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CO₂ HEDGING STRATEGIES
THE IMPACT OF UNCERTAINTY UPON EMISSIONS

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CO₂ HEDGING STRATEGIES
THE IMPACT OF UNCERTAINTY UPON EMISSIONS

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1. Introduction

In the greenhouse debate, a central role is often played by a "baseline" or business-as-usual scenario. This describes how emissions might evolve in the absence of carbon constraints. By indicating how much carbon will be deposited in the atmosphere if emissions continue unabated, the baseline provides a point of reference for evaluating the efficacy of strategies to limit emissions.

The Energy Modeling Forum (1993) recently compared baseline projections from several prominent energy models. Although the models differ in a number of aspects they share one important feature. They all employ deterministic approaches. That is, the analyses proceed as if all uncertainty is resolved prior to decision-making. To the extent that uncertainty is addressed, it is through sensitivity analysis.

When applying a deterministic approach to calculating the business-as-usual scenario, one assumes that technology choices are made without consideration of the ongoing greenhouse debate. It is as if decision-makers know, once and for all, that carbon emissions will remain unconstrained.

This may have been a reasonable view a decade ago when the greenhouse effect was a purely scientific issue. The situation, however, is quite different today. Investors are well aware of the possibility of a carbon constraint. Given the long-lived nature of energy investments, the threat of emission limits can affect their choice of technologies.

Today, business as usual means developing an effective hedging strategy in the face of climate-related uncertainties. In the absence of assurances that no constraint will be imposed, investors are likely to opt for a less carbon-intensive supply- and demand-side mix. The degree of precautionary action will depend on the likelihood they assign to future emission limits. The higher the probability of a constraint, the greater will be the incentive to invest in less carbon-intensive alternatives.

In this paper, we examine the extent to which current approaches to estimating the baseline may overestimate emissions -- at least for those periods in which there is still uncertainty concerning the imposition of a carbon constraint. We present an alternative approach which accounts for anticipatory

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behaviour on the part of energy investors. Decision-making is modeled as a sequential process with opportunities for hedging, learning and midcourse adjustments. The approach is used to examine the impact of uncertainty on near-term emissions.

The proposed framework is also useful for exploring an important issue related to the credibility of long-term economic models in general. The greenhouse debate often encompasses exceptionally long time horizons. This is certainly the case when it comes to the costs and benefits of alternative avoidance, mitigation and adaptation strategies. Some have questioned the usefulness of quantitative models for such analyses given the difficulty of modeling economic activity beyond a decade or two.

This concern may be less troublesome than it appears at first. Decision-makers are not being called upon to make decisions today for the next century. Decision-making is an ongoing process of act - then learn. If we find that we are off course, there will be an opportunity for adjustments. The real issue is the sensitivity of today’s decisions to the long-term uncertainties. The approach put forward in this paper provides a useful framework for examining this question. By incorporating the opportunity for learning, we can examine the impact of uncertainty on current and future investment decisions.

2. A Framework for Dealing with Uncertainty

The analysis is based on two alternative formulations of the Global 2100 model. In the one case, uncertainty is treated only indirectly through sensitivity analysis. In the other, it is incorporated explicitly into the model formulation. In both cases, the model employs a "look ahead" rather than a recursive methodology. For a description of the model and its underlying database, see Manne and Richels (1992).

Deterministic models assume that all uncertainties are resolved prior to decision-making. The analysis proceeds as if we had the opportunity to learn the state of the world before taking action. Figure 1a shows the decision tree for this "learn -- then act" characterisation of the decision problem. A circle denotes a chance node -- a point at which uncertainty is resolved. A square denotes a decision node -- a point at which actions are required.

Some studies have attempted to characterize the uncertainty surrounding future emissions by placing likelihoods on scenarios and constructing probability distributions for future emissions (Nordhaus and Yohe 1983, Edmonds and Reilly 1986, and Manne and Richels 1993). Although these studies characterize the uncertainty across scenarios, they ignore the uncertainty within scenarios. Each scenario is evaluated as if all uncertainty were resolved prior to decision-making. In this sense, these studies are still deterministic.

Figure 1b indicates the basic structure that underlies the introduction of uncertainty into Global 2100. It is characterized by the phrase "act - then learn." Decisions are taken at discrete points in time separated by intervals of one decade. Prior to 2010, the energy sector’s supply and demand decisions must be made under uncertainty about the imposition of a carbon constraint. From 2010 onward, decisions will be made after the resolution of uncertainty.

In order to introduce uncertainty into the model, a state-of-world (SOW) subscript is attached to each of the original decision variables and constraints. During the initial period (2000), the decision variables must take on identical values for both SOW, but during the subsequent periods (from 2010 on), they may take on different values, depending on the magnitude of the carbon constraint.
Figure 1. Alternative Characterizations of Decision Problem

(a) Learn − Then Act

(b) Act − Then Learn
Figure 1 shows two long-term possibilities regarding a carbon constraint: emissions will remain unconstrained, or they are to be stabilized at 1990 levels beginning in 2010. Under learn-then act, we know the true state-of-the-world prior to having to make energy sector investment decisions. Under act-then learn, we make the decisions for 2000 without knowing which of these two states will occur. We must therefore select an optimal hedging policy for the near-term emissions level. This policy will depend on the probabilities assigned to alternative outcomes.

Clearly, the imposition of a carbon constraint is not the sole uncertainty facing energy sector decision-makers. There are a number of other highly uncertain parameters. These include economic growth, the rate of price-induced and non-price conservation, technical progress, etc. We begin by assuming that the values for these parameters are known with certainty and adopt the 50th percentile values from a recent expert survey (Manne and Richels 1993). Later on, we will explore the sensitivity of the hedging strategy to the longer-term uncertainties.

3. Alternative Emission Projections for the U.S.

Figure 2 compares U.S. carbon emissions under the two approaches: learn-then act versus act-then learn. Along the dashed lines, we make decisions for 2000 in full knowledge of whether or not the emissions constraint will be imposed. The upper dashed line shows the path commonly termed the business-as-usual or baseline emissions path. It is the path that would be selected if we were certain that emissions will remain unconstrained.

The lower dashed line shows the optimal path when we are told today that it will be necessary to stabilize emissions at 1990 levels by 2010. Interestingly, we choose to reduce emissions in 2000 even though the constraint does not take effect until 2010. This happens for two reasons. First, we allow for the possibility that carbon emission rights may remain unused during one period, but may be carried over for use at a later date. Hence, energy suppliers receive credit for voluntary reductions in 2000. To the extent that emission rights are more valuable in subsequent periods, there is an incentive to reduce emissions early on.

It should be noted that the two dashed lines would differ in 2000 even in the absence of intertemporal trading of emissions rights. If investors are certain that a carbon constraint will be imposed, they will opt for a less carbon-intensive energy system. Given the long-lived nature of energy supply and conservation investments, they will begin moving well in advance of the date that the constraint is actually scheduled to take effect.

For this illustration, we have assumed that there is a 50-50 chance that there will be a political consensus on stabilizing emissions. The solid lines show what happens when the outcome remains unknown through 2000. In this case, the carbon emissions paths do not diverge until after the turn of the century. The hedging strategy consists of adopting an emissions level that lies between the two extreme cases shown along the dashed lines.

It is not surprising that the hedging strategy results in lower near-term emissions than would occur if we were certain that emissions will remain unconstrained. If decision-makers are uncertain as to whether or not a carbon constraint will be imposed, they are likely to hedge their bets and select a mix of supply and demand-side options that is somewhat less carbon-intensive.
Figure 3. U.S. Electric Sector Comparison for the Year 2000
Figure 3 compares the composition of the electric sector in 2000 for the upper dashed line and the solid line. At the margin, the tradeoffs are between investments in new coal-fired power plants and in conservation through demand-side management (DSM). The hedging strategy entails more DSM than would be economically justifiable if we were certain that emissions will continue to be unconstrained. Figure 4 provides the corresponding comparison for the nonelectric sector. The tradeoff here is between imported oil and renewables.

As a result of the hedging strategy, emissions for the year 2000 are only 5.5 per cent higher than they were in 1990. This compares to an 11 per cent increase for the baseline scenario (upper dashed line). Hence, ignoring the possible impact of uncertainty on investment decisions can lead to an upward bias in estimating the growth in emissions -- at least during the next few decades. Once uncertainty is resolved, however, the paths converge.

It should be noted that this emissions reduction comes at a cost. The hedging strategy entails investments that make sense only because of the threat of a carbon constraint. According to our calculations, the incremental costs could be of the order of several billions of dollars annually.

There is another characteristic of the hedging strategy that should be noted. Regardless of the outcome, we will find ourselves somewhat off course. If it turns out that emissions remain unconstrained, we will have invested too heavily in carbon-free alternatives. On the other hand, if stabilization is eventually deemed necessary, we will wish that we had spent more on conservation and renewables. The solid line represents the appropriate investment strategy in the face of 50-50 uncertainty. It minimizes the expected costs of being off course.

Deterministic models ignore the possibility of hedging behaviour on the part of energy sector investors. They assume that we will be able to chart the right course of action from the outset. To the extent that uncertainty results in the need for midcourse adjustments, deterministic models are apt to underestimate the costs of meeting a particular target.

The analysis also has some implications for the debate over carbon taxes. The purpose of such taxes is to raise the price of carbon-intensive fuels sufficiently to achieve the desired emissions target. The higher the tax, the greater the investment in price-induced conservation and the more fuel switching towards less carbon-intensive fuels. Figures 3 and 4 suggest that uncertainty regarding the future imposition of a carbon constraint leads to similar behaviour in the electric and nonelectric sectors. That is, it induces increased investment in conservation and renewables.

This implies that technology choice decisions are being made as if there were an implicit tax on carbon. According to our calculations, in this example, energy sector decision-makers are acting as though a carbon tax of $17.50 per ton were already in place.

4. Some Sensitivity Analyses

For the previous calculations, we assumed that there is a 50-50 chance that we will be required to stabilize emissions by 2010. Otherwise, emissions continue unconstrained. Figure 5 shows the level of precautionary reductions in 2000 as a function of the likelihood of stabilization.

The extreme points on the horizontal axis (0 and 1) correspond to the two learn - then act scenarios. When the probability is zero, we are certain that emissions will remain unconstrained. Conversely, when the probability is one, we are certain that a constraint will be imposed. As we would expect, the degree of precautionary action increases with the likelihood that stabilization will be required.
Figure 4. U.S. Nonelectric Sector Comparison for the Year 2000

Exajoules

Unlimited Emissions (perfect foresight)  Hedging Strategy

- Renewables
- Oil-imported
- Oil domestic
- Gas
- Coal direct use
Figure 5. Reduction Below U.S. "Business As Usual" in 2000
Figure 6 shows the corresponding analysis for the implicit tax on carbon. If the likelihood of stabilization is zero, there will be no precautionary actions. In this case, decision-makers behave as if the tax on carbon-based fuels is zero. The higher the degree of precautionary action, the higher the implicit tax.

It is also instructive to look at the uncertainty regarding eventual goals for reduction. So far, we have assumed that the target will be completely determined by 2010. Figure 7 may provide a more realistic representation of the decision problem. Here, uncertainty about the nature of the carbon constraint is resolved in two stages.

The decision tree in figure 7 describes the sequence of decisions and resolution of uncertainty. As before, the energy sector’s initial supply and demand decisions must be made under uncertainty about the imposition of a carbon constraint. But now investors may have to contend with a second uncertainty -- the ultimate goal. If a constraint is imposed, they must wait until 2030 to find out whether the final target is stabilizing emissions or the more ambitious goal of stabilizing atmospheric concentrations. In the latter case, U.S. emissions are gradually tightened to 30 percent of 1990 emissions by 2050. According to Houghton et al. (1992), a reduction of this magnitude would be required to stabilize atmospheric concentrations of CO₂.

For example, suppose that there is a fifty-fifty chance of a carbon constraint. Further suppose that if a constraint is imposed, there is only one chance in five that the ultimate target will be stabilizing concentrations. Otherwise, we will continue to stabilize emissions. Figure 8 provides a comparison between the optimal emissions paths under learn-then-act and act-then-learn.

Among the dashed lines, we make decisions for 2000 in full knowledge of whether an emissions constraint will be imposed and, if so, the ultimate target. The upper and middle dashed lines are identical to those reported earlier. The lower dashed line is for the case in which emissions are initially reduced to 1990 levels by 2010 and further reduced to 30 percent of 1990 levels by 2050.

The solid lines, in effect, show two hedging strategies. The first is through 2000. During this period, it is unclear as to whether any carbon constraint will be imposed. If we learn that emissions are to be constrained, we launch into a second hedging strategy. Once we learn the final target, emissions either remain stabilized or are reduced an additional 70 percent.

Interestingly, the initial hedging strategy is almost identical to that reported earlier in this paper. That is, the long-term uncertainty regarding the ultimate target has little effect on near-term decisions. We see a similar result when the conditional probability of having to stabilize concentrations is raised to .50. This is because we assume that the timetable for achieving the long-term target is 2050. Hence, there is ample time for the transition.

5. Sensitivity of Today’s Decisions to Long-Term Uncertainties

This discussion raises an important issue. Just how sensitive are today’s decisions to the future character of the energy system? Much of the economic analysis needed for the greenhouse debate encompasses exceptionally long time horizons -- often a century or longer. Assumptions are required about a number of factors that are inherently uncertain, e.g., economic growth, energy intensity, technical progress, etc. Critics point to the difficulty of projecting economic activity into the next decade and question the credibility of the longer-term analyses.
Figure 6. Implicit Tax on Carbon in 2000
Figure 7. Decision Tree for Two-Stage Resolution of Uncertainty

Initial Hedging Strategy | Initial Resolution of Uncertainty | Subsequent Strategy | Subsequent Resolution of Uncertainty

2000 | 2010 | 2030 and Beyond

- B - A - U
- Stabilize Emissions
- Continue to Stabilize Emissions
- Stabilize Concentrations
Figure 8. U.S. Carbon Emissions

- Unlimited Emissions
- Emissions Stabilization
- Stabilization of Concentrations

- Hedging Strategies
- Perfect Foresight
This concern may not be as troublesome as it seems initially. Decision-makers are not being called upon to make decisions for the next one hundred years. Decision-making is a sequential process, with many opportunities for learning. The real issue is the sensitivity of today’s decisions to these longer-term uncertainties. The approach put forward in this paper provides a conceptual framework for addressing this question.

We have already seen that the initial hedging strategy is sensitive to the possibility of a carbon constraint in 2010. The higher the likelihood of having to stabilize emissions, the higher the degree of precautionary action. Near-term emissions, however, do not seem highly sensitive to the level of the carbon constraint beyond 2020.

But what about other long-term uncertainties? How important is it to know what energy demands will be in 30 years? Or to identify the technologies that will be in place to meet those demands? An exhaustive analysis of these questions is beyond the scope of this paper, but considerable insight can be gleaned from a few examples.

We begin with a highly controversial demand-side parameter: the rate of Autonomous energy efficiency improvements (AEEI). Non-price efficiency improvements may be brought about by deliberate changes in public policy, e.g., speed limits for automobiles. Energy consumption may also decline as a result of shifts in the basic economic mix away from manufactured goods and toward more services. Thus, the AEEI summarizes all sources of reductions in the economy-wide energy intensity per unit of output. Based on our expert elicitation, the previous calculations employ an AEEI of 0.70.

To explore the impact of the long-term AEEI value on today’s decisions, we focused on the AEEI for the year 2020 and beyond. The sensitivity analysis explored values which were 50 per cent lower and 100 per cent higher than those employed in the earlier analysis. As it turns out, the optimal hedging strategy for 2000 is insensitive to assumptions about the long-term rate of autonomous energy efficiency improvements -- at least within the range considered here.

We see the same phenomenon with regard to the supply side. A great deal of discussion has been devoted to the cost of the nonelectric back-stop. This represents the cost of a long-term carbon-free alternative to conventional oil and coal-based synthetic fuels. For the previous calculations, we assumed that the nonelectric back-stop becomes available in 2020 at a cost of approximately $80 per barrel. The hedging strategy for 2000 turns out to be insensitive to assumptions about the cost of the nonelectric backstop. Emissions for 2000 are essentially the same for a backstop costing anything between $40 and $120 per barrel.

This is not to say that information regarding these two parameters will be unimportant to future decisions. It obviously will. But such information is of little value to today’s decisions.

These results have important implications for long-term energy system modeling. We need not be overly concerned with our inability to predict the detailed character of the energy system several decades into the future. Uncertainty is important only to the extent that it confounds near-term decision-making. Today’s decisions appear to be relatively insensitive to some of the more controversial longer-term uncertainties in the greenhouse debate.

6. Conclusions

This paper examines how deterministic approaches to modeling the emissions baseline are apt to overestimate carbon emissions -- at least in those periods in which there is still uncertainty over the
imposition of a carbon constraint. The problem lies with the definition of business as usual. When calculating the baseline, deterministic models assume that investors know, once and for all, that emissions will continue unconstrained.

This may have been an appropriate definition of business as usual in the past when investors assigned negligible probability to a carbon constraint. Today the situation is quite different. The need to reduce emissions is being hotly debated both domestically and internationally. Until this issue is resolved, investors are apt to hedge their bets and opt for a less carbon-intensive mix of supply and demand-side alternatives.

The approach put forward in this paper takes account of anticipatory behaviour on the part of energy sector decision-makers. We show how even the threat of a carbon constraint can reduce the rate of growth in emissions. The higher the probability one assigns to a constraint, the greater the optimal degree of precautionary action.

The analysis also shows that the emission reductions will be costly. The hedging strategy entails investments that make sense only because of the risk of a carbon constraint. In particular, we are likely to see more investment in conservation and renewables than would otherwise be warranted.

Whereas deterministic approaches may overstate emissions, they may also understate costs. The perfect foresight assumption implies that we are able to chart the ideal course of action for the energy sector from the start. This is not the case. Greenhouse decision-making is apt be a sequential process with learning and with midcourse corrections. Analyses which ignore the "act - then learn" nature of the decision process are likely to underestimate the costs of meeting a particular target.
REFERENCES


