade is powered by heavy fuel oil could be transformed into a world in which global trade is powered by a fuel like "green" ammonia. Similarly, international aviation might switch to synthetic fuels made from "green" hydrogen and CO_2 captured from the air. Note that while funding of R&D would normally be vulnerable to free riding, so long as the R&D is linked to the take-up of the new technology, as Mission Innovation is doing, countries will have an incentive to finance the R&D.[32]

To spread, the new technologies must also be priced appropriately. Prices must be high enough for private investors to have an incentive to develop the new technologies, but not so high as to discourage take-up. If the products are sold at a single price globally, all users will pay the same markup for the monopoly afforded by intellectual property rights. Take-up—and, hence, economic efficiency—would increase if countries with a lower ability to pay are offered the new technologies at a lower price than countries with a higher ability to pay. Market segmentation can increase distribution of the new technologies—a key need for a global technology transition—while still providing strong incentives for innovation and investment.

Also, R&D and innovation shouldn't be directed only at technologies that reduce emissions predominately in rich countries, but also at technologies that would be especially attractive in developing countries, such as distributed solar energy and battery storage.

Previously, we explained that a carbon price alone is not a "first-best" strategy for addressing climate change given the many barriers to achieving an accelerated transition to net-zero emissions. Here we can add another reason. In the absence of a capability to enforce a broad global climate treaty, it may be difficult to get countries to set a carbon price that is high enough, even as part of a portfolio of climate policies, to achieve their collective goal of keeping mean global temperature change well below two degrees Celsius. The approaches outlined here, involving technical standards and regulations, investments in R&D and infrastructure, and trade measures, can be effective complements to relatively low carbon prices because they ease the enforcement problem that has bedeviled climate negotiations in the past.

Finally, we wish to emphasize that the approach outlined here is fundamentally cooperative and multilateral in orientation. It is very different from a country or small group of countries imposing trade measures unilaterally for purposes of coercion—an approach that may only invite retaliation, and that in any case will not elicit the kind of cooperation required to successfully address climate change, let alone the myriad of other problems requiring global collective action. In particular, issues of fairness in addressing climate change can be addressed within the multilateral framework we have described. As noted before, and as was done in the Montreal Protocol, the use of trade measures ("sticks") can be coupled with side payments ("carrots"), with wealthy countries helping to finance development and take-up of new technology-fuel combinations in poorer countries, addressing the fundamental equity issues that have always been an integral part of the multilateral negotiations. Also, the purpose of trade measures in the multilateral framework is not only to provide an incentive for every country to participate in the agreement but to assure every country that the other countries will also play their part in meeting the collective goal. When all countries participate in the agreement, trade is not restricted.

The use of carbon border adjustments has a different motivation and effect. They would be imposed unilaterally or by a small number of countries, with the main purpose, ostensibly, being to limit "trade leakage" (that is, preventing a shift in production, and thus an increase in emissions, in other countries). One of the problems with carbon border adjustments is that they require that all imports, including from developing countries, meet the standard determined by the country or countries imposing the border adjustment, bypassing the negotiation process. Relatedly, the choice of a standard for imposing carbon border adjustments could be taken for protectionist reasons. For example, the country imposing the border adjustment could choose a standard that reflects an advantage that this country happens to have in terms of emissions intensity, say, and that has little if anything to do with its climate policy.

The climate negotiations have always reflected a combination of common and opposing interests, but the pendulum seems to be swinging more in the direction of competition rather than cooperation. For example, the Inflation Reduction Act will reduce emissions in the US, and so contribute to meeting the global goal of avoiding dangerous climate change. By promoting certain technologies, the IRA may also enable other countries to reduce their emissions at a lower cost. However, the IRA is also intended to give the US industry an advantage in meeting this challenge relative to other countries. We recognize that there may be a domestic political trade-off here. But if all countries adopt such an approach, wanting to help their economy at the expense of others, the achievement of the collective goal of addressing climate change may be put at risk (They might be entitled to impose countervailing duties, so that the benefit of the green technologies adopted in the US would be limited to domestic consumption.) Most importantly, global warming is a global public good, and all policies should be designed to promote cooperation in fighting climate change, rather than designed to win the war for green jobs.

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CONCLUSION

When climate change emerged as a global problem in the late 1980s, it seemed pretty clear what needed to be done. Countries needed to begin reducing their emissions, and to reduce emissions by more and more every year, including by the use of carbon prices. Countries needed to cooperate to achieve these reductions.

The same is true today, but the picture looks different. Because global emissions have continued to increase, achieving similar climate goals requires more radical actions. Because cooperation has fallen short, new approaches are needed to promote collective action.

We have also learned a great deal from both scholarship and trial and error. We cannot "optimize" climate actions with any useful precision by balancing the benefits and costs of action — understanding risk and uncertainty and the concomitant urgency of addressing climate change are central to climate policy. Carbon prices work best when combined with other policies to support the development of infrastructure, institutions, regulations, and alternative technologies. In addition, international treaties are most effective when they combine sticks and carrots to encourage deeper cuts in emissions over time while maintaining broad — if not universal — participation. As befits a "wicked" problem, we need to continue to learn from the past and adapt our strategies for reducing emissions as we go.

ENDNOTES

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