



## EDITOR'S CORNER

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*It is time to slam on the brakes.*

—Felipe Calderón, President of Mexico

## Pricing Climate Change Risk Appropriately

CFA charterholders are well positioned to understand the economics of climate change, which is fundamentally a problem of risk management. The key conclusion of recent scientific and economic research is that in our risk-averse society, carbon emissions should be priced at high levels *immediately* because of the real risk of catastrophic damages. The appropriate price is the expected present value of the uncertain future damages those emissions will create.

But that simple statement hides a raft of hidden assumptions and complexities. For example, a price can be optimal only in the context of a plan because future damages are a function of the levels of greenhouse gases over time, not simply today's emissions. If society were to price emissions at a high level in the near term, we would expect the damages caused by today's emissions to be less than if society failed to price emissions for an extended period. Complexities aside (I will return to them later), the optimal policy today can be summarized as setting the tax on emissions equal to the present value of the future damages that the emissions are expected to cause. Under this policy, nature's emissions-absorbing capacity—a scarce resource—is used up appropriately over time.

Recent research has highlighted how the present value of future damages depends on societal risk aversion and low probabilities of disaster. We are all filling up a common reservoir of limited, if unknown, capacity to absorb emissions safely, and we need to decide how much to charge each other for filling it up. Any underpricing early on will inevitably be compensated through overpricing (relative to the optimal path) later on. If the reservoir overflows, a catastrophe could ensue. At last year's UN climate conference in Cancún, Mexico, Felipe Calderón, the president of Mexico, told the attendees that we should charge a high price; with respect to climate change, he said, "It is time to slam on the brakes."

It turns out, perhaps intuitively, that the optimal amount to brake—that is, the appropriate price for carbon emissions—depends critically on how risk averse society is. In this brief review of the recent literature on the economics of climate change, I attempt to relate some of the new findings to finance topics familiar to CFA charterholders—for example, the equity risk premium puzzle: the surprising degree of societal risk aversion as evidenced globally by the high historical returns to risky assets.

## Uncertainty about Catastrophic Risks

Economists Frank Ackerman and Elizabeth A. Stanton offer the following summary:<sup>1</sup>

Recent scientific research has deepened and transformed our knowledge of climate change. The Earth's climate is a complex, nonlinear system with dynamics that cannot be predicted in detail—including, among other hazards, the possibility of thresholds at which abrupt, irreversible transitions could occur. A range of feedback effects intensify the warming caused by rising concentrations of greenhouse gases, leading to a rapid, though perhaps irreducibly uncertain, pace of climate change. There is also a growing understanding of the numerous harmful impacts that are expected before the end of this century, even at the most likely rate of climate change, and of the additional, catastrophic outcomes that could result—with lower but non-trivial probability—if climate change proceeds more rapidly. (p. 64)

Economic theory tells us that the optimal policy is to price risk immediately and appropriately. Until recently, however, economists focused on the expected outcome and the uncertainty caused by economic growth and not on the uncertainty caused by climate impacts because they assumed that economic growth would dominate climate impacts over a long horizon. These models did not put much weight on catastrophic outcomes. According to the Ackerman–Stanton summary of recent research, "Long-term catastrophic risk is the

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subject of some of the most important recent developments in climate economics” (p. 6).<sup>2</sup> The latest economic research is drawing attention to the important role of worst-case climate change outcomes, about which there is tremendous uncertainty. Moreover, until very recently, economists assumed that society has a very high tolerance for risk—in fact, a value totally inconsistent with market risk premiums. The typical “reasonable” risk-aversion assumption used by economists would imply an equity risk premium in the range of 13–19 bps, not the 600–800 bps that we have seen in equity markets historically. In recent years, the combination of the recognition of uncertainty in worst-case outcomes and the need to incorporate risk aversion realistically has had a powerful impact—namely, to raise the appropriate price of emissions significantly.

Another important development has to do with discounting and the risk aversion embedded in utility functions. Appropriately, researchers have started to apply principles of risk pricing to climate risk. In particular, outcomes should be not only probability weighted but also weighted by the marginal utility in the state of nature in which they occur. In other words, the appropriate discount rate for cash flows depends on their risk profile. Equities should—and do—have low prices (and high expected returns) because their cash flows are discounted by society at high rates. The reason has to do with the anti-insurance aspect of equities: Their cash flows are highest in good states of nature whereby the value placed on the cash flows is low. In contrast, efforts to mitigate climate change by pricing carbon emissions will be most valuable to society if climate change turns out to have catastrophic consequences for society’s well-being. Because of this insurance aspect, society should be willing to pay higher prices for climate change mitigation.

Until recently, economists assumed a very low level of risk aversion, a level too low to be consistent with the high rate of return on equities. Calibrating the curvature of the utility function in order to match both the equity risk premium and the risk-free rate implies a much higher societal risk aversion, which, in turn, implies lower discount rates for projects that have high payoffs primarily in bad states of nature (e.g., climate mitigation). Under this calibration, the appropriate price for carbon emissions is much higher than the values in earlier studies that assumed high risk tolerance.

### **CRRA Utility**

The rather complex explanation of why economists typically assumed very high levels of risk

tolerance has to do with their use of the standard constant relative risk aversion (CRRA) utility. This utility function uses one parameter—a degree of curvature—to try to capture two very different aggregate economic behaviors: intertemporal substitution and risk aversion. Intertemporal substitution (the willingness to postpone consumption today for consumption in the future) determines the risk-free interest rate. Risk aversion determines the willingness to accept risk and, therefore, the equity risk premium. Obviously, interest rates and equity risk premiums are two of the most fundamental economic phenomena, about which we have extensive historical observations. As is well known in the finance literature, however, CRRA utility cannot come close to simultaneously fitting both the low real market interest rates, which reflect a high degree of intertemporal substitution and thus a low curvature of utility over time, and the high equity risk premium, which reflects high risk aversion and a high degree of curvature across different states of nature. This well-known inability of CRRA utility to fit both phenomena at the same time—first recognized two decades ago in the financial economics literature—is called the *equity risk premium puzzle*.

The rigidity of CRRA utility is also a serious problem in climate economics because both intertemporal substitution and risk aversion are key determinants of the appropriate price for carbon emissions, which when emitted today create increased risk in the distant future. Under CRRA utility and typical assumptions about economic growth and damages, the interest rate effect of increasing curvature dominates. Thus, increasing the risk aversion in the context of CRRA utility generally implies higher discount rates and (counterintuitively) reduces the appropriate price for emissions. There is no good reason to impose the rigidity of CRRA utility. In the mid-1980s, economists developed a more general class of utility function (Epstein–Zin being the leading example) that allows calibration to realistic values for both interest rates and the equity risk premium. Calibrating utility functions to these market reflections of aggregate societal behavior suggests much higher risk aversion and higher prices for emissions than in previous economic models.

If governments were to price carbon emissions appropriately, the costs borne by society today would balance the potential benefits to future generations. But what is the appropriate price? No one knows. What we do know is that it is significant. A recent U.S. government study<sup>3</sup> suggested a range of values centered on \$21 per metric ton of carbon dioxide. This study relied on models that use the

CRRA utility function; in a section titled “Limitations of the Analysis,” the authors list “incomplete treatment of potential catastrophic damages” and “risk aversion” and go on to point out that “a key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes” (p. 31). Significantly, the study also does not address the most obvious policy implication: If every ton of carbon dioxide emitted is expected to create some amount of damage, then the emission should be taxed at that level to balance that externality.

When governments fail to price climate risk at all, society fails to make appropriate investments in mitigation and the costs of future damages are wastefully magnified. As is well understood, not pricing risk appropriately can lead to disaster. And climate risk is a case in point. When risks are not priced appropriately, investment behavior creates the potential for the catastrophic—and unnecessary—future loss of society’s well-being. Unfortunately, it is very difficult for governments to know—and even more difficult to explain to an uninterested public—how to price the unknown risks associated with increasing the levels of greenhouse gases in the atmosphere. The ambiguity in ascertaining the appropriate price, together with such well-known frictions as organized political opposition and the difficulty of enforcing global cooperation, has prevented climate risk from being priced at all in most countries.

### Other Complexities

Beyond the need to calibrate risk aversion in a manner at least mildly consistent with the equity risk premium lie other complexities in computing the present value of future damages. As noted earlier, present value is a function of future policies. It represents the beginning of an optimal plan that must respond appropriately in the future to the resolution of uncertainty and to technological change. In order to decide how vigorously to press on the brake today, we must form an optimized plan for dealing with future contingencies—much like a cyclist racing down a mountain who, seeing a dangerous circumstance ahead, recognizes that he is going too fast and must brake appropriately while developing a plan for dealing with the situation.

Still other complexities must be addressed. The most obvious is the tremendous—many would say “fundamental”—uncertainty about the science of *what will happen*. It is not a simple exercise in probability weighting a known distribution of outcomes. Unknown risks doubtless exist.

Investors have relevant experience in making the required assessments, not only in terms of understanding discount rates and optimal planning but also in terms of dealing with uncertainty. When we make investments, we assign probabilities to various uncertain scenarios. Through experience, we learn to appreciate how difficult, but essential, it is to assign probabilities to scenarios that have never been experienced or perhaps even imagined. Investors have experience in pricing unknown risks.

In making an investment, we recognize that how much we should charge for exposure to unknown risks depends on how confident we are in the investment’s performance. That degree of confidence will itself depend on how well we understand the investment’s environment, how stable it is, and how much experience we have in operating in that environment.

Consider examples of systems that have small probabilities of catastrophic failure. On the one hand, we have such systems as commercial aircraft, in which experts have a very deep understanding of the environment in which they operate and vast experience in operating in that environment. Over time, the appropriate price for exposure to catastrophic failure on commercial aircraft has become quite low. On the other hand, when we push into less familiar territory, such as operating a spacecraft, even the experts have more limited experience and confidence. The appropriate price is higher.

Similarly, catastrophic events in less familiar environments have been observed recently—for example, deepwater oil drilling and operating nuclear reactors. The lack of experience with these kinds of investments has led to catastrophic failures due to unforeseen circumstances. Perhaps not surprisingly, the probabilities of such outcomes are now seen, with the benefit of hindsight, as higher than they were appreciated before the events. Most governments have responded to these catastrophic failures by indicating that they will raise the risk premiums for these types of investments.

This logic applies similarly to climate change, except that society cannot afford to wait to see whether truly catastrophic outcomes will result. Scientists do not understand climate sensitivities all that well. Despite our best efforts, the earth’s natural environment remains, along many dimensions, a very uncertain system. For example, there is significant uncertainty about how large the ultimate temperature response will be to any given level of greenhouse gases in the atmosphere; there is even more uncertainty as to how ecosystems—and the human experience—would be affected by severe warming.

Because relevant experiments are extremely difficult to perform, the unknown risks are significant and will likely remain so for a long time. Whether catastrophic risks will be realized can only be determined decades from now, long after the time for taking appropriate preventive actions has passed. Clearly, however, scientists have become increasingly concerned as the evidence has confirmed earlier warnings about risks. Because the known and unknown risks of catastrophic consequences are significant, the risk premium for increased emissions today should reflect those risks. What we do know with virtual certainty is that increasing the level of greenhouse gases in the atmosphere increases the risk of catastrophic outcomes.

## Conclusion

When investing in financial markets, investors must think carefully about risk premiums and whether those premiums properly reflect both known and unknown risks. In the case of carbon emissions, the risk premium for increased exposure to unknown risks is clearly not being set

appropriately. In the United States and most of the rest of the world, the risk of carbon emissions is not being priced at all. In fact, fossil fuel costs are still being subsidized in the United States and many other countries. Investors—who generally develop long horizons and have extensive experience in dealing with uncertainty and unknown risks—are a natural constituency that should pull together globally to support government action on climate change and to educate the public about the benefits of pricing emissions.

Climate risk is not being priced. It should be priced immediately at a level that appropriately reflects fundamental uncertainty about catastrophic risks and a high level of societal risk aversion.

As President Calderón put it so clearly, it is time to slam on the brakes.

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*Without attributing any responsibility for the views presented, I thank Kent Daniel, Patrick Bolton, and Frank Ackerman for their efforts in educating me about the economics of greenhouse gas emissions and for significant improvements to this piece.*

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## Notes

1. Frank Ackerman and Elizabeth A. Stanton, "Climate Economics: The State of the Art," Stockholm Environment Institute (30 June 2011). Dr. Ackerman is director of the Climate Economics Group and Dr. Stanton is a senior economist at the Stockholm Environment Institute's U.S. Center at Tufts University.
2. I highly recommend reading the entire summary at [www.worldwildlife.org/climate/wwfbinaryitem23166.pdf](http://www.worldwildlife.org/climate/wwfbinaryitem23166.pdf).
3. U.S. Interagency Working Group on Social Cost of Carbon, "Appendix 15A. Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866" ([www1.eere.energy.gov/buildings/appliance\\_standards/commercial/pdfs/sem\\_finalrule\\_appendix15a.pdf](http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf)).