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Energy R&D portfolio analysis based on climate change mitigation

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ABSTRACT

The diverse nature and uncertain potential of the energy technologies that are or may be available to mitigate greenhouse gas emissions pose a challenge to policymakers trying to invest public funds in an optimal R&D portfolio. This paper discusses two analytical approaches to this challenge used to inform funding decisions related to the U.S. Department of Energy (DOE) applied energy R&D portfolio. The two approaches are distinguished by the constraints under which they were conducted: the need to provide an end-to-end portfolio analysis as input to internal DOE budgeting processes, but with limited time and subject to institutional constraints regarding important issues such as expert judgment. Because of these constraints, neither approach should be viewed as an attempt to push forward the state of the art in portfolio analysis in the abstract. Instead, they are an attempt to use more stylized, heuristic methods that can provide first-order insights in the DOE institutional context. Both approaches make use of advanced technology scenarios implemented in an integrated assessment modeling framework and then apply expert judgment regarding the likelihood of achieving associated R&D and commercialization goals. The approaches differ in the granularity of the scenarios used and in the definition of the benefits of technological advance: in one approach the benefits are defined as the cumulative emission reduction attributable to a particular technology; in the other approach benefits are defined as the cumulative cost reduction. In both approaches a return on investment (ROI) criterion is established based on benefits divided by federal R&D investment. The ROI is then used to build a first-order approximation of an optimal applied energy R&D investment portfolio. Although these methodologies have been used to inform an actual budget request, the results reflect only one input among many used in budget formulation. The results are therefore not representative of an official U.S. government or DOE funding recommendation but should instead be considered illustrative of the way in which methodologies such as these could be applied.

1. Introduction

Integrated assessment modeling incorporating advanced technology has shown that the availability of, or improvement in, such technologies significantly lowers the cost of meeting a specified climate constraint (see, e.g., Edmonds et al., 2007, or Richels and Blanford, 2008). These results provide a strong motivation for policymakers to take steps to promote technology development. Funding for public sector R&D programs is one approach often used to achieve this goal, with the aim of lowering cost or accelerating the readiness of technologies. This is often characterized as the “technology push” approach, in contrast to policies that provide incentives for commercialization by the private sector, which are described as “demand pull” (Nemet, 2009). Although an analysis of the effectiveness and optimal allocation of resources between these approaches is a useful and important area of study, the focus of this paper is on optimization of U.S. government energy R&D.

One of the challenges associated with government energy R&D is deciding on what basis to make decisions about overall funding and its distribution across technologies. For example, U.S. Department of Energy (DOE) R&D funding for applied technology (i.e., excluding basic research) has varied between $1 billion and $6 billion annually since 1978, with considerable change in the distribution among technologies in the portfolio over that period (Anadon et al., 2009). These changes have been driven by factors such as oil supply disruptions, oil prices, political interest in investment or disinvestment in particular technologies, and, more recently, concern about climate change. Although it is unlikely that a federal R&D portfolio would ever be structured entirely around consideration of a single issue, it is useful to consider how one might develop a methodology for such an analysis as an input into the portfolio design. Because of the broad implications of greenhouse gas (GHG) emission reduction goals for the energy sector, a portfolio analysis methodology based on meeting a GHG emissions constraint is a particularly interesting challenge.

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An approach often used to estimate the GHG reduction benefits of individual technologies in a portfolio is to evaluate those technologies using a bottom-up approach focusing on their technical potential. That is, the current or projected characteristics of a technology are used to estimate its potential for achieving emission reductions in the absence of economic or policy constraints (Pacala and Socolow, 2004; James et al., 2007). Such studies can be very useful to illuminate the scale of technology deployment required to meet climate objectives, or to illustrate the emission reductions that could be associated with achieving technology goals. However, because the actual contribution of a technology to emission reduction will depend on its cost relative to those of other technologies available in the portfolio, the utility of these studies for comparative, integrated technology analysis is limited.

Models that incorporate technology representations in an integrated energy-economic framework address this shortcoming. These integrated assessment models are of particular interest because they include both technologies and economics and explicitly incorporate GHG emissions. Using these models to analyze policy frameworks that limit GHG emissions enables an explication of the combined effects of climate and technology policy. The U.S. Climate Change Technology Program (CCTP) has sponsored two recent efforts in that regard, described in Clarke et al. (2006a, 2008a). Both of these studies make use of GCAM (formerly MiniCAM), an integrated assessment model notable for its use of detailed technology representations (Brenkert et al., 2003; Kim et al., 2006).

Whether using a bottom-up, technical potential approach or an integrated economic framework, a full understanding of the potential of an R&D portfolio to contribute to GHG emission reduction requires establishing a linkage between R&D funding and full-scale commercialization of technologies. Efforts to discern the effect of R&D in retrospective evaluations of technology cost or commercialization (National Research Council, 2001; Nemet, 2006) are made difficult by a number of factors, including variation in the rate of progress across technologies, the difficulty of determining whether to attribute technological progress to R&D or to increases in deployment (learning by doing), and spillover effects between technologies. The policy environment may make such an analysis difficult as well, in that technology-specific barriers to commercial deployment implicit in the regulatory regime may act as a brake on certain technologies (Brown et al., 2007), or there may be incentives for private sector R&D whose effects may be difficult to distinguish from those of public R&D. It may also be that public R&D investment "crowds out" private sector investment in some technologies, which would imply that the public sector investment was unnecessary.

The lack of certainty associated with the linkage between R&D and technology improvement makes it difficult to incorporate technology characterizations into models (Clarke et al., 2006b, 2008b; Pizer and Popp, 2008). Even if one ignores the attribution problems already identified, it is difficult to specify the effect of progress generically for all technologies. Baker et al. (2008) show that some representations of technology improvement result in a uniform downward shift in the marginal abatement cost curve, others pivot the curve down about the origin, while still others actually result in increased marginal abatement costs at high levels of abatement. They also suggest that each of these behaviors is reasonable depending on the nature of the technology being considered.

Another consideration when using models to look at improvements in technology characteristics over time is whether those improvements have been endogenously or exogenously determined. Some models incorporate endogenous learning by doing or productivity improvements that can obscure assumptions about technology characteristics (Gillingham et al., 2008). Others define technology characteristics exogenously, as specified improvements over time supplied as inputs to the model. From the perspective of a policymaker or R&D manager seeking a clear comparison of R&D goals relative to a modeled technology representation, exogenous specification of technology characteristics is preferable. One can use multiple levels of exogenously defined technology performance to evaluate the effects of technology improvement, with the results bounded by the least advanced and the most advanced technology states. The question of attribution of technology improvements between those states—whether to public or private sector R&D, learning by doing, or a policy framework that addresses technology-specific barriers—can then be addressed explicitly outside the framework of the model.

This paper discusses two analytical approaches for end-to-end portfolio analysis that were used to develop first-order insights to inform decisions about funding for an applied energy R&D portfolio. These approaches are characterized by the constraints under which they were conducted: the need to perform an end-to-end portfolio analysis as input to internal U.S. DOE budgeting processes, but with limited time and subject to institutional controls regarding important issues such as expert uncertainty assessment. Because of these constraints, neither approach should be viewed as an attempt to push forward the state of the art in portfolio analysis in the abstract. Instead, they are an attempt to use more stylized, heuristic methods that can provide first-order insights in the DOE institutional context.

The two approaches are described in Sections 2 and 3 of this paper. The first, based on the 2006 set of CCTP scenarios, defines the value of a technology in terms of the quantity of carbon emissions it reduces, a metric attended by important conceptual challenges but with strong currency in climate technology discussions. The second, based on the more extensive 2008 set of CCTP scenarios, defines the value of a technology in terms of the cost reduction associated with its use in a portfolio. In both cases the expected benefits of a technology are estimated using a risk-weighting methodology that attempts to incorporate the effects of both technical and market risks—an explicit nod to the fact that R&D must be considered in the context of other important factors. The portfolio is then built based on a rank-ordered return-on-investment metric associated with different levels of available federal R&D investment. The relative merits of the two approaches and opportunities for improvement are discussed in Section 4.

2. First approach

The first portfolio analysis described in this paper was based on the set of three advanced technology scenarios described in Clarke et al. (2006a). An unconstrained reference technology scenario defines the emissions baseline, i.e., global emissions in the absence of climate policy and with a "business as usual" rate of technology improvement. A constrained reference technology scenario defines the baseline policy costs, where the constraint is a specified limit on the GHG concentration in the atmosphere. The constraint is global, which means that assumptions must be made about GHG reductions in all other world regions. GCAM has 14 such regions with separate specification of economic growth, energy service demands, and resource supply curves in each. In these scenarios all regions act simultaneously to reduce their emissions to the level required to meet the constraint while minimizing total cost. The three advanced technology scenarios, run under the same constraint, determine the cost reductions relative to baseline (the constrained reference technology scenario), since advanced technology lowers the cost of meeting the constraint. ("Cost" here refers to the total cost of mitigation, including both consumer and producer surplus, as represented by calculating the area under the marginal abatement cost function.) The reference and advanced technology characteristics are exogenously defined, and no other learning is assumed. Although the climate problem is global in nature, the desire to frame the analysis around U.S. government technology investments necessitated a focus on the U.S. share of a global CO_2 emission reduction path. A 450-ppm CO_2 constraint was chosen to provide an aggressive goal for technology deployment.

The set of three scenarios used in this analysis is based on hypothetical futures in which different clusters of technologies have