Energy Economics 31 (2009) S27–S36

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

R&D investment strategy for climate change

Geoffrey J. Blanford

Electric Power Research Institute, Palo Alto, CA 94304, United States

ARTICLE INFO

Article history:
Received 5 March 2007
Received in revised form 13 March 2008
Accepted 27 March 2008
Available online 9 April 2008

Keywords:
R&D strategy
Investment portfolios
Technology policy
Climate change

ABSTRACT

The economic costs of stabilizing greenhouse gas concentrations over the coming century depend critically on the development of new technologies in the energy sector. Our research and development (R&D) investment strategy is the control variable for technology availability. This paper proposes an analytic framework for determining optimal R&D investment allocation and presents some numerical results to demonstrate the implementation of the methodology. The value of technological advance in three targeted areas–fossil-based generation, renewables, and carbon capture and storage–is represented by the increase in expected welfare in the presence of an emissions policy constraint of initially uncertain stringency. R&D expenditure increases the probability of advance. Optimal investment is determined by its relationship with success probability, which is assumed to exhibit decreasing returns to scale, relative to the value of success. While the numerical results are speculative, the paper offers insights into the nature of an optimal technology strategy for addressing climate change.

1. Introduction

The role of technology development in designing an effective policy response to increasing anthropogenic greenhouse gas emissions is critical. The traditional treatment of an environmental externality is to adjust private actors' incentives so as to induce the socially optimal deployment of known abatement technology. In the case of greenhouse gases, particularly carbon dioxide emissions from the electric power, transportation, and direct energy sectors, technological options for meaningful abatement at a reasonable cost are currently not available (Hoffert et al., 2002; Caldeira et al., 2003). However, because a solution to the climate change problem must occur over several decades, there is scope for the introduction of new technology to future periods. Thus today's policy-makers must have a twofold strategy: first, to induce optimal adoption of existing technology, and second, to ensure optimal development of future abatement technology.

A general result in the economics literature is that because these objectives stem from two separate externalities, they must be addressed by two separate instruments. The suite of technologies chosen by private actors at a given moment is suboptimal in that it does not take into account the environmental damages associated with the emissions it produces, suggesting the use of Pigouvian market-based instrument to “price in” the externality. On the other hand, the allocation of investment to the development of future technologies by the private sector is likely to be suboptimal because of a collection of factors known as innovation market failures. The primary market failure, first articulated by Arrow (1962), is the inability of a private innovator to fully appropriate the benefits of her invention due to knowledge spillovers. Also suppressing the level of private investment in innovation relative to the social optimum are factors such as lower risk tolerance, higher discount rates, and difficulties financing an intangible asset.[1]

To a certain extent, emissions policies can facilitate technology development through processes known as induced technical change (ITC). A large body of literature has examined two distinct links: increased expenditure on research and development (R&D) as a result of policy incentives, and cost reductions in abatement technologies as a direct result of deployment experience (increased by policy incentives).[2] Analytical, numerical, and empirical results of these studies all indicate that technological change is indeed accelerated by abatement policy, and that this induced change can provide significant cost savings with respect to achieving a fixed environmental target. However, the focus on ITC describes the stimulus of a contemporaneous price signal on learning or R&D by private actors. As such, the *type* of technological change brought about in this manner is limited to short-term, incremental improvements whose costs are fully justified by benefits accruing only to the innovating firm. Therefore an emissions penalty alone cannot be the agent of a long-term, radical technological transformation.

There are several sides to this argument. First, in the case of an endogenous R&D response, technology development is limited by the set of innovation market failures discussed above. In the case of learning effects, a similar issue arises in that costs for all firms typically

[1] See Clarke (2002) and Jaffe et al. (2001) for more detailed discussion of innovation market failures in environmental technologies.

[2] Important examples include Goulder and Schneider (1999), Goulder and Mathai (2000), and van der Zwaan et al. (2002).

E-mail address: gblanford@epri.com.

0140-9883/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.eneco.2008.03.010

decrease in aggregate deployment of a new technology, suggesting a "free-rider" problem. Moreover, it is not clear whether technological change stemming from experience occurs strategically or coincidentally. Thus the rate of technical change of any type from endogenous processes is likely to be lower than the social optimum. Secondly, only developments with benefits accruing in roughly the same time period can be induced by the current emissions penalty. In general, since private discount rates are typically lower than social rates, firms do not optimize over long timeframes. Moreover, if they did, beliefs about future abatement policy conditions, rather than the concurrent policy, would determine R&D investment decisions.[3] Finally, the presence of innovation market failures and the abbreviated time horizon of ITC together suggest the distinction between the basic and applied ends of the research spectrum. Applied research refers to the development of proven concepts into commercially viable configurations, including incremental, rather than fundamental, design improvements. Basic research refers to the creation of new concepts, perhaps with broad applicability to several areas, and often characterized by radical improvements in cost or efficiency. Applied research typically has a shorter time cycle and more deterministic outcomes, whereas basic research requires an extended timeframe and has highly uncertain outcomes. Because of limited planning horizons, comparatively low risk tolerance, and acute appropriability failures for basic research outcomes, the private sector's capabilities are largely centered on applied technology development.

The inability of an emissions policy to motivate investment in targeted long-term, basic research is a critical gap in the public strategy to address climate change, since fundamentally new technology is required for a cost-effective transition to a low- or zero-carbon energy system consistent with the stated goal of climate stabilization (UNFCCC, 1992). There is significant uncertainty about the optimal stabilization level, which will reflect the severity of damages from climate change, as well as about the availability of mitigation options. As opposed to uncertainty about damages, the probability distribution over the set of technological possibilities can be controlled; our R&D investment strategy is the control variable. The extent and allocation of this investment must therefore be viewed as a risk management problem. This paper proposes an analytic framework for determining optimal R&D investment allocation and presents numerical results from a sample implementation of the methodology in the context of climate change policy.

2. Approach

Measuring the benefits of R&D investment consists of two steps. The first is the valuation of potential research outcomes, as determined by the markets in which they will diffuse. The second is assessing the relationship between investment and the achievement of these potential outcomes. The approach employed here is to separate the two steps. An energy-economy model is used to calculate the aggregate economic welfare in a variety of technology scenarios, which are interpreted as alternative outcomes to corresponding R&D programs. This modeling exercise is applied under a range of assumptions about policies controlling GHG emissions. While the focus is on technologies that enable emissions reductions, note that the impact of their development is denominated in dollars. The results of these simulations are then used as inputs into a simple decision model linking R&D investment to a probability distribution over alternative outcomes, yielding an optimal portfolio.

There are several examples in the climate policy literature of the use of energy-economy models in evaluating the impact of alternative technology scenarios. These include the Energy Modeling Forum (EMF) 19 study examining alternative technology strategies for climate change (Weyant, 2004) and the Global Technology Strategy Project (GTSP), which has shown the value of improved technologies in reducing the cost of meeting a fixed climate goal (Edmonds and Smith, 2006). Some modeling studies have incorporated R&D investment decisions into the representation of the economy, such as the WITCH model, described in this volume by Bosetti and Tavoni (2009-this issue). In this paper, R&D investment is essentially modeled as the control process for the state of technology separate from private market outcomes. Although this approach omits general equilibrium effects such as "crowding out" of other research expenditure, as discussed in Popp (2006), it allows a direct comparison of the costs and benefits of a targeted climate change technology development program.

The processes underlying the relationship between R&D investment and research outcomes are poorly understood and difficult to measure—the approach taken here attempts to capture the essential elements in a simple analytical framework. In particular, R&D outcomes are linked stochastically, rather than deterministically, to investment; they require a significant time horizon to materialize; and returns to scale are decreasing in expenditure. To satisfy these characteristics, the probability distribution over technological outcomes is modeled as a concave function of investment in basic research, with successes entering the market in a subsequent decision period. This analytical model of R&D investment is described in detail in Blanford (2006). Similar analytical approaches are used by Baker et al. (2006) in their analysis of increasing uncertainty, and Loch and Kavadias (2002) in the context of new product development.

3. Part I: The value of technology

3.1. Model description

The numerical results for the value of technology exercise are based on the MERGE model (a *m*odel for *e*valuating *r*egional and *g*lobal *e*ffects of GHG reduction policies). MERGE is an intertemporal general equilibrium model with nine geopolitical regions and a reduced-form description of atmospheric GHG accumulation, radiative forcing, and in some cases, climate impacts. The model includes a bottom-up representation of the energy supply sector in which choices are made among specific activities for the generation of electricity and for the production of non-electric energy. Energy demand is represented using a nested production function to determine how aggregate economic output depends upon the inputs of capital, labor, electric and non-electric energy. In this way, the model allows for both price-induced and autonomous (non-price) energy conservation and for interfuel substitution. Each of the model's nine regions maximizes the discounted utility of its consumption subject to an intertemporal budget constraint. GHG mitigation effort can be simulated by applying constraints on annual emissions levels from participating countries, or by allowing optimal emissions reductions with respect to a long-term stabilization target.[4]

Of critical importance to the results for this study is the definition of the R&D programs and corresponding technology scenarios implemented in MERGE. For purposes of illustration, the analysis focuses on three areas of technology in the electric generation sector that are key determinants of CO_2 emissions: the performance of fossil-based generation (FOS), the cost of renewable generation (RNW), and the viability of carbon capture and storage (CCS). The R&D portfolio consists of a program in each of these areas, for which two technology pathways are defined. An "optimistic" pathway represents the success of the R&D program in achieving a series of aggressive cost and

[3] Because future policy conditions actually depend on the actions of firms in the interim, such dynamic considerations lead to a game formulation between the regulator and the firm. Montgomery and Smith (2005) suggest an "announcement effect" that undermines the credibility of a future price.

[4] Further background on MERGE can be found in Manne et al. (1995) or Richels et al. (2007), or at www.stanford.edu/group/MERGE.