Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Technovation 24 (2004) 615–629
technovation
www.elsevier.com/locate/technovation

Endogenizing R&D and market experience in the "bottom-up" energy-systems ERIS model

Leonardo Barreto [a,*], Socrates Kypreos [b]

[a] International Institute for Applied Systems Analysis, Schlossplatz 1, Laxenburg 2361, Austria
[b] Paul Scherrer Institute, Energy Modelling Group, Villigen 5232, Switzerland

Abstract

ERIS, an energy-systems optimization model that endogenizes learning curves, is modified in order to incorporate the effects of R&D investments, an important contributing factor to the technological progress of a given technology. For such purpose a modified version of the standard learning curve formulation is applied, where the investment costs of the technologies depend both on cumulative capacity and the so-called knowledge stock. The knowledge stock is a function of R&D expenditures that takes into account depreciation and lags in the knowledge accumulated through R&D. An endogenous specification of the R&D expenditures per technology allows the model to perform an optimal allocation of R&D funds among competing technologies. The formulation is described, illustrative results presented, some insights are derived, and further research needs are identified.

Keywords: Learning curves; R&D; Market experience; Energy-systems models

1. Introduction

Research and development (R&D) is one of the basic driving forces of technological progress, contributing to productivity increases and economic growth. Although difficult to measure, the payoffs produced by R&D expenditures are high, both at social and private levels (Griliches, 1995). R&D is also one of the variables that government policies may affect, as private companies are likely to not invest enough in R&D from a public interest perspective, particularly in technologies that are promising only in the long run.

In the case of energy systems, R&D constitutes a fundamental factor for the successful introduction of new, more efficient and clean supply and end-use technologies and the achievement of economic, safety, environmental and other goals. Therefore, it is important to study the main mechanisms by which R&D investments contribute to cost and performance improvements of individual technologies and productivity increases of the energy system as a whole. By the same token, it is also interesting to gain insights about the optimal allocation of scarce R&D resources, taking into account that such allocation is influenced by expectations of market opportunities. Thus, it becomes necessary to incorporate those mechanisms into the energy policy decision-support frameworks, e.g., in energy-systems optimization models.

However, assessing and quantifying the effects of R&D efforts in energy technology innovation is particularly difficult because of a number of reasons, the broad range of R&D activities relevant to energy issues, the variety of institutions carrying R&D, the difficulties in assessing the (central) role played by industrial R&D and the lack of underlying data, among others (see, e.g., Sagar and Holdren, 2002 for a discussion). Moreover, the role of R&D must be examined within the context of the whole energy innovation system, of which R&D activities are only a part. Demonstration and deployment of energy technologies in the marketplace also play a very important role in their improvement, in particular regarding cost reductions (Grübler, 1998; PCAST, 1999; IEA, 2000, among others).

Technological learning plays an important role in technological change. Learning has many different sources, such as production (learning-by-doing), usage (learning-by-using), R&D efforts (learning-by-searching) and interaction between different social actors

* Corresponding author. Tel.: +43-2236-807-578; fax: +43-2236-71313.
E-mail address: barreto@iiasa.ac.at (L. Barreto).

0166-4972/$ - see front matter © 2002 Elsevier Ltd. All rights reserved.
doi:10.1016/S0166-4972(02)00124-4

(learning-by-interacting), among others (Grübler, 1998). There are a number of technical, social, economical, environmental and organizational factors that influence the presence (or absence) and rate of technological learning processes.

The typical representation of this phenomenon is through learning, or experience, curves. The standard learning curve considers the specific investment cost of a given technology as a function of cumulative capacity or cumulative production, which is used as an approximation for the experience accumulated when the technology is deployed. The formulation reflects the fact that some technologies experience declining costs as a result of their increasing adoption (Argote and Epple, 1990). As such, it takes into account the effects of experience due to actual deployment of technologies but it does not provide a mechanism to capture explicitly the effects of public and private R&D efforts, which also constitute an essential component of cost reductions and performance improvements, particularly in the early stages of development of a technology.

There is a need to incorporate R&D activities within the technological learning conceptual framework. R&D and market experience can be thought of as two learning mechanisms that act as complementary channels for knowledge and experience accumulation (Goulder and Mathai, 2000). Both mechanisms play an important role. R&D is critical at early stages of development and to respond to market needs, but market experience is essential to achieve competitiveness. There are also feedbacks between these two learning mechanisms. Successful R&D may increase the possibilities of a particular technology to diffuse. Market experience, on the other hand, may contribute to increment the effectiveness of R&D efforts, helping to target them towards needs identified when manufacturing and using the technology.

Examples of this interaction have been described in the literature. Neij (1999) and Loiter and Norberg-Bohm (1999), for instance, discuss the case of wind turbines. As a rule, experience gained with deployment of capacity seems to have been critical for progress in wind turbines, having also an influence in the effectiveness of R&D efforts. R&D programs seem to have been more successful when addressing specific problems made evident by the operation experience (Loiter and Norberg-Bohm, 1999). Having a market where new R&D results could be tested was an important feedback mechanism for research and focusing on concrete challenges allowed a more agile and wide incorporation of the innovations produced in such programs in subsequent generations of the technology. Watanabe (1999) performed an analysis of the role of public and private R&D expenses and industrial production in the competitiveness of solar photovoltaics in Japan and, on such basis, they identified the existence of a "virtual cycle" or positive feedback loop between R&D, market growth and price reduction which stimulated its development.

Thus, a comprehensive view of technological learning processes and associated policy measures must encompass Research, Development, Demonstration and Deployment (RD3) activities (PCAST, 1999), since all of them play a role in stimulating energy innovation and in the successful diffusion of emerging energy technologies. Energy technology RD3 strategies require, among other actions, a combination of "technology push" and "demand pull" policy measures.

On the "technology push" side, well-defined technology roadmaps and strategic R&D portfolios that conciliate short-term and long-term needs may contribute to make technologies available that could enable the provision of energy services in a cleaner, more flexible and reliable way and that can respond to objectives such as climate change mitigation and sustainability. On the "demand pull" side, buy-down policies, procurement and market transformation programs, for instance, could support cleaner and more efficient energy supply and demand technologies, which are currently expensive but with a promising learning potential (Payne et al., 2001; Neij, 2001; Olerup, 2001). Such policies could contribute to finance the "learning investments" (also called maturation costs), i.e., the investments necessary for these technologies to move along their learning curves until they become competitive.

However, R&D productivity is difficult to measure, not least because the observable variables can provide only a partial view of the innovation process. R&D expenditures are used as one of the typical measures of R&D activity. However, there are obstacles in establishing cause/effects relationships between R&D expenditures and technological progress, since R&D expenditures measure an input to the innovation process and not its output(s). In addition, even gathering R&D expenditures can be difficult, particularly for industrial R&D activities.

In addition, sound models for the role of R&D in the energy innovation system are not yet available. Clearly, because of the multiple feedbacks between the different factors, a linear model of innovation cannot be established (i.e., with R&D exclusively preceding market experience). However, there is a need for defining, if possible, basic stylized causal rules of interaction between R&D and market experience and their respective effects on technological progress, e.g., cost reductions and/or performance improvements. Regarding the latter, one of the difficulties is that R&D results may not necessarily contribute to the progress of a single technology but to that of several products or services.

Different approaches to model the R&D factor as an endogenous driver of technological change in "top-down" and "bottom-up" models have been reported in the literature (see e.g., Grübler and Gritsevskyi, 1997;