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The optimal time path of clean energy R&D policy when patents have finite lifetime[☆]

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ABSTRACT

We study the optimal time path for clean energy innovation policy. In a model with emission reduction through clean energy deployment, and with R&D increasing the overall productivity of clean energy, we describe optimal R&D policies jointly with emission pricing policies. We find that while emission prices can be set at the Pigouvian level independently of innovation policy, the optimal level of R&D subsidies and patent lifetime change with the stages of the climate problem. In the early stages of clean energy development, innovators find it more difficult to capture the social value of their innovations. Thus, for a given finite patent lifetime, optimal clean energy R&D subsidies are initially high, but then fall over time. Alternatively, if research subsidies are kept constant, the optimal patent lifetime should initially be long and fall over time.

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Introduction

Worldwide emissions of greenhouse gases are growing, and it is recognized that technology improvements are an important element for achieving the deep emission cuts that are suggested in the climate negotiations (see, e.g., surveys in Carraro et al., 2003; Jaffe et al., 2005). For instance, they are essential for the success of the European Union's Roadmap for moving to a low-carbon economy, which suggests that the EU by 2050 should cut its emissions to 80% below 1990 levels.¹ The question we address in this paper is whether, in general, setting the emission prices right is sufficient to trigger the required technological developments, or whether there is need for extra policies directed specifically at the enhancement of abatement technologies, e.g. the development of clean energy. Furthermore, if the answer to the latter question is affirmative, what characterizes the profile of such policies?

Our first main result follows from establishing a benchmark. If innovation markets function perfectly, e.g., through complete patents with infinite lifetime, then the stage of technological development plays no role in optimal emissions pricing. The emissions price can be set at the Pigouvian level, where the marginal costs to the emitter equals the present value of the future stream of marginal damages associated with the emissions.² Technology response to environmental policy does not change this fact. In other words, climate policy can be set independently of climate innovation policy.

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¹ http://ec.europa.eu/clima/policies/roadmap/index_en.htm

² We limit the interpretation of the Pigouvian tax to include only environmental damages. This is a choice for convenience, common in environmental economics. In this paper we specify a cumulative absorption capacity for the atmosphere and define the Pigouvian tax as the marginal social costs of meeting the target.

Various studies on climate R&D, or more broadly environmental R&D, implicitly assume such perfect markets for innovation (cf. [Goulder and Mathai, 2000](#)). It is believed, though, that the market for innovations is imperfect, and it is important to extend the analysis of economic policy to imperfect economies ([Stern, 2010](#)). [Nordhaus \(2002\)](#), [Popp \(2004, 2006\)](#), and [Gerlagh and Lise \(2005\)](#), for example, in their numerical analyses of R&D and climate policy, assume that the social value of innovations exceeds the private value of innovations by a constant factor 4. Under these circumstances, the apparent question becomes whether environmental policy needs to complement the Pigouvian tax with innovation policy directed at environmental technology.

The case for a dedicated climate technology policy is often contested by economists who point out that it is not implied as such by an imperfect market for innovations. If the gap between social and private returns on innovation is identical over different economic sectors, then a generic innovation policy can correct the innovation market failure for all sectors jointly. Only recently have there been studies pointing to reasons why clean energy R&D should be treated differently ([Popp and Newell, 2009](#); [Acemoglu et al., 2012](#)). But the arguments brought forward do not include the main focus of this paper, which is that patents typically expire after a certain period and this creates a temporal structure that links the state of the climate to the attractiveness of clean energy R&D for private entrepreneurs. [Krysiak \(2011\)](#) makes such a connection, but does not address the time pattern of optimal R&D policy as in this paper. The mechanism that we recover in our model is that private and social returns on clean energy R&D follow their own, quite different, dynamic patterns. The gap between social and private returns on innovation then changes over the life-cycle of the climate problem, and optimal clean energy R&D policy varies along. [Hart \(2008\)](#) studies how this affects the optimal time path of CO₂ taxes, whereas [Goeschl and Perino \(2007\)](#) study R&D sequences when human kind is confronted with repeating cycles of various environmental problems. Our paper can be considered a more detailed study of one such cycle, such as climate change. In this context, when we refer to a cyclical pattern, we refer to the increase and decline of a pollutant over the life-cycle of an environmental problem as typical for an Environmental Kuznets Curve; we do not imply a repetition of cycles.

Our second and most interesting main finding is that the optimal clean energy R&D policy has a cyclical pattern counter to the pricing policy (e.g. carbon pricing): Assuming finite and constant patent lifetime, the optimal R&D subsidy should initially be high when carbon prices are low, and then gradually decline over time while carbon prices increase; optimal research subsidies might even become negative when carbon prices reach a maximum. After sufficient knowledge has been produced so that carbon emissions fall close to zero, at moderate carbon prices, the innovation subsidy should increase again and converge to a constant rate (not necessarily positive). In a similar way, if R&D subsidies are kept constant, the imperfections in the clean energy market can be corrected by the patent lifetime. It will have a similar pattern as the R&D subsidy when patent lifetime is constant, i.e., decrease monotonically when carbon prices increase and increase again when carbon emissions drop to zero.

If we focus on innovation subsidies, the intuition for this pattern is that innovations will be biased towards technologies that pay back within the patent's lifetime, so that there is insufficient support through markets to develop and improve abatement technologies when the climate problem is emerging and (e.g. carbon) prices are still low. Yet at the point in time when the carbon price is close to its maximum, the market offers innovators a large incentive for emission-reducing research. Innovations will peak without the need for research subsidies. Such a pattern has been seen for SO₂ emissions. SO₂ is an interesting pollutant to evaluate as its emissions peaked a few decades ago in most industrialized countries. While there was no supporting research policy, patents spiked for SO₂ abatement technologies when more stringent regulatory standards came into effect ([Dekker et al. 2012](#), Fig. 2). In case that 'clean energy' research tends to crowd out other research, the incentive for clean energy innovations might as well be 'too much', e.g. when carbon prices are at a temporarily high level. In the long run when the environmental life-cycle has ended, there is no reason anymore to treat clean energy research differently from other research. That is, in the long run the optimal subsidy may rise again because the proportion of social returns captured by the innovator is declining.

Thus, the level of the clean energy subsidies must vary over time, targeted to the early phases of the technology development. The mechanism laid out here resembles the learning-by-doing models; in this paper we present conditions on patent-lifetime when the same mechanisms play a role in a learning-by-research model. The model we present bridges part of the gap between the learning-by-doing and learning-by-research strands of literature. The time-dependence of optimal policies has generally been overlooked in earlier R&D models. [Nordhaus \(2002\)](#), [Popp \(2004\)](#) and [Fischer and Newell \(2008\)](#) combine and compare carbon prices and research subsidies for clean innovation, but they only consider constant research subsidies. Our analysis shows how their results would change if they had explicitly included the expiration of patents in their numerical models.

The basis of our analytical framework we borrow from the early literature on endogenous growth and environmental policy. Much of the early work in this field studied balanced growth paths (cf. [Bovenberg and Smulders, 1995](#)), or transition dynamics where the environment moves from a dirty to a clean steady state (cf. [Bovenberg and Smulders, 1996](#)). However, apart from the questions analyzed, there are two major differences in our analytical model compared to this strand of literature.

First, we do not consider a closed economy but for convenience apply a partial analysis. This choice is based on the observation that the climate problem is mostly associated specifically with the energy sector. For climate change, the single most important question concerns the costs, speed, and policies required to guide the transition of the energy supply sector towards carbon neutral energy sources. Working with a closed economy model will complicate the analysis

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