What Is the Right Price for Carbon Emissions?

The unknown potential for devastating effects from climate change complicates pricing.

BY BOB LITTERMAN

As concern over climate change grows, policymakers face a difficult question: How much should society spend today to protect future generations against the unknown risks emissions create? Two issues make determining the appropriate price of carbon emissions a particularly difficult question for economists. First, the unusually long time before environmental damages are expected to be realized makes them difficult to value today. Second, the potential for a low-probability, high-damage scenario to occur is fundamentally uncertain.

There is no disagreement among economists on the benefits of pricing carbon emissions. Prices create the appropriate incentives for producers and consumers to reduce emissions and shift them to higher-value uses. They do this by internalizing the externality of future damages created by economic activities that produce emissions. Relying on prices to allocate scarce resources is vastly superior to the command-and-control approaches of current policies, which rely on public subsidies and mandates to use particular alternatives to fossil fuels.

What is the correct tax on emissions? The views range from $5 per ton of carbon dioxide at the low end (around 4 cents per gallon of gas) to over $100 per ton (as much as $1 per gallon). The current consensus of economists is at the low end of this wide range. Frustrating that effort is the fact that, on average across the world, the net subsidies to fossil fuel consumption (primarily in developing countries) are on the order of $16 per ton of carbon emissions created, according to the International Energy Agency. The European Commission Emission Database for Global Atmospheric Research estimates that carbon dioxide emissions for 2011 totaled 33.376 gigatons, and were boosted by subsidies of $523 billion.

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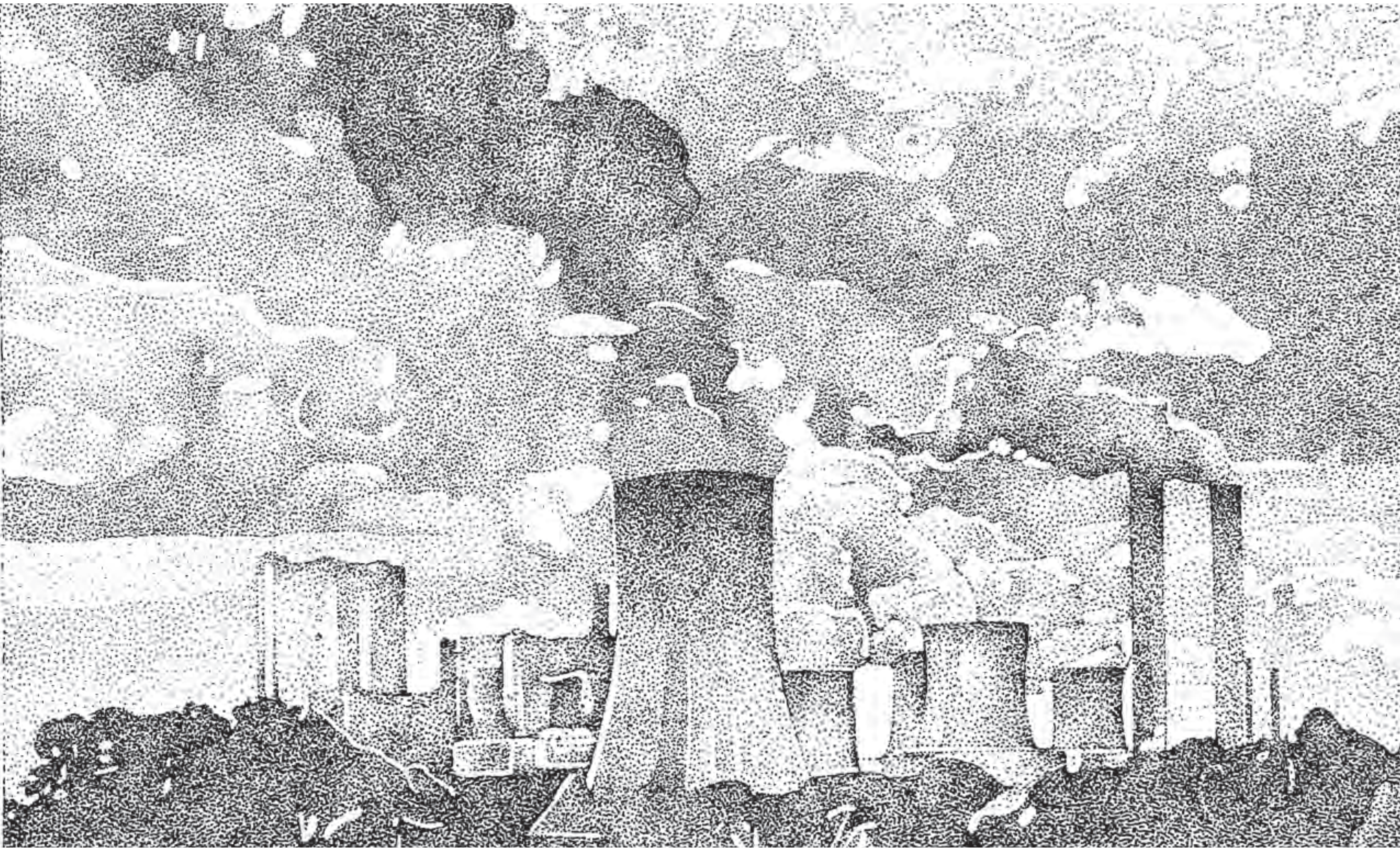
Is Climate Change a Hedge or a Risk?

Because of the long time horizon until damages are expected to occur, the present value of the expected climate damages is distressingly sensitive to alternative discount rates that are not observable in the market and thus difficult to justify. Interestingly, however, the valuation of these expected damages is the less controversial part of the debate. There is a general consensus among economists that future generations will be able to deal with the average impacts of climate change relatively uneventfully. The present value of damages is generally thought to be in a range of $5 to $35 per ton of carbon dioxide. The U.S. government recently estimated this present value to be $20 per ton, and the International Monetary Fund has suggested using a value of $25 per ton.

The more controversial issue is how to deal with uncertainty. In fact, economists do not even agree on the direction of this effect. A sensible argument can be made that the risk embedded in emissions actually lowers the appropriate price of carbon dioxide emissions relative to the price that correctly reflects expected damages. Another sensible argument can be made that the risk created by emissions increases the appropriate price.

Economists generally assume that global real per-capita



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income growth will be around 2 percent per year, meaning that people will be much better off in the distant future. Given even a very pessimistic assumption about real income growth of, say, 1 percent per year without factoring in climate damages, people will have 64 percent higher income in 50 years. At 2 percent per year of economic growth, the average per-capita income will be 169 percent higher. In recent decades, despite the recent recession in developed economies, the global per-capita income growth has been much higher than those values, averaging 2.8 percent over the past 50 years and 3.8 percent over the past 10 years, according to the World Bank. At 2.8 percent growth per year, people in 50 years will have four times as much income as today, and in 100 years they will have 16 times.

How does climate change affect those economic growth possibilities? Faster economic growth will most likely create a higher level of emissions and therefore lead to more climate-related damages. That is, in scenarios in which average economic growth is high, climate damages are more likely and will reduce growth from what it otherwise would have been. In contrast, if future economic growth is low, emissions will probably be lower, climate damages smaller, and the damages will most likely subtract less from the low growth results. Thus, many economists regard climate risk as a factor that will reduce the dispersion of potential future growth scenarios, and therefore as a potential hedge against other random factors affecting future economic well-being.

From this perspective, the key issue is whether climate impacts are small relative to growth uncertainty. All *known* climate impacts are generally assumed to be very small relative to the uncertainty of wealth creation over the relevant time horizons. If this assumption is correct, then the incorporation of a risk premium into carbon dioxide emissions prices has the paradoxical effect of reducing the appropriate price relative to consideration of the expected (average) damages alone.

But an argument can be made that climate-related damages are highly uncertain. There is a very small chance that climate effects may not just reduce subsequent growth, but may cause it to plummet catastrophically. Such scenarios require positive feedbacks; for example, warmer temperatures cause the release of methane from the currently permanently frozen tundra, triggering catastrophic warming impacts beyond the ability of future generations to adapt. How should society today rationally price the possibility of such unknown, very-low-probability outcomes in the future?

Economics of Nondiversifiable Risk

How much should society spend today to insure the future against climate risk? When risks are diversifiable—that is, not

statistically related to other bad outcomes in the aggregate economy—then insurance prices depend only on average damages. The cost of insuring a diversifiable risk is a simple calculation of the discounted value of expected (average) future damages. Pricing fire insurance appropriately is a good example. Empirical evidence on the distribution of damages caused by fires and the level of interest rates determines the cost of the insurance. Risk aversion does not enter into the calculation.

Of course, no one can credibly promise to provide insurance to future generations against a catastrophic climate disaster. Thus, catastrophic climate risk is a nondiversifiable risk. And nondiversifiable risk is different from insurable risks; it commands a risk premium determined by societal risk aversion. What society can do is price that risk appropriately. The atmosphere's unknown capacity to safely absorb carbon emissions can usefully be viewed as a scarce, nonrenewable resource. The economics of pricing emissions are very similar to those of pricing other valuable nonrenewable resources. How much should society charge its members for using up this resource?

Carbon dioxide emissions should be priced high enough today that people have appropriate incentives to avoid future damages and scientific and economic experts are extremely confident that catastrophic risks will be avoided. If the price is too high today, people both now and in the future will give up too much consumption relative to what would have been possible. If the price is allowed to remain too low, however, then future generations will face greater-than-optimal expected damages, higher-than-necessary prices for their emissions, and a higher probability of a catastrophic scenario.

The first determinant of the price is the marginal increase in the net present value of the expected climate impacts created by increased emissions today. There are many such expected impacts. Some are positive, such as warmer weather in cold latitudes. Others are negative, such as sea level rise and ocean acidification. The net value of these expected costs and benefits in the near future is the starting point of an answer.

The second and much more highly uncertain determinant of the price is the value of the bulk of the damages that are expected to occur in the distant future when the impact of emissions on temperature is expected to be many times larger than today, but when people are assumed to be much wealthier and to have better technology. Economists generally assume that people in the distant future will spend only a small part of their considerably larger incomes adapting to expected climate impacts.

If we knew with absolute assurance that the worst potential risks of climate change could be addressed successfully in the future, then it would make sense to focus only on average damages even for those damages in the distant future. Emissions should still be priced immediately, of course, but the appropriate price would be at a relatively low level today and would be expected to increase slowly over time as the damages increase.

That relatively benign view, which has been clearly articulated for many years by Yale economist William Nordhaus, had been the consensus view among economists until recently. But that view was dramatically questioned by Harvard economist Martin Weitzman in a 2009 article in which he developed an argument that he called the "dismal theorem." Weitzman claimed that the possibility of extremely rare but potentially catastrophic outcomes made it impossible to put an upper bound on the appropriate price for emissions today. The theorem didn't help determine the appropriate price for emissions and it relied on an unbounded utility function, which many economists object to, but Weitzman did succeed in shifting the academic discussion in a new direction.

Pricing of High-Cost, Low-Probability Events

The problem raised by Weitzman's theorem is that there is fundamental uncertainty about the probability of catastrophic outcomes. Clearly they are highly unlikely, but does such a scenario have a probability similar to flipping a coin and seeing five heads in a row, 10 heads in a row, or 50 heads in a row? Knowing which probability is appropriate would make a huge difference, but there is no way of knowing which is closest to being right.

Another important consideration in pricing emissions today is the uncertain current and expected future costs of reducing emissions, as well as the uncertain cost of adapting to higher temperatures and other known, as well as potentially unknown, impacts. Once emissions are priced, incentives will exist to develop technologies that reduce emissions creation and release. Given those incentives, it is highly likely, but not certain, that unknown technologies can be developed to reduce the climate problem significantly. Is the appropriate price still in the conventional range of $20 to $25 per metric ton of carbon dioxide, or does the potential for catastrophe make it much higher?

In a recent article, Massachusetts Institute of Technology economist Robert Pindyck asks, "Is there a case to be made for the early adoption of a *stringent* GHG [greenhouse gas] abatement policy that would sharply reduce emissions and thereby limit the accumulation of GHGs in the atmosphere, at an annual cost of more than 2 percent or 3 percent of [gross domestic product]?" (In contrast, prices based on estimates of average effects are less than 1 percent of GDP.) "Put simply, is there a good economic argument for a stringent policy that is likely to be costly to implement and that would yield highly uncertain benefits only 50 or 100 years from now?"

Pindyck doesn't answer that question one way or the other. He simply lists the unknowns. "We simply don't know much about how worse off the world would be if by the end of the century the global mean temperature increased by 3° or 5°C. In fact, we may never be able to resolve these uncertainties (at least not over the next 50 years). It may be that the impact of higher temperatures is not just unknown, but also unknowable." He concludes that "the case for stringent abatement—if that case is to be made at all—must be based on an analysis of potential catastrophic outcomes."

But Pindyck then argues that too many non-GHG-related low-probability, high-damage scenarios exist. He writes, "Readers can use their imaginations to come up with their own examples, but a few that come to my mind include a nuclear or biological terror-

ist attack (far worse than 9/11), a highly contagious 'mega-virus' that spreads uncontrollably, or an environmental catastrophe unrelated to GHG emissions and climate change." He concludes that society cannot afford to respond strongly to all those threats.

Weitzman and Pindyck agree on many of the issues. They both recognize the importance of confronting catastrophic outcomes. However, while Pindyck refused to answer the question, Weitzman argues for a precautionary approach that would react to catastrophic risk—although he does not quantify that reaction. In his words, "Qualitatively, fat tails favor more aggressive policies to lower GHGs than the 'standard' benefit-cost analysis. Alas, the quantitative implications are less clear."

What about Pindyck's argument about many other potential low-probability, high-damage risks facing mankind? Weitzman writes that there are a number of "potentially catastrophic global impacts with nonnegligible probabilities—biotechnology, nanotechnology, asteroids, 'strangelets,' pandemics, runaway rogue computers, nuclear proliferation." "It may well be" that each "deserves its own ballpark estimate of tail probabilities along with extremely crude calculations of policy implications, which is about the best we can do with potential catastrophes." Nonetheless, Weitzman concludes, "I think that climate change is especially worrisome."

Societal Discounting

Even if uncertainty did not exist, we would still have to decide how much to spend today to give us known benefits in the distant future. There is a large, confusing, and largely irrelevant literature on the question of how individuals discount future outcomes. If you ask individuals how much would they give up today in order to obtain a fixed amount of wealth at some date in the future, the answers are quite varied and often difficult to fit into any rational theory. Luckily such research is unnecessary to answer the carbon dioxide pricing question, both because societal discounting is different from individual discounting, but more importantly because at any point in time there is an observable market price that tells both the individual and society how much they would give up today in order to obtain a fixed amount of wealth in the future.

The most appropriate rates at which to discount expected damages at different time horizons are provided by the yield curve of risk-free bonds, today perhaps best represented by the U.S. government Treasury Inflation Protected Securities (TIPS). They equilibrate the market for risk-free transfer of current wealth into the future at each future date out to about 30 years.

Suppose, for argument's sake, we ignore uncertainty and consider a simple example in which it is known that three tons of emissions will create a one-time damage 30 years from now of exactly $100. Further suppose that the market price is $60 for a government bond that delivers a risk-free promise to pay $100 worth of principal on the same date 30 years from now (a discount rate of 1.7 percent). The $100 taxpayer obligation in 30 years has the same value whether the government issues the bond or if it insures the damage that three tons of emissions are going to create. In this simplified example, the appropriate tax is $60 today on three tons of emissions, or $20 per ton. There is no need to appeal to ethical considerations or individual preferences in order to calculate the current value of those damages.

Long-term risk-free bonds have historically provided real yields of between 1 and 2 percent, but there are limitations on using such observable rates. Obviously, when the damage extends beyond 30 years and there is uncertainty, then the appropriate discount rate becomes less clear. Climate damages are expected to continue for much further into the future, perhaps for hundreds of years. Some economists have argued that in extending the yield curve beyond 30 years we should assume low or declining discount rates. In his climate change report to the British government, for example, Lord Nicholas Stern argued for a low discount rate on ethical grounds.

Small changes in low, long-term discount rates make a huge difference in the present-value of damages in the distant future. Thus the choice of the discount rate necessarily has large effects on the appropriate expenditure on damage prevention. For instance, $1 billion in damages 100 years from now has a present discounted value of only $138 million when discounted at 2 percent per year, but $607 million—more than four times as large—if discounted at 0.5 percent per year.

As economists' focus has shifted from expected climate damages to potential catastrophic risks, their attention in financial markets has shifted as well, from the risk-free rate reflected in bond markets to the required risk premium for nondiversifiable risk. The primary evidence we have about how society prices nondiversifiable risk is the equity risk premium—the long-run excess return of equities relative to government bonds. It is puzzlingly large, reflecting an implausibly high degree of societal risk aversion. But the question of how that high level of societal risk aversion affects the price of emissions depends critically on whether climate change is viewed as a risk or a hedge.

The Economics of Risk Pricing

Modern understanding of the determinants of risk premiums began with the Capital Asset Pricing Model (CAPM) in the mid-1960s. In this simple, one-factor, one-period equilibrium model, the central result is that the risk premium for any asset depends on the covariance between its returns and the returns of the market, a parameter academics call "beta."

The intuition is very straightforward. In equilibrium, all investors hold the market portfolio and each asset's contribution to the risk of that portfolio is measured by its beta. Assets whose returns tend to pay off in good times when the market return is positive are more risky and thus less valuable. They require a higher risk premium. Assets that pay off in bad times have an insurance-like property that makes them more valuable and requires a lower risk premium. Any risk premiums that differ from the level reflecting the asset's beta will create incentives for investors to adjust their portfolio holdings, causing the risk

premiums to move toward the equilibrium level.

While the empirical evidence about the validity of this theory is mixed, the basic intuition is clearly valid. Equities have a payoff that is expected to be higher in good times. Historically, across almost all countries, equities have returned a surprisingly high average return. Owning financial instruments that pay off when equities go down in value (shorting equities) is equally volatile, but provides an insurance-like return profile: positive payoffs when times are tough, but large negative average returns.

CAPM is a very simple model that provides useful intuition. Those investments that create higher returns during good times (when extra cash is less valuable) have a higher risk premium. Those that create insurance-like payoffs by creating more returns during bad times (when extra cash is really valuable) require lower expected returns.

Investments in reducing emissions have payoffs that will be more valuable in scenarios with higher climate damage. If climate risk dominates economic growth risk because there are enough potential scenarios with catastrophic damages, then the appropriate discount rate for emissions investments is lower that the risk-free rate and the current price of carbon dioxide emissions should be higher. In those scenarios, the "beta" of climate risk is a large negative value and emissions mitigation investments provide insurance benefits. If, on the other hand, growth risk is always dominant because catastrophic damages are essentially impossible and minor climate damages are more likely to occur when growth is strong, times are good, and marginal utility is low, then the "beta" of climate risk is positive, the discount rate should be higher than the risk-free rate, and the price of carbon dioxide emissions should be lower.

For a given distribution of emissions reduction payoffs and consumption, the magnitude of the impact on the emissions price of risk considerations should be a function of the degree of societal risk aversion. The high level of societal risk aversion, as demonstrated by the empirical regularity of the high returns on equities, suggests that those risk considerations should matter. Thus, the message from the financial markets is that if catastrophic risk cannot be completely ruled out, then the combination of potential catastrophic scenarios and high societal risk aversion could imply a significant increase in the appropriate price of emissions.

It turns out that in most economic models, the two key economic considerations—the risk-free rate used for discounting expected damages and the size of the risk premium—are connected. The usual approach ties both of these concepts to one construct: the degree of curvature in a societal utility function.

Unfortunately, as was noted decades ago in the context of financial markets, one parameter cannot fit both low interest rates and the high equity risk premium. This incompatibility is the essence of the equity risk premium puzzle. In order to address this problem, financial economists have developed more general utility functions that can be calibrated to fit both low real interest rates and the high equity risk premium. These utility functions use two separate parameters to specify changes in utility over time that result from consumption now versus consumption later: intertemporal substitution and risk aversion. The former is calibrated to interest rates, the latter to the equity risk premium.

Such two-parameter calibration matters because in the standard climate model there is only one utility curvature parameter and it is generally used to fit low interest rates. Low curvature, which fits historical interest rates, implies a degree of risk aversion at least an order of magnitude too low to be compatible with the equity risk premium observed in financial markets. Higher curvature in the context of the standard utility function would lead to increased risk aversion, but in the context of climate models the greater discounting of damages associated with the implied higher interest rates would overwhelm the impact of the increased risk aversion. The implication of using just one parameter to fit both effects is that raising the degree of curvature (which increases risk aversion) in the standard climate models lowers the price of carbon dioxide emissions.

Without addressing the issue, the standard approach of economists has been to assume a very low degree of curvature in order to fit the low interest rates that we see in bond markets. Ironically, the implication of that approach has been, in effect, to eliminate any consideration of risk in these models altogether. Neither hedging growth nor catastrophic risk matters in these models.

But when a more flexible utility function is used—a utility function designed to fit both the low risk-free rates and high equity risk premiums that we see in financial markets—then the stand one takes on hedging versus catastrophic risk can matter a lot.

The stand one takes on hedging versus risk also affects the expected future path of emissions prices. The appropriate carbon dioxide emissions price will be expected to increase at the rate used to discount damages caused by emissions. If the hedge approach is taken, the discount rate rises relative to the risk-free rate, and emissions prices are expected to increase at a higher rate over time. This has been the conventional view and justifies the expected increases in emissions prices at rates of 3 percent to 5 percent per year, which are proposed in the work of most economists.

On the other hand, if the approach taken is to assume that catastrophic risk dominates, then the discount rate drops below the risk-free rate. The implication of this assumption is that the optimal current price is higher, but emissions prices should be expected to rise more slowly over time. Using this approach could raise the current price well above the conventional view, but at the same time reduce the expected price 30 years from now to below that of the conventional view. And if the risk premium is large enough, then the insurance benefits could even require a negative discount rate and such a high current price of emissions that the price would actually be expected to drop over time as the problem diminishes and uncertainty is resolved.

Simple intuition is behind these results. Imagine riding a bicycle down a steep mountain road along a cliff, with a sharp corner up ahead. If you are risk-tolerant and very confident that you will have full control as you go around that corner,

you will brake slowly and expect to increase your pressure as you approach the corner, making necessary adjustments along the way. If, however, you are more risk-averse and at some point realize that you might be going too fast and worry that there is a possibility that you lose control and go off the edge, then you immediately brake hard and expect to ease off as you feel that you have regained full control.

Conclusion

Climate change is a risk management issue. If we knew for sure that the worst outcomes from climate change could be addressed successfully in the future, then the appropriate price for emissions would actually be less than the average damages discounted by the risk-free interest rate because climate change damages would be a hedge. If one believes that scientifically plausible scenarios exist in which the worst outcomes from climate change are catastrophic for future consumption, then the appropriate price for emissions would be higher now than the estimate of average damages discounted by the risk-free interest rate.

The fundamental problem, of course, with the insights provided by the economics of risk management is that the answer depends at its core on something unknowable. How significant is the risk of an unimaginable and unmanageable catastrophe? I believe that given that uncertainty, a cautious approach that weighs the cost of catastrophic outcomes above the potential benefits of hedging future economic growth is justified. It would be best to get started immediately by pricing carbon emissions no lower, and perhaps well above, a reasonable estimate of the present value of expected future damages, and allow the price to respond appropriately to new information as it becomes known. R

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Pricing Carbon When We Don't Know the Right Price

Despite the unknowns, we should begin to tax carbon.

BY ROBERT S. PINDYCK

There is almost no disagreement among economists that the true cost to society of burning a ton of carbon is greater than its private cost. Burning carbon produces carbon dioxide and other greenhouse gases (GHGs) that accumulate in the atmosphere. Over time, an increasing concentration of atmospheric GHGs will result in unwanted climate change: higher global temperatures, greater climate variability, and possible increases in sea levels. Burning carbon thereby imposes an externality on society, the cost of which is not incurred by the consumer or firm that is doing the burning. This external cost is referred to as the social cost of carbon (SCC) and is the basis for the idea of imposing a tax on carbon emissions or adopting a similar policy such as a cap-and-trade system.

However, agreeing that the SCC is greater than zero isn't really agreeing on very much. Some would argue that any increases in global temperatures will be moderate, will occur in the far distant future, and will have only a small impact on the economies of most countries. If that's all true, it would imply that the SCC is small, perhaps only around $10 per ton of CO_2, which would justify a very small (almost negligible) tax on carbon emissions, e.g., something like 10 cents per gallon of gasoline. Others would argue that without an immediate and stringent GHG abatement policy, there is a reasonable possibility that substantial temperature increases will occur and might have a catastrophic effect. That would suggest the SCC is large, perhaps $100 or $200 per ton of CO_2, which would imply a substantial tax on carbon, e.g., as much as $2 per gallon of gas.

So who is right, and why is there such wide disagreement? Should we aim for a relatively small tax on carbon, at least initially? Or should we push for a substantial tax that would lead to a large reduction in emissions on the grounds that we need an "insurance policy" against a possible catastrophic outcome?

I begin by briefly reviewing the fundamental uncertainties surrounding climate change and thus the SCC, and I explain why it is so difficult to arrive at a number for the SCC. I then turn to the likelihood and possible effect of a climate catastrophe: an increase in global mean temperature in the next 50 to 100 years that is much

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