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Analysis

Innovation and diffusion of environmental technology: Industrial NOx abatement in Sweden under refunded emission payments

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ABSTRACT

We study the actual process of technical change in the case of NOx abatement from large stationary sources that have been regulated by very forceful policies in Sweden. Considerable progress has been made in lowering aggregate emissions and this paper seeks to disaggregate average industry improvements to study how much of it is due to innovations by first movers, and how much is achieved by adoption and diffusion of technology. We find both factors very important. Innovation has been rapid: the best firms have cut emissions on the order of 70%. In spite of this, reductions have actually been even more rapid for the majority of firms so that the median firms have caught up with best practice. We analyze various characteristics of the technological change observed.

1. Introduction

Technical change is at the heart of environmental improvements and of economic development in general. It is one of the main forces in economic and social development and rightly belongs at the centre of ecological economics analyses. It is, however, elusive. Its very nature is to be partly unknown and incalculable ex ante. It is also complex: products not only become cheaper but they are transformed, acquiring new properties that often transcend the relatively simple numerical and conceptual models we make.

Despite the importance of innovation for the environment, there are relatively few studies in environmental economics that truly delve into the characteristics of technical change and capture empirically the features that make it essential for pollution abatement and the development of more environmentally benign production systems. The study of technology is by tradition quite different in economics and in technical engineering, partly because engineers inevitably are more interested in the workings of the chemistry and the machinery than are economists who in turn are more interested in the incentives that cause or enable technical change. To capture the economic importance of technical change and its possible directions, it is necessary to understand both technical and economic aspects, and interdisciplinary work is thus useful in this area.

The refunded emission payments used in Sweden for NOx abatement in large stationary combustion sources was explicitly selected as an instrument to have an effect on technology. It was not the desire of the policy maker to close power plants or paper mills or to drive them out of the country, or to reduce the consumption of their final products by making them more expensive. Rather, their goal was simply to affect combustion technology (in the broadest sense of the word — including fuel choice, post combustion treatment, and other aspects of operations) and thereby NOx emissions.

Sweden has ecosystems that are naturally very sensitive to acidification and, like all policies on acid rain in Sweden, this policy was ambitious, imposing marginal costs of pollution several orders of magnitude higher than those in other countries. It therefore provides us with a good opportunity to study the mechanisms of technical change — including the separate processes of innovation and of technology spread and adoption.

This paper seeks to refine indicators of technical development in abatement through a case study. It sheds light on the complexities involved in abatement technologies and strategies, thus enabling a link between the typically macro-level perspective of the policymaker and the micro-level behaviour of operators facing a number of decisions, constraints and established routines.

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It starts with an overview of some theories for technological development in Section 2. We then provide an overview of the chemistry and technology of NOx formation and abatement in Section 3, followed by a presentation of the main policy instrument, the refunded emission payment used in Section 4 and the empirical findings of the technical change observed in Section 5, some technical explanations in Section 6 and finally Section 7 concludes.

2. Theories of technology

A large literature addresses the importance of the advantages to society that come from technological innovation. Such innovation may reduce the cost of environmental protection and could be more important than the static welfare gains from correcting a pollution externality. A critical consideration for the choice of environmental policy instrument would then be its impact on incentives for cleaner production technologies. In the long run, the cumulative effect of technological innovation might in fact resolve what in the short run often appears as an irresolvable conflict between environmental quality and material standards of living (see Jaffe and Stavins, 1995; Kneese and Schultz, 1978).

That cumulative effect should make a strong argument for focusing more on technology policy. Parry et al. (2000) however show that this is generally not the case. They find that the gains from innovation are typically smaller than the standard welfare gains from choosing the cost-minimizing level of abatement. The reasons are that the long-run gain from innovation is bounded by the maximum reduction in abatement costs and that research and development are slow, uncertain and costly. These authors nevertheless also show conditions under which innovation may be very important: when innovation substantially reduces abatement costs quickly and when the optimal (Pigouvian) amount of abatement is modest.

These two conditions appear to have a good chance of being fulfilled in the case we are studying. NOx abatement in large stationary furnaces can really take place only through either technical change or reduced production and consumption. Reducing production was not an option for the Swedish policymakers. Fuel switching was a third possibility, but it is heavily influenced by other factors (other environmental priorities as well as price differentials). Moreover, fuel switching and fuel flexibility are intimately tied to technical change in the furnace. Many of the technical options for abatement were still new but appeared fairly promising and thus one explicit purpose of this program in Sweden was to speed up technical progress.

Starting with Milliman and Prince (1989) and Downing and White (1986), there is a broad literature on the characteristics of innovation and the role played by economic instruments for technical progress (see also Jaffe and Stavins, 1995; Jaffe et al., 2000, 2002, 2005; Jung et al., 1996; Kemp, 1997; Parry, 1995, 1998; Freeman and Soete, 1997; Fischer et al., 2003). This literature often makes an explicit distinction between the process of research and development (R&D) on the one hand and the diffusion and adoption or use of the new technology on the other. Diffusion studies are concerned with explaining the rate of adoption of a new technology by a population of potential adopting firms. Stoneman and Diederen (1994) particularly analyse the importance of a particular policy for diffusion. Conversely, adoption studies are concerned with explaining individual firm's adoption decision; see further Thirtle and Ruttan (1987). While this is a first step towards recognising the complexity that is characteristic of what we simply call "technical change", it should not be viewed as a linear progression of stages from idea to market adoption.

It is sometimes the case that different agents are active in the different stages involved in technological change. In the invention and innovation phase, the R&D may be conducted mainly by specialised firms (possibly in collaboration with production firms) or by the producers themselves. Kemp (2000) reminds us that, in traditional industries, "new technologies are [often] developed by firms outside the regulated industry", thus relying upon "suppliers, capital goods suppliers and environmental technology suppliers." At this first level all the technological uncertainties are related to R&D. There may be issues of market structure – it is quite common to find thin markets with small numbers of firms in this kind of niche – and "learning by doing" (Arrow, 1962) may prevail.

Once the innovation has been made and tried at one unit and suited to a population of potential adopters, it may enter a phase of diffusion. Generally, but not always, the innovations are patented. Adopters have to make the decision whether and when to acquire the new technology and how to use it. Common technology diffusion modelling approaches include probit models (existence of a moving threshold defining economic feasibility of the innovation for adopter classes), epidemic models (information-based adoptive capacity of potential adopters) and capital stock adjustment models (old capital stock is replaced by more advanced technology). As shown by many of the articles cited above, various instruments provide quite different incentives for adopters. With permits, for instance, the equilibrium price for emissions will be affected by innovation and by other firms' adoption, whereas for an environmental tax, there is no such immediate effect.

The distinction between innovation and diffusion of new technologies is not a clear-cut one, and remains contested. As we have previously said; innovation and technical change are not strictly linear processes following clear developmental stages from research to markets. Innovation may instead be described as multi-stage iterative interactions, see for instance the chain-linked model in Kline and Rosenberg (1986). Often, these processes are interwoven, and multiple iterations involving manufacturers, users, and other sources of knowledge are necessary to achieve a workable innovation along with its required manufacturing process and user competence. These theoretical features have been taken into account in our empirical work, and identified through interviews that highlighted the collaborative and trial-and-error aspects of innovation processes as engaging users, manufacturers and knowledge centres in the elaboration of new or modified process technologies. Additionally, what may be seen as technology of the same range (here "abatement technology") may in practice be of a totally heterogeneous nature. Abatement technologies may well differ in terms of designs, but also, as we will see, they can be embodied in hardware, software, and/or "org"-ware.

Fig. 1 provides a first stylized impression of how one can disaggregate technical progress into innovation and diffusion from the perspective of the emitting sector. For the purpose of simplification, we take here *emission intensity* as an indicator of innovation, understood broadly as new (abatement) technology, processes and optimal use from user experience. In this simplified, one-dimensional, diagram with a histogram of emission intensities (in this case, for

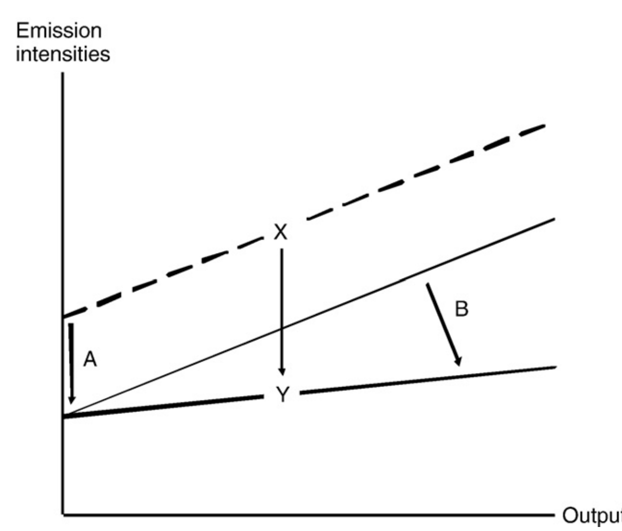

Fig. 1. A simple model of innovation and diffusion.