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Technological Change and Carbon Markets*

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ABSTRACT

In this brief note we discuss the innovation impacts of different market-based policy instruments in the climate field, and in particular the case of markets for carbon allowances. The note provides a brief review of the theoretical and empirical literature, and addresses important issues concerning policy instrument choice, the need for multiple policies as well as the timing and commitment strategies of the regulating agency. The analysis suggests that technological progress depends critically on developing and maintaining efficient carbon markets. In the case emissions are under-priced and/or adoption behaviour distorted by, for instance, inefficient plant entrants and closure provisions, any new carbon-free innovation will not be sufficiently exploited. However, for both economic and political reasons other policy instruments-most notably public R&D and technology support-will be needed to complement the price signals provided by carbon markets.

Keywords: *Carbon Markets, Innovation, Climate Policy, Environmental Economics*

1. Introduction

It is frequently argued that the nature and the pace of technological change and the associated innovation activities will be keys to addressing climate change in the future. Technological change is the process by which the economy changes over time in terms of the character of productive activity (e.g., processes used for production etc.). Technological progress (advance) thus enables the production of greater output from the same inputs (or the same output with less input). The long-term and potentially very negative effects of climate change on society require policy efforts to be heavily focused on innovation and technological change in the energy sector. Still, at the same time some analysts question the ability of the most significant climate policy instruments, markets for carbon allowances such as the European emissions trading system (EU ETS), to promote innovation and the development of new carbon-free technology [1].

In this brief note we therefore discuss the extent to which (mandatory) carbon markets may induce the development of new-and less costly-abatement technologies. We first provide a brief review of the theoretical and empirical literature on the potential innovation impacts triggered by different types of climate policy instruments and with particular emphasis on emissions trading schemes (see Section 2).[1] For our purposes the term innovation is primarily used for a new or improved (e.g., less costly) product or the use of new or different material. Innovations can however differ in the sense that some are radical and fundamentally alter the energy system and any associated supply chains (e.g., the electric car) while some are largely incremental and path-dependent (e.g., coal blending in electric power plants) [4]. Moreover, in Section 3 we discuss also some important policy issues, such as the importance of complementing policy instruments to promote innovation as well as the timing and commitment strategies of the regulating agency. Finally, Section 4 provides some final remarks.

Before proceeding, though, it should be noted that the literature on environmental innovation and policy is extensive, and it builds on several research paradigms (evolutionary economics, institutionalism etc.) (e.g., [5]). In this note however, we rely heavily on the most important lessons that can be drawn from the environmental

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[1]The discussion focuses mainly on research and development (R & D) of new technology, and thus not on the adoption of existing technology. Still, it should be acknowledged that this distinction is far from straight-forward. For instance, technology adoption may induce significant learning-by-doing impacts (e.g., [2]), and therefore any policy design that affects adoption, such as the treatment of new entrants and closures [3], may also have an impact on technological progress.

economics literature, but on occasion we also highlight some of the limitations of this approach.

2. The Innovation Effects of Carbon Pricing

The incentive for innovation refers to the benefit a firm enjoys from developing a new techno-logy. In other words, profit-maximizing firms will be willing to allocate resources to, for instance, environmental R&D activities if the result will be lower abatement costs. The theoretical studies on policy instrument choice and innovation incentives (see [6] for a comprehensive survey) essentially show that there exist a number of different outcomes contingent on particular assumptions about, for instance, the degree of competition in the output market and/or in the carbon market itself, the slope of the marginal damage function, uncertainty, which timing and commitment strategies are available for the regulator etc. Overall therefore it is virtually impossible to present a unanimous ranking of policy instruments with respect to their innovation-stimulating effects [7]. Still, market-based instruments tend to perform better than command and control policies (in particular technology standards or performance standards). The reason is that in the latter case the firm would have no incentive to perform beyond the pre-determined standard, while market-based instruments such as carbon taxes or markets for tradable allowances induce firms to conduct low-cost compliance beyond the current level (since this reduces tax or the allowance payments).

The latter results are however mainly valid in the case where innovation is a private good, and thus where the incentives considered concern only the firm's own gains from lower abatement costs [8]. In practice, however, innovation is typically a public good implying that some of the new knowledge may benefit other firms, which can adopt the new technology (at a price). These 'knowledge spillovers' (for which the innovator is not compensated) imply that R&D activities will be underprovided from a societal perspective. This in itself can be an argument for using additional technology and R&D support. In this setting the conclusions on how different policy instruments affect innovation become more ambiguous. Moreover, the specific design of the policy instrument rather than the choice of the instrument itself may be more influential for innovation outcomes (e.g., [9]). Of particular interest is a comparison of the innovation incentive effects of carbon markets that rely on freely distributed allowances and auctioned allowances, respectively. In the following we therefore pay attention to some key differences across the various market-based instruments: emission taxes, freely distributed allowances and auctioned allowances.

The literature suggests (e.g., [6]) that overall emission taxes provide a stronger incentive to invest in R&D as compared to freely distributed allowances. The reason is that the allowance price falls with the diffusion of new technology, thus implying that the adopting firms will not be willing to pay as much for the innovation under the (now cheaper) allowances as under a (constant) emission tax. Fischer *et al.* [7] show that if the (single) innovator is able to exercise market power, this can raise the gains to innovation in that a lower allowance price means that the innovator does not need to pay as much for the rest of its emissions. However, this benefit only emerges in the case of auctioned allowances. The choice between auctioned allowances and an emission tax is however ambiguous. The efficient policy will depend, in part, on the slope of the marginal damage curve[2], and on how imperfectly the innovative technology can be imitated. For instance, emission taxes provide more innovation incentive if imitation is difficult, while auctioned allowances perform better in the case with substantial knowledge spillovers to the adopting firms [8].

The above indicates some important implications for the design of mandatory tradable allowance scheme such as the EU ETS. For instance, within the EU ETS freely distributed allowances have been the dominant allocation principle, while the innovation impacts of auctioned allowances typically are greater (see also [10]). The announcement of full auctioning for the electric power sector starting in the year 2013 may thus induce more innovation activities in this sector compared to the case where allowances are freely distributed. Moreover, the price-reducing impact of innovation may be limited in the EU ETS due to the relatively wide sector-scope of the scheme. Innovations in one sector may not be of interest to the other sectors, and for this reason the impact on allowance price may be small (and even non-existent) [8]. In a broad-based allowance market, the incentives to innovate in a given sector will thus resemble closely the corresponding incentives under an emission tax.

Most of the empirical studies on the potential innovation effects of emission allowance markets have focused on the pioneering US systems such as the Acid Rain Program and the Lead Phase-out Program [9]. For the former case Popp [11] investigates innovations in the so-called scrubber technology, one of many strategies to abate sulphur dioxide emissions under the Acid Rain program. He compares the outcomes under the allowance program versus the command and control approach that was in force before 1990. He uses patent data and data on

[2]For instance, the steeper the marginal damage curve the more do tradable allowances dominate the tax regime [7]. A steep marginal damage curve implies that pollution beyond a certain threshold causes very negative effects on the environment, and for this reason it's better to regulate by means of quotas rather than prices.

the diffusion of this technology in a large number of power plants during the time period 1972-1997. The results show that both policy instruments induced lower scrubber costs, but the switch to allowance trading did not induce more innovation overall. Nevertheless, the introduction of an allowance market improved the sulphur removal efficiency of the scrubber technology, thus implying a more targeted and environmentally benign technological change. Another important-and largely unexpected-innovation induced by the Acid Rain Program was the improved ability to pursue coal blending, thus mixing high-with low-sulphur coal in power plants [12].

Many other studies confirm the positive impact of allowance markets[3] on the deployment of existing technologies and incremental innovations, but some also question their effectiveness in inducing radical innovations (e.g., [1]). The latter result can be attributed in part to the lack of stringency (*i.e.*, generous allocation and thus lenient targets), and predictability of many existing allowance markets (e.g., [10]). Still, in many instances carbon pricing needs to be complemented by other policy instruments that explicitly address other significant barriers to radical innovation. These include (again) R&D support to address the issue of knowledge spillovers, but also infrastructure investment in order to reap the benefits of network externalities and economies of scale [14]. Clearly, in the case where there is a lack of policy support for, say, the introduction of strict emission quotas and auctioned allowances, other instruments (such as technology subsidies) may be needed to address the long-term climate policy targets [15].

At the policy level the EU ETS is frequently expected to induce significant innovation (e.g., [16]), but given the novelty of this scheme empirical studies of its innovation impacts are scarce. Schneider *et al.* [17] and the accompanying paper by Rogge and Hoffman [18] are exceptions, though. They perform a large a number of interviews to trace the impact of EU ETS on technological change and adoption in the German electric power sector. Their results show that EU ETS has affected both the pace and the direction of technological change, although the authors also acknowledge that it is difficult to empirically separate the effects of EU ETS on the one hand and the general development of EU climate policy on the other.

Power generators and technology suppliers have significantly increased their R&D budgets during the last ten years, and the pricing of carbon has been an important motive behind this increase. Moreover, the main innovation impacts of the allowance scheme are to be found in coal-fired power generation. R&D efforts are directed towards increasing the fuel efficiencies of both new and existing plants; in the past such efforts were only induced by fuel savings but with a price on carbon there is an additional benefit of improving efficiency. However, the EU ETS appears also to be a prime motivator behind the strong R&D activities in the carbon capture and storage (CCS) technology, and firms are, for instance, teaming up with chemical process technology providers to acquire the necessary chemical-engineering know-how. These impacts of EU ETS on R&D and innovation can in part be understood by the fact that the electric power sectors in most European countries had not faced explicit climate policy instruments before the advent of EU ETS.

In contrast, R & D activities in the competing technologies have been much less prevalent. For instance, neither gas-fired generators nor wind power developers in Germany claim to have increased their R&D efforts as a result of EU ETS. In the wind power case, the feed-in tariff system in Germany is instead the most important driver of innovation activities (e.g., [19]). Overall these experiences of EU ETS point towards a rather path-dependent process of technological change in which R&D efforts largely build upon and reinforce existing competencies and know-how. This probably depends in part on the power of lobby groups over policy making and these issues are in need of more research.

3. The Interaction of Climate Policy and Innovation

So far in this brief note we have implicitly assumed the presence of an essentially myopic regulator, who does not anticipate a new technology and therefore commits *ex ante* to, for instance, a certain emissions cap that is efficient with respect to the existing technology. However, as pointed out by Fischer [8], just as “the amount of innovation depends on […] price signals, getting the right price signals depends on the amount of innovation,” (p. 11). The environmental economics literature has paid increased attention to the strategy space of both the regulator and the regulated agent. This strand of research shows, for instance, that under perfect foresight and competitive conditions *ex ante* commitment and *ex post* optimal policies generate very similar allocations (e.g., [20]). However, in imperfect markets the policy conclusions are less clear. One relevant example is where there exists a monopolistic innovator, who can determine the price of his new technology. Here a policy commitment to a certain emission tax level will minimize the distortions from this monopoly situation, while an allowance market would be more distorting given that the innovator

[3] As also shown in Sterner and Thurnheim [13], price based policies such as the refunded emission payment can have significant effects on technological innovation and diffusion.

will be able to influence the price of allowances.

Moreover, the regulator's optimal response to innovation is complicated by the presence of significant uncertainty in abatement costs (due to the difficulty in predicting innovation outcomes). In the case of allowance markets, which cap emissions, too little abatement will take place in the presence of innovation. However, since the environmental damages of carbon dioxide emissions are relatively insensitive to the rate of emissions at any particular point in time, the efficiency benefit of reducing volume uncertainty would be limited. Thus, in the case of uncertainty in abatement costs due to future innovation activities, a constant tax on carbon emissions would be favoured [21].

In a recent paper, though, Weber and Neuhoff [22] examine the effect of firm-level innovation in carbon abatement technology (*i.e*., the new knowledge is a private good) on the optimal design of carbon allowance markets, with or without a price cap and a price floor, respectively. They show that in the presence of innovation the optimal emission cap decreases, and this can lead to a higher than expected carbon price so as to provide sufficient incentives for private R & D. This tends to speak in favour of carbon allowance markets versus carbon taxes. In allowance markets certainty about emission outcomes are obtained at the cost of increased price uncertainty (compared to an emission tax), but when prices increase this serves as an additional innovation incentive.

Finally, while it is clear that allowance markets such as the EU ETS can have significant innovation-promoting impacts, other policies may be necessary to spur an efficient level of innovation. As was noted above, R & D activities generate knowledge with substantial public good characteristics. This means that a single firm cannot generally reap the benefits of its investment in new knowledge, and it does therefore not have enough incentives to undertake such activities. An important policy lesson from this is that even if policies to correct for environmental externalities are in place, the level of environmental R & D may be suboptimal (and too low). Two types of market imperfections call for two types of policy instruments [23], but while carbon pricing should be the engine of climate policy it is less clear how technology policies should be designed in practice.

Although the social benefits of R&D activities in new abatement technology are higher than the private ones, it must be acknowledged that this is the case for many R & D activities throughout the entire economy (including many environmental projects). This implies that the opportunity cost of specific R & D projects may also be high, and the economics literature suggests that technology policy should-as a starting point-primarily address a broad set of knowledge spillovers through generic policy instruments (such as patents and broad R & D subsidies) rather than focus on R & D and innovation activities in one specific activity or sector (e.g., [24]). As noted by Fischer [25]:

"The role for publicly supported innovation is strongest when some spillover effects are present and at least a moderate share of the social costs-including the marginal damages of emissions is reflected in the price. [...] While mitigation policy must be the engine for reaching environmental policy goals; technology policy can help that engine run faster and more efficiently, but it only helps if the engine is running." (p. 500)

Thus, technology policy is no substitute for emissions pricing [25]. Indeed Parry *et al.* [26] show that the welfare gains from environmental innovation may not be much greater than the corresponding social benefits of cost-effectively abating carbon emissions by means of existing technologies. This highlights the importance of developing and maintaining efficient carbon markets; if emissions are under-priced and/or adoption behaviour distorted, any new carbon-free innovation will not be sufficiently exploited. For instance, the introduction of auctioned allowances and more efficient plant entrants and closure provisions in the EU ETS (e.g., [3]) and other similar carbon markets could therefore well be just as important for innovation outcomes as public R&D and technology support.

4. Final Remarks

Previous research confirms the important role of carbon pricing in spurring innovation activities in the energy sector, but such policies need also to be complemented by explicit technology policy to address the presence of knowledge spillovers. Still, technology policy is no substitute for emissions pricing. Technological progress depends critically on developing and maintaining efficient carbon markets; in the case emissions are under-priced and/or adoption behaviour distorted by, for instance, inefficient plant entrants and closure provisions, any new carbon-free innovation will not be sufficiently exploited. Given the importance of future technological progress for combating climate change additional research that addresses the impact of different combinations of policy instruments on technological change is needed, including also a stronger emphasis on multi-disciplinary approaches.

In addressing the policy challenges involved in developing new carbon-free technology it is also important to recognize that policy acceptance may be just as important as policy effectiveness, and future research will benefit from addressing any trade-offs between acceptance and effectiveness. The establishment of carbon markets typically involves compromises (e.g., the use of free allocation of permits in EU ETS). However, such compromises may interfere with an efficient market design and they therefore come at a cost. If our understanding of the magnitude of these costs are improved policy makers could be helped in identifying the most important issues for improvement. In a word, while the research so far has highlighted a number of distortions in existing permit markets, future research efforts could also investigate the magnitude of these distortions.[4]

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[4]It is sometimes argued that carbon pricing represents an ineffective policy instrument since it may be difficult to implement high carbon prices for political reasons. However, it is useful to distinguish between policy acceptance (the scope for getting the policy implemented) and policy effectiveness (once the policy has been implemented). A high carbon price will be effective, but the scope for implementing such a high price may differ depending on, for instance, allocation rules, competitiveness concerns and revenue recycling schemes etc.).

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