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ANALYSIS

Carbon taxes: A drop in the ocean, or a drop that erodes the stone? The effect of carbon taxes on technological change

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Abstract

We develop an economic partial equilibrium model for energy supply and demand with capital and labor as production factors, and endogenous technological change through learning by research and learning by doing. Our model can reproduce the learning curve typical for (bottom-up) energy-system models. The model also produces an endogenous S-curved transition from fossil-fuel energy sources to carbon-free energy sources over the coming two centuries. We use the model to study carbon taxes' effects on fossil-fuel and carbon-free energy use and carbon dioxide emissions. It is shown that without induced technological change, carbon taxes have a modest effect on emissions, while with induced technological change, they accelerate the substitution of carbon-free energy for fossil fuels substantially.

Keywords: Induced technological change; Environmental taxes; Partial equilibrium; Learning by doing; R&D

JEL classification: H23; O31; O41; Q42; Q43

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1. Introduction

Environmental taxes and regulation reduce pollution by shifting behavior away from polluting activities, but they also encourage the development of new technologies that make pollution control less costly in the long run (Newell et al., 1999; Popp, 2000). Understanding of the response of technology to economic incentives–dubbed induced innovation or induced technological change (ITC)–will prove crucial for designing appropriate environmental policies (Jaffe et al., 2002). In the literature, the subject of ITC has been studied mostly in the context of one representative aggregate production technology (e.g. Verdier, 1995; Beltratti, 1997; Newell et al., 1999; Goulder and Mathai, 2000; Nordhaus, 2002). In that context,

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technology is treated as a production factor, and ITC stands for a substitution of the factor technology for other production factors. This paper extends the literature as it addresses ITC in the context of two competing technologies (energy sources).

Induced technological change is receiving considerable attention in the climate change related literature where the potential contribution of ITC to policies aiming at greenhouse gas emission reductions is subject of a yet undecided debate (Carraro et al., 2003). Various studies try to estimate the impact of ITC relative to the factor substitution effects without technological change through scenario analyses (Carraro and Galeotti, 1997; Grübler and Messner, 1998; Goulder and Schneider, 1999; Nordhaus, 2002; Van der Zwaan et al., 2002; Buonanno et al., 2003; Gerlagh and Van der Zwaan, 2003). But the estimated contribution of ITC varies considerably between the studies. Carraro and Galeotti (1997) employ an econometric model for the EU and come to an optimistic conclusion. ITC can bring about a double dividend when proper R&D incentives will reduce emissions without the need for decreasing consumption. Grübler and Messner (1998) use an energy-system model and conclude that ITC substantially decrease costs and warrant early emission reduction efforts. Goulder and Schneider (1999) and Nordhaus (2002) are more pessimistic and conclude that, though ITC is not negligible, its contribution to greenhouse gas emission abatement is small when compared to the contribution of factor substitution for given technology. The somewhat disappointing result of these two studies may, however, be explained by the set up of the analyses. Nordhaus'(2002) study is based on one representative technology, and assumes that the reduction of carbon dioxide emissions requires the substitution of knowledge for energy. It abstracts from changes in energy composition, that is, the substitution of carbon-poor energy sources for carbon-rich energy sources. The substitution between energy sources is included in the other study by Goulder and Schneider (1999), who consider fossil fuels versus renewable energy sources. These two energy sources are, however, treated as complements (elasticity of substitution below unity), so that substitution and competition is limited. Such an approach may be quite realistic in the short run, as global energy demand is ever increasing and renewables are, not yet, substitutes. They may become so in the long run, which is the focus of our analysis.

ITC is a more prominent factor in a context with multiple competing energy sources (Van der Zwaan et al., 2002; Gerlagh and Van der Zwaan, 2003; Gerlagh, 2003) and such a context would also be in line with many so-called Integrated Assessment Models that pay more attention to the energy system (e.g. Peck and Teisberg, 1992; Manne et al., 1995). To constrain climate change, the substitution between various energy sources is essential. In the long term, energy savings will be insufficient to reach substantial abatement levels of carbon dioxide emissions, since energy is an essential production factor. Instead, if a substantial emission abatement strategy is aimed for, a shift away from fossil-fuel-based energy sources towards carbon-free energy sources is unavoidable (Chakravorty et al., 1997; Caldeira et al., 2003). For this reason, in studying the added value of ITC, we have to take into account the effect of ITC on the relative contribution of various competing technologies used for energy production (Weyant and Olavson, 1999).[1]

The objective of this paper is twofold. First, our methodological objective is to bridge the gap between an energy-system (bottom-up) and an economic (top-down) approach. Second, we carry out policy analyses to verify the role of ITC in climate change policy, relative to factor substitution. To study these questions, we develop a partial energy model, DEMETER-2E;[2] the first DEMETER model has been described and used in Van der Zwaan et al. (2002) and Gerlagh

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[1] More in general, a representative aggregate technology does not perform well when there are increasing returns to scale at the disaggregate level, e.g. because of endogenous technological change (Basu and Fernald, 1997).

[2] DEMETER is an acronym for DE-carbonization Model with Endogenous Technologies for Emission Reduction. For this paper, we apply a part of version 2, in which only the Energy sector is considered (DEMETER-2E). As DEMETER-2E only describes the energy sector, it is limited when compared with DEMETER-1, but on the other hand it extends DEMETER-1 by including learning by research and distinguishing between private and public innovations. In the future, we intend to extend DEMETER-2E with the production of non-energy consumer goods as well. The GAMS source code of the model used for this paper is available at the website of the first author: http://www.vu.nl/ivm/organisation/staff/reyer_gerlagh.html.