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Analysis

An integrated assessment model with endogenous growth[☆]

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ABSTRACT

We introduce endogenous directed technical change into numerical integrated climate and development policy assessment. We distinguish expenditures on innovation (R&D) and imitation (international technology spillovers) and consider the role of capital investment in creating and implementing new technologies. Our main contribution is to calibrate and numerically solve the model and to examine the model's sensitivity. As an application, we assess a carbon budget-based climate policy and vary the beginning of energy-saving technology transfer. Accordingly, China is a main beneficiary of early technology transfer. Herein, our results highlight the importance of timely international technology transfer for efficiently meeting global emission targets. Most of the consumption gains from endogenous growth are captured in the baseline. Moreover, mitigation costs turn out to be insensitive to changes in most of the parameters of endogenous growth. A higher effectivity of energy-specific relative to labor-specific expenditures on innovation and imitation reduces mitigation costs, though.

1. Introduction

Innovation as well as imitation and international diffusion of technologies can be a key for successfully coping with poverty and climate change. Herein, (climate) policy interventions have an impact on the strength and direction of innovation, imitation and technology diffusion. Therefore, a (climate) policy analysis that takes these aspects into account requires a rigorous model of endogenous directed technical progress. Setting up such a model and calibrating it to real world data is the first and main contribution of this paper. Due to the uncertainties in the parameter values in a model of endogenous growth, we conduct a careful sensitivity analysis. This is the second contribution of this paper.

It is widely agreed that the OECD countries bear the main responsibility for climate change while the developing countries will bear most of its impacts. Private investment on a national or international scale is expected to bring about the relevant capacities and technologies for climate change mitigation and adaptation. China as a prominent example has successfully improved its energy productivity and has become a leading producer and exporter of clean energy equipment. But in general, many developing and emerging economies lack in financial resources, knowledge, technological capabilities and the ability to adopt foreign technologies. International trade policy and patent regulation (WTO and TRIPS[1]) can on the one hand spur innovation but on the other hand hinder international technology diffusion and technological catching up. Therefore, many economies will probably not be able to achieve technical progress, economic development and carbon emissions reductions simultaneously within a short time frame. Thus international support will be required.

Therefore, in recent climate negotiations (Bali Roadmap 2007, Copenhagen 2009 and Cancún 2010 summit), developing countries called for financial and technological support for mitigation, and industrialized countries announced to provide such support. So far, the Kyoto Protocol has enabled international financing in (and technology transfer to) developing countries within the Clean Development Mechanism (CDM) framework. Herein, China has been the biggest seller of CDM credits with a market share of 72% in 2009 (Kossoy and Ambrosi, 2010, Section 4). The total volume of CDM transactions amounted to US-$ 6.5 billion in 2008 and only US-$

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[1] World Trade Organization and Trade-Related Aspects of Intellectual Property Rights.

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2.7 billion in 2009 (Kossoy and Ambrosi, 2010, Section 4). Moreover, developing countries can receive such support through technology funds like the World Bank Climate Investment Funds (World Bank, 2010) as announced at the Cancún 2010 summit. In particular, industrialized countries announced future transfers amounting to US-$ 100 billion per annum by 2020 in the Copenhagen Accord. This volume exceeds the volumes of annual financial transfers within the CDM framework cited above by far. However, no legally binding commitments have been achieved that settle which countries will pay and receive how much beginning at which date. This uncertainty gives rise to the question how mitigation costs of different regions are affected by postponing international technology transfer. Against this background, in this article, we apply our model of endogenous growth to the assessment of mitigation costs induced by a carbon budget-based policy and the costs of delaying international technology transfer.[2] Thereby, we intend to contribute to the literature that discusses the future of the Kyoto Protocol against the backdrop of efficient (carbon) markets and north–south equity (c.f. Chichilnisky and Heal, 2000; Chichilnisky and Sheeran, 2009). This is the third contribution of this paper.

Our model approach refers to state-of-the-art theoretical models of endogenous growth.[3] Product variety models in the style of Romer (1990) describe growth as a process that stems from an increasing number of innovative intermediate products (e.g. Grossman and Helpman, 1991). Product quality models in the style of Aghion and Howitt (1992) rather describe growth as a process that stems from quality improvements of products wherein new varieties replace old varieties, which is also called 'creative destruction'. We refer to the latter model type, however on a stylized macro level without taking profit maximizing firms explicitly into account. Acemoglu et al. (2003, 2006) provide microfoundations and a rigorous analysis of the influence of the distance between the technology in practice and the technology frontier (along the lines of the seminal contribution by Nelson and Phelps, 1966). They show that an imitation-based strategy is preferable when being further away from the technology frontier while an innovation-based strategy is preferable when being closer to the technology frontier. We follow this idea by including a 'distance to technology frontier' term (more specifically a 'technology pool' term) in our model. Herein, the model allows an endogenous simultaneous choice between innovation and imitation which are treated as substitutes. It basically reproduces the findings by Acemoglu et al. (2003, 2006) endogenously. Furthermore, we follow approaches in the style of Arrow (1962) such as Greiner and Semmler (2002) that view learning related to capital investment as a driver of technical progress. In our context, the positive impact of capital investment on technical progress in an economy is a supplement to the following consideration: New technologies such as energy-saving technologies that exist as blueprints become increasingly used in the economy through capital investment. As a result, they become increasingly embodied in the new capital stock and raise its productivity. We implement this feature in the style of the Schumpeterian model as a novel theoretical detail. Finally, we follow the literature in the style of Acemoglu (2002) that emphasizes the possibility to direct technical change towards specific factors depending on the abundance of factors or relative factor prices. Technical progress directed towards a certain factor will reduce the demand for this factor (factor-saving technical progress) when the elasticity of substitution between the production factors is smaller than one, which is the case in our model (in the upper CES level).

However, endogenous growth along these lines of the theoretical literature has not yet been fully worked out in an integrated assessment framework. Therefore, it is our main contribution to implement endogenous, directed technical progress resulting in fully endogenous economic growth into our multi-region integrated assessment model. Therein, our approach contributes to the literature that numerically describes endogenous innovation (e.g. Edenhofer et al., 2005; Gerlagh, 2008; Goulder and Schneider, 1999; Kemfert, 2005; Otto et al., 2007, 2008; Löschel and Otto, 2009; Popp, 2004, 2006) and international technology spillovers (e.g. Diao et al., 2005; Hübler, 2011; Leimbach and Baumstark, 2010). Our model is mostly comparable to the integrated assessment model WITCH (Bosetti et al., 2006). The original version of WITCH, described and applied by Bosetti et al. (2008), focuses on disembodied international technology spillovers of energy-specific R&D (research and development). Herein, the strength of spillovers depending on the distance to the technology frontier has an inverted U shape. This means, technology spillovers are highest at a medium distance to the technology frontier. Bosetti et al. (2011) apply WITCH to show that innovation policy in combination with climate policy results in substantial efficiency gains. Our model additionally allows for R&D and international spillovers that are directed to labor inputs and assumes that spillovers increase in the distance to the technology frontier. The modified version, used by Nicita et al. (2009), also allows for the direction of R&D towards energy or non-energy (capital and labor) inputs and thus endogenizes crowding out effects. Their model version seems not to model international technology spillovers, though. Their analysis shows that climate policy shifts R&D more towards energy inputs while R&D declines in total since total output declines. Our model combines both effects, international spillovers and directed technical change, with respect to labor and energy productivity. Compared to WITCH, our model also represents international (and 'intertemporal') trade in goods which aggravates the numerical solution of the multi-region model. Moreover, compared to WITCH, our model represents endogenous resource extraction that yields a kind of Hotelling path. On the contrary, we do not take climate damages into account in our model. We do not model international R&D spillovers of energy conversion technologies either but apply a global learning curve for the technologies wind and solar photovoltaic. This means, domestic investment costs of these technologies decrease in the installed capacity world-wide. This clearly has an impact on technology choice and technology diffusion. We apply our model to an analysis that is new in the literature: The effects of delaying international technology diffusion.

In our policy analysis, our model of endogenous growth will be embedded into the integrated assessment model REMIND (Refined Model of Investment and Technological Development, Leimbach et al., 2010a, c.f. Figs. 1 and 2 in the Supplementary Appendix B), a Ramsey type model of intertemporally optimal investment in physical capital and energy technology capacities. The model version under scrutiny consists of five world regions and includes trade (in a composite commodity, coal, gas, oil, uranium and carbon emissions permits) between these regions. Technology spillovers are controlled in a centralized way. International trade is subject to an intertemporal trade budget restriction following Negishi (1972) which creates a decentralized solution for trade. The macro model is coupled with an energy system module that represents several energy sources and related capacities of energy technologies (coal, gas, oil, uranium, hydro, biomass, solar, wind, geothermal, carbon capture and storage (CCS) of coal, gas and biomass; c.f. Leimbach et al., 2010a,b). The energy system module includes endogenous investment into capacities of different energy technologies as well as learning-by-doing of wind and solar technologies following the literature that emphasizes learning effects (e.g. Crassous et al., 2006; Kahouli-Brahmi, 2008). The energy system module takes increasing costs of resource extraction into account as well as operation and maintenance costs. Carbon emissions stemming from fossil fuels burned in production and consumption processes can be translated into resulting temperature increases in a climate module (Tanaka and Kriegler, 2007). The climate module is not used in this analysis of endogenous growth, though. The time horizon under scrutiny is 2005 until 2100 in five-year steps.

Section 2 derives our model of endogenous growth from economic theory. Section 3 describes the numerical calibration and shows baseline simulation results. Section 4 applies the model to the assessment

[2] We leave the specific channels – such as FDI – and policy instruments – for instance a technology fund – for achieving international technology transfer open.

[3] As comprehensively described by Aghion and Howitt (2009), chapter 4 and Acemoglu (2009), chapters 14, 15 and 18.