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Timing of Environmental Policy when Technology Advances

Innovation and sustainable growth

Though nowadays economic growth is as easily taken as given, or otherwise considered as a thermometer for the health of the economy, when looked upon on a scale of centuries, the current economic growth rates constitute a rather surprising and abrupt event.[1] In North America, Western Europe, Japan, Australia, and in many other countries, income has grown more than tenfold over one century, and there is still no end in sight. The rise in income was made possible by a series of scientific and technological innovations, each successively increasing the productivity of labour, and along with it, the power of mankind over nature. Ford's development of the assembly line, which streamlined production processes in factories and was copied all over the world, is a famous stepping stone in the continuing process of technological advancement. Remarkably, though innovations have long been recognized as the fundamental source of long-term income growth (Solow 1957), it still took a long time thereafter before economists started to study the sources of innovations, leading to the so-called endogenous growth literature (e.g. Romer 1987, Aghion and Howitt 1992). Only subsequently, environmental economists started to study the role of technology in environmental policy. The link between technology and environmental policy is thus a relatively recent subject of research.

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Growth in production and consumption has brought fortune to many citizens, but it has also caused caution regarding the sustainability this seemingly ever-increasing burden lays on the environmental systems. Climate change is a case in point and has received ample attention over the past years. But it is certainly not the only pressing environmental problem. The global fishing beyond eco-system recovery of the coastal and high seas will become a subject of public concern as well, sooner rather than later. The increased productivity has thus contributed to the common good in terms of wealth, and also to the common bad in terms of the potential overtaxation of nature. One likely question to ask is whether the historic record of coupled economic growth and more environmental pressure is really a necessity in the sense that technological progress is always biased towards increasing resource inputs, ultimately

1: Before the industrial revolution, world-wide per capita economic growth was estimated at well below 0.2 per cent per year, increasing to about 1 per cent per year in the period between the industrial revolution and WWII, and exceeding 2 per cent per year for the post-WWII period (Jones 2002, Fig. 1.3).

exhausting nature's capacity to supply raw materials. Alternatively, the historical record might rather reflect our ignorance or lack of steering ability. To answer this question, one needs to investigate the relationships between economic growth, technological change, its direction, and the use of natural and environmental resources.

The first studies that applied the endogenous growth theories to environmental economics addressed the issue of growth and environmental conservation (cf. Bovenberg and Smulders 1995). The conclusion from this literature is that technological change makes it more probable that we can decouple economic growth from environmental pressure. The mechanism is not too difficult to understand. If we use economic incentives to increase the value of 'clean' innovations – e.g. pollution taxes will stimulate the use and thereby the value of clean technologies – then more clean technologies will be developed compared with 'dirty' technologies. Thus, from the outset, there is no reason for pessimism as to the possibility of resource-saving growth.

Though the study of innovation as the engine of growth may not have altered our understanding of the feasibility of growth combined with environmental conservation (as opposed to common practice), it has led to a certain spread in opinions regarding the need for environmental policy, and the timing of such policy. From the side of technology optimists, it is argued that higher income will boost environmental awareness, leading to greener innovations without the need to worry. On the part of pessimist environmentalists, it is argued that the markets do not reflect environmental scarcity and will not stimulate the development of greener technologies unless the government interferes. The common economist's view is that the government should create new markets for environmental use, e.g. for emission permits, so that prices on these markets reflect the social benefits of constraining the use of these environmental resources. During my stay at the *Centre for Advanced Study* (CAS), I specifically looked into the question of whether the government should do just that, create markets that reflect social environmental values, or the mechanism of greening through innovations warrant more, or less, action. This subject I worked on together with Snorre Kverndokk from the *Frisch Centre* and Knut Einar Rosendahl from *Statistics Norway*.

Dynamics of innovation and environmental policy

Studying the interaction between innovation and environmental policy requires dynamic analysis, since both innovations and environment problems cannot be understood without understanding the dynamic processes behind them. I choose climate change as the environmental issue to be used for illustration of the economic analysis, because there is already much discussion on the efficient timing of climate change policy. When we want to prevent potentially dangerous anthropogenic interference with the global climate system, then in the coming decades radical policy interventions are necessary to bring a halt to the continuing increase in the atmospheric greenhouse gas concentrations. Though most scientists agree on the need for some abatement in the coming decades, they differ as to whether the majority of these abatement efforts should be pursued from the very start, or alternatively, whether the largest share of abatement efforts should be delayed for later. In the literature, various reasons are presented for preferring delayed action, but here I want to mention the argument that delaying abatement efforts will allow us to benefit from cheaper abatement options that are available in the future, and added to that, delayed abatement will allow us to develop these options through innovation. This argument has raised a lively debate among economists studying technological change in relation to environmental policy. Our study contributes to this debate. We argue that the private sector will not develop innovations before these innovations are used. We thus consider the 'develop-and-wait' approach unfeasible, unless a public agent takes responsibility for the innovation process.

Since the largest share of greenhouse gas emissions comes from the combustion of fossil fuels for energy supply, energy system analysts have figured prominently in this debate. Energy system analysts have clear empirical evidence for so-called experience curves suggesting that new low-carbon energy technologies, which will define the major long-term options for carbon dioxide emission reduction, the need to accrue experience for costs to come down sufficiently to make these technologies become competitive with existing fossil-fuel based energy technologies. Based on these experience curves, the more general argument is made that there is a need for up-front investment in abatement technologies to make these technologies available at low prices, and thus, technological change would warrant early abatement action rather than a delay (Ha-Duong et al. 1997, Grübler and Messner 1998; van der Zwaan et al. 2002, Kverndokk and Rosendahl 2006). Models exploring experience curves are typically referred to as learning-by-doing models.

Though experience and diffusion curves have a strong empirical basis, many economists consider it a mechanistic view on technological development that hides the incentive-based structures that determine the level of research efforts by innovators. Many economists prefer models with an explicit representation of R&D efforts as the engine of innovation, and they have found that modelling innovation through R&D can lead to potentially very different outcomes of optimal timing of abatement policy. An important difference between learning-by-doing and R&D models is that the latter category of models does not assume from the outset that the technology needs to be used for costs to come down. Thus, through R&D, future cheap abatement options may be made available without the need to deploy them while costs are still high. In an R&D model, it is then most efficient to focus mainly on R&D in the early stages of abatement policy, without employing the abatement technologies, and to apply the technologies only after the costs have sufficiently come down. Indeed, Goulder and Mathai (2000) found this pattern an optimal environmental policy. They concluded that whereas learning-by-doing may warrant an advance of using abatement technologies compared with a situation without technological change, the presence of R&D unambiguously implies a delay in the use of abatement technologies.

Within the community of environmental economists, the above-mentioned paper by Goulder and Mathai has created a divide between proponents of learning-by-doing models and early action, and proponents of R&D models and delayed action. During my stay at CAS, Snorre Kverndokk, Knut Einar Rosendahl and I conjectured that this divide was based on a premature analysis, and we decided to take a closer look. The R&D case for delayed action requires that policy-makers have the ability to first stimulate clean innovations, and at a later stage to stimulate the use of these innovations. For this, policy makers need to have a tailored instrument available to bring environmental R&D efforts to their socially optimal level. In most cases, however, policy makers will use a generic R&D instrument such as R&D subsidies, and a generic environmental instrument such as environmental taxes. An R&D subsidy limited to environmental innovations is not likely to be feasible. Such a constraint on environmental instruments prevents the implementation of an innovation-first, action-later policy.

Furthermore, we have to better understand the incentives that determine the functioning of the innovation market. Patents play an essential role, as they protect innovators from being copied without due payment. At the same time, patents disclose the knowledge base underlying the innovation, which can then be used by rivals to develop substitute technologies. Also, not unimportantly, patents have a finite lifetime and expire after a certain period. Since innovators need to secure revenues to pay for research costs – in this sense they are not different from other producers – innovations will only occur when innovators can appropriate their use-value in production. That is, innovators will give priority to innovations that are used before the patents expire. Low or no priority will be given to research whose output becomes tangibly valuable only after expiration of possible patents. The patent system thus couples innovation and use. Innovation will only occur jointly with its use, which is very similar to the coupling in learning-by-doing models, where technology only advances if it is used.

In modern economics, it is required that arguments be given rigor by mathematical analysis to unveil the precise assumptions and data underlying the result. Snorre, Knut Einar and I have thus developed a formal analysis of a growth model along the lines of modern innovation theory (specifically, growth through expanding varieties, see Barro and Sala-i-Martin, 1995). In this model, we have shown that the R&D model gives results very close to (and in some cases precisely equal to) the learning-by-doing model. The early results of R&D models advocating a first-innovate then-take-action strategy, we have shown to be a peculiar consequence of some simplifying assumptions in the early models. To conclude, our research suggests that it is right to start with early policy action (e.g. environmental taxes) on emerging environmental problems, both when learning-by-doing and when R&D drives innovations.

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