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# Investment in risky R&D programs in the face of climate uncertainty

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**Abstract**

We analyze how the socially optimal technology R&D investment changes with the risk-profile of the R&D program and with uncertainty about climate damages. We show that how technology is represented in the model is crucial to the results; and that uncertainty in damages interacts with uncertainty in the returns to R&D. We consider R&D that reduces the cost of abatement multiplicatively, and argue that this is a good representation of R&D into non-carbon technologies; and R&D that reduces the emissions-to-output ratio, and argue that this is a good representation of R&D into fossil fuel technologies. For R&D programs into non-carbon technologies, optimal investment is higher in riskier programs. Our empirical model indicates that the optimal investment in a risky program is about 3 1/2 times larger than in a program with certain returns. For R&D programs aimed at reducing emissions in fossil fuel based technologies, our results show that, qualitatively, investment is higher in less risky programs under most uncertain damage scenarios. Our empirical model shows, however, that the risk-profile of fossil fuel based R&D programs generally has little quantitative impact on optimal investment. The exception is that when the probability of a catastrophe inducing full abatement is very high, investment is about twice as high in risky programs compared to programs with certain returns.


*Keywords:* Climate change; Technology R&D; Uncertainty; Environmental policy

## 1. Introduction

Policy makers are concerned with limiting the future cost of climate change. The economics literature has focussed on the optimal abatement path (e.g. Baker, 2005; Gollier et al., 2000;

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Keller et al., 2004; Kolstad, 1996; Nordhaus and Boyer, 2000; Manne, 1996; Pizer, 1999; Ulph and Ulph, 1997; Webster, 2002) and the relative merits of different abatement-related policy instruments for climate change or related environmental issues.[1] Policy makers in the U.S., however, have shied away from any emissions policy, and instead have focussed on technology policy.[2] In the face of uncertainty – about both eventual climate-related damages and technical success – it is unclear how much R&D is desirable and which categories of technologies should be targeted. Baker et al. (2006) analyzed how socially optimal investment in broad classes of technology R&D was impacted by uncertainty in the damages from climate change. In this paper, we extend their model, considering two categories of technologies, and analyze how the optimal technology R&D investment changes with the risk-profile of the R&D program as well as with uncertainty about climate damages.

This paper is related to the literature on investment under uncertainty and stochastic dominance, as well as R&D portfolio problems. The classic investment under uncertainty problem considers how optimal investment is impacted by uncertainty in the environment, such as prices or demand (see Dixit and Pyndyck (1994); Caballero (1991). This literature has also considered R&D programs with uncertain returns and has shown that there may be an option value to investing even when the program has an overall negative expected value, and that this option value may increase in the riskiness of the project (Huchzermeier and Loch, 2001; Roberts and Weitzman, 1981). Much of the stochastic dominance literature is focused on determining what kinds of stochastic shifts in the environment induce more investment (Athey, 2002). Another strand of the literature considers how the choice between risky prospects is related to the level of risk aversion (Gollier, 1995; Jewitt, 1989).

In this paper we combine exogenous uncertainty in climate damages with uncertainty in R&D, for multiple technologies, to determine how the riskiness of the R&D program impacts the optimal level of investment in that program; and how this is impacted by uncertainty in the damages from climate change. We recognize that different R&D programs can have different levels of risk. Some programs are primarily aimed at incremental improvements, and tend to be low-risk: a larger investment leads to larger incremental returns with a great deal of certainty. Other programs are aimed at achieving breakthroughs, and tend to be high risk: an increase in investment increases the probability of success. We define a breakthrough as technological change that will reduce the cost of abatement to near zero, for example a reduction in the cost of very low-carbon energy that makes it widely economically competitive with fossil fuel technologies, or a combination of efficiency gains and sequestration that would allow for near zero-emissions fossil fuel based energy.[3] We model an investment in a risky R&D program as inducing a first order shift in the probability distribution over the possible outcomes of that program. We consider how an increase in the riskiness of a program impacts the optimal investment in a first order shift in the program.

This problem differs from classic R&D portfolio problems (See Keefer et al., 2004 for a review) because the effect of technological change is not inherent in the technology alone, but

[1] See Aidt and Dutta (2004); Baldursson and Von der Fehr (2004); Bansal and Gangopadhyay (2003) for recent work comparing instruments for generic environmental regulation and Hahn and Stavins (1995); Stavins (1997) for an overview of instrument choice for climate change. See Downing and White (1986); Fischer et al. (2003); Goulder and Mathai (2000); Jung et al. (1996); Milliman and Prince (1989); Montero (2002); Parry (1998) for discussions of the impact of policy instruments on environmental technical change.

[2] See http://www.doe.gov for information on the Climate Change Technology Program.

[3] The main greenhouse gasses (GHG) are Carbon Dioxide ($CO_2$), Nitrous Oxide, Methane, and CFCs. We will often refer to carbon, as it is the most economically important of the GHGs and the largest contributor to climate change.