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Restricted carbon emissions and directed R&D support; an applied general equilibrium analysis

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ABSTRACT

We analyse welfare effects of supporting general versus emission-saving technological development when carbon emissions are regulated by a carbon tax. We use a computable general equilibrium model with induced technological change (ITC). ITC is driven by two separate, economically motivated research and development (R&D) activities, one general and one emission-saving specified as carbon capture and storage (CCS). We study public revenue neutral policy alternatives targeted towards general R&D and CCS R&D. Support to general R&D is the welfare superior. However, the welfare gap between the two R&D policy alternatives is reduced with higher carbon tax levels. For sufficiently high levels of the carbon tax equal subsidy rates are preferred.

1. Introduction

In several European countries there is substantial governmental support towards the development and implementation of new environmentally sound energy technologies such as emission-saving carbon capture and storage (CCS) and new renewable energy sources.[1] Technology policy can be a costly approach, however, if it is used as a substitute for, rather than complementary to, an emission-reducing policy (Jaffe et al., 2005). In our policy analysis, we address governmental support for the development of CCS technologies by investigating innovation policy reforms in the presence of a first-best emission-reducing policy. We ask two questions: *1)* What are the economic welfare effects of distributing a given amount of innovation support to the development of general technologies compared to the development of CCS technologies? *2)* How will the economic welfare effects depend on the carbon tax level?

First-best carbon policy is characterised by uniform carbon pricing that equals the marginal environmental damages of carbon emissions which are independent of source, while first-best arguments for subsidising innovation activities are imperfections in the research markets. Examples of such imperfections are external spillovers from previous research and development (R&D) activities, learning externalities and other market imperfections that make the level of R&D effort too low,[2] Romer (1990) and Jones and Williams (2000). The literature on efficient carbon policies when emission-saving technological change is present has until recently mainly disregarded the innovation policy issue and concentrated on *second-best optimal* carbon policy design and the carbon policies' influence on the timing and direction of technological change (Goulder and Schneider, 1999; Popp, 2004, 2006b; Nordhaus, 2002; Rosendahl, 2004; Otto et al., 2007; Hart, 2008; Gerlagh, 2008). In general, the second-best optimal carbon tax is higher than the first-best rate if positive learning or other innovation externalities are present. The second-best optimal carbon tax may differ between different end uses and should be largest for the technologies with largest innovation externalities (Rosendahl, 2004). Gerlagh et al. (2007) find in a Romer (1990) based R&D model that in the absence of explicit innovation policies the second-best

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[1] As an example, the Norwegian governmental support for the development and implementation of CCS and environmental friendly technologies in 2009 is approximately 220 million euro.

[2] We disregard imperfections in the research markets indicating that the level of R&D activity is too high, such as in "creative destruction" (Aghion and Howitt, 1992).

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optimal carbon tax should be higher than the first-best level when an abatement industry is developing. More recent analyses, such as Kverndokk and Rosendahl (2007), find that a *first-best* subsidy for the adoption of different competing technologies should be larger for technologies that are newly adopted and where the learning effects are large. A falling time path of first-best innovation subsidies is supported by Gerlagh et al. (2007) in their R&D based model with a finite lifetime of patents.

Otto et al. (2008) and Otto and Reilly (2008) analyse second-best and third-best combinations of carbon and innovations policies to reach a domestic carbon emission target. In a Romer (1990) inspired CGE model, Otto et al. (2008) find that it is second-best optimal to subsidise non-emission intensive R&D, combined with differentiated carbon pricing. The different policy alternatives in Otto et al. (2008) are not revenue neutral, making welfare comparisons difficult. Offering large subsidies to R&D without paying attention to the public revenue effect of the subsidies (incl. lump sum taxation) will overvalue the positive welfare effects of R&D subsidies. Further analyses of public revenue neutral innovation policy alternatives combined with optimal carbon policy are necessary in order to draw more general conclusions about optimal directions of innovation policies.

Several of the earlier analyses of carbon policies and induced technological change were based on ad hoc modelling of the innovation processes without specifying profit maximising innovative producers (e.g. Nordhaus, 2002; Popp, 2004, 2006a,b; Hart, 2008). In line with Gerlagh et al. (2007); Otto et al. (2007, 2008), and Otto and Reilly (2008), we model the innovation processes as R&D based growth of the Romer (1990) type with imperfect competition in the markets for new technologies embodied in variety-capital, Jones and Williams (2000).

Our contribution to the literature is three-fold. Firstly, our carbon policy is first-best and we study first-best innovation policies even though the subsidy rates are not first-best levels. In order to identify first-best subsidy rates we have to rely on uncertain estimates of the externalities in the research markets. In addition, optimising subsidy rates without limiting the total governmental support for R&D activities is not a realistic policy alternative.[3] Secondly, we perform analyses of carbon and innovation policies that are revenue neutral and perform consistent welfare comparisons. Thirdly, we specify a computable general equilibrium (CGE) model with endogenous technological change based on the Romer (1990) approach for a small open economy. The small open economy characteristic adds interactions with the rest of the world into the analyses. Export possibilities of new technologies and commitment to international climate treaties introduce new elements into the policy analyses not elaborated on in this literature.

In the presence of environmental and innovation market externalities and imperfections, the relative performance of different innovation and carbon policy alternatives is not obvious. Further, other market imperfections and existing public interventions will affect outcomes. Our CGE model incorporates these relevant market imperfections and public interventions. We specify R&D producing processes in both general and CCS technologies.[4] The CGE model is calibrated to the small, open economy Norway with all its special characteristics. In spite of the included endogeneities of growth, the dominant growth impulses in the model are driven by external factors, though, in accordance with the findings for small, open countries (Coe and Helpman, 1995; Keller, 2004).[5] The small, open economy approach allows us to model exports of the domestically developed CCS and general technologies as an important channel for product diffusion. The new technologies embodied in capital varieties are exported at given world market prices. A global price on carbon secures the export demand for CCS technologies. The export channel plays a crucial role in expanding domestic technology production since the domestic market is limited.

Our carbon and innovation policy analyses show that reallocating R&D support from CCS R&D to general R&D improves welfare, while reallocating support from general R&D to CCS R&D reduces welfare. With a higher carbon tax, the welfare gap between the two policy alternatives is reduced and flattens out for large values of the carbon tax. Our results do not, however, contradict the first-best result that the carbon tax should target the environmental externality and the R&D subsidy should target the imperfections in the research markets. Rather, it states that the carbon tax influences the productivity of both general and CCS R&D, and that the welfare effects of R&D support for the development of CCS technologies depend on the carbon emission restriction represented by the price of carbon emissions. The effect that the productivity of CCS R&D increases with the carbon tax level is confirmed by other studies (Greaker and Rosendahl, 2006; Heggedal and Jacobsen, 2008).

The paper is organised as follows: Section 2 presents the main structure of the CGE model, while Section 3 describes the calibration and baseline growth path. The policy reforms are presented and discussed in Section 4, while Section 5 concludes.

2. Basic features of the CGE model

We use a dynamic CGE model that captures the links between technological change, CO_2-emissions and the economy. A detailed description of the model is provided in Appendix B.[6] In this section we limit ourselves to only presenting the basic features of the model, with special emphasis on the modelling of technological change and production of gas power.

The CGE model is a dynamic growth model with intertemporally optimising representative firms and a single representative consumer.[7] The agents behave rationally and have perfect foresight. The representative consumer maximises discounted utility subject to the intertemporal budget constraint. Utility is a function of consumption in each period. Environmental quality depends on global carbon emissions, which are constant in our policy simulations. Thus environmental quality is not included in the utility function.

Our model extends the model in Romer (1990) by replicating a detailed industry structure with two R&D industries; general technology and CCS in gas power technology, two corresponding variety-capital industries (Romer's intermediates industries), and 16 final goods industries (one public, 15 private; see Table A.1). The final goods industries deliver goods to each other according to the empirical input-output structure. Our CGE model differs from the Romer model in assuming a small, open economy, where variety-capital and final goods are traded in the world markets at exogenous prices. Imports are modelled as imperfect substitutes for domestically produced goods (Armington function), while export deliveries are imperfect substitutes for home market deliveries (constant-elasticity-of-transformation (CET) technology). The domestic factor and product markets' prices are determined by equilibrium conditions and taken as given by firms. One exception is in the domestic variety-capital market, where the firms face monopolistic competition and exhibit some market power. Another feature of the small, open economy is that firm productivity is affected both by domestic growth mechanisms as in the Romer model and by exogenous technological

[3] Popp (2006a) also points to macroeconomic effects of unlimited support for emission-saving R&D.

[4] Gas power production with CCS is politically “hot” in many countries, including Norway, where it receives governmental support. Plants with full-scale carbon extraction at high costs are planned to be in production within 5 to 8 years.

[5] Otto et al. (2008) and Otto and Reilly (2008) assume that all productivity growth stems from domestic R&D. This enhances the effects of domestic R&D policy stimulation substantially.

[6] Bye et al. (2008) gives a complete description of the model and the calibration procedures.

[7] This is a long-term model with a time horizon longer than 100 years.