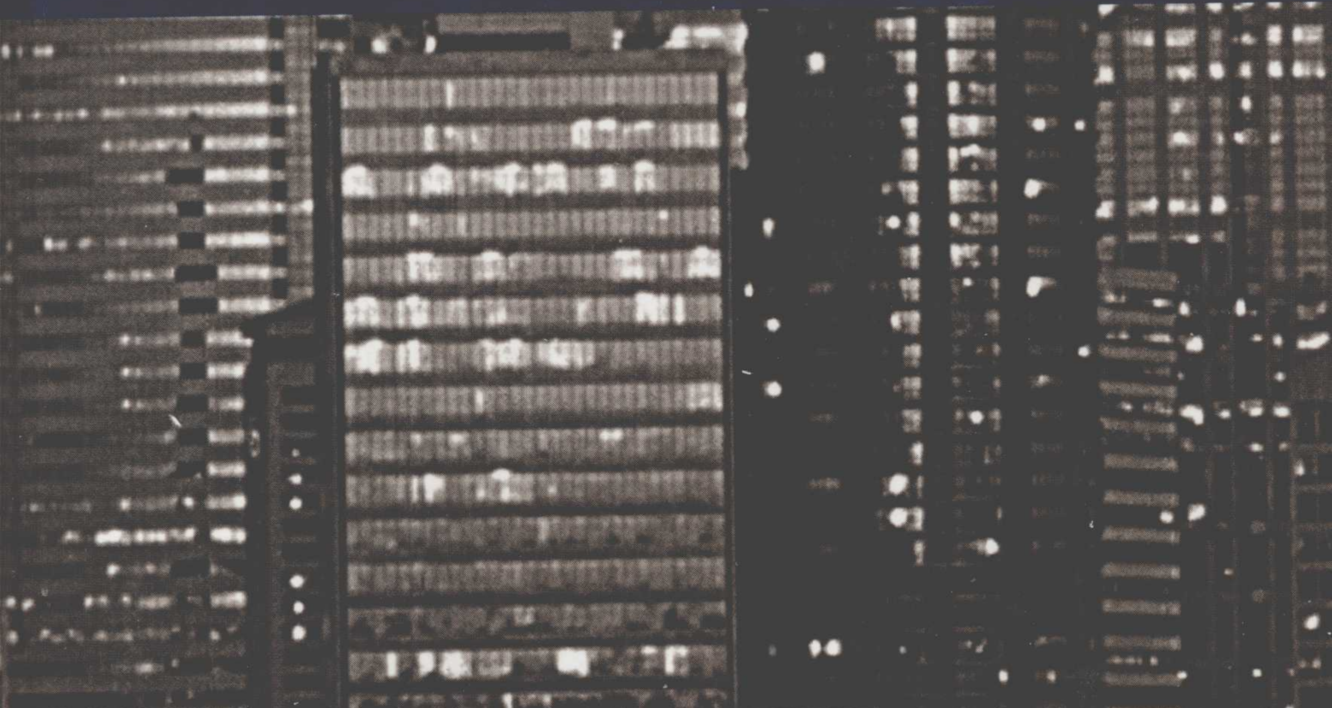
The Economics of Technology Diffusion and Energy Efficiency

Peter Mulder



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Peter Mulder

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PART I

Introduction

1. Technological change, economic growth and energy use

1.1 INTRODUCTION

Energy is an essential factor that fuels economic growth and serves human well-being. World primary energy use has grown enormously since the middle of the nineteenth century due to unprecedented growth of population and technological revolutions in industry. This increase in the scale of energy demand comes at a certain price, including environmental externalities. Nowadays one of the most prominent environmental problems is the enhanced greenhouse effect, which is to a large extent caused by the cumulative impact of burning fossil fuels on an increasing scale, in order to meet the increasing energy demand. Currently most governments in the developed world strive explicitly for sustainable development, aiming to decouple economic growth and environmental pressure. Notwithstanding the need for renewable energy sources, this also asks for further improvements in energy efficiency. Technological change plays a crucial role in both developing alternative energy sources and realizing energy efficiency improvements, and hence in ameliorating the conflict between economic growth and environmental quality. At the same time it is known that diffusion of new technologies is a lengthy process and that many firms do not invest in best-practice technologies. These are the issues that set the stage for this book.

The aim of this book is to contribute to our understanding of the interplay between economic growth, energy use and technological change. The principal focus of this book is the adoption and diffusion of energy-saving technologies. This implies a choice to analyse technological change rather than economic growth, diffusion of technologies rather than their innovation, and energy use rather than other environmentally damaging activities. The first concern of this book is with the dynamic aspects of the choice of technology at the firm level and how this choice is affected by characteristics of technological change as well as by environmental policy. With this aim, we develop two small analytical models of technology adoption, inspired by recent developments in economic theorizing about technological change that stress the role of knowledge accumulation (learning), knowledge spillovers, uncertainty and irreversibility (path dependency). Does this view of technological change shed new light on the observed slow diffusion of new energy-saving technologies? What are the possible implications for the role of policies aiming to stimulate the adoption of energy-saving technologies?

The second concern of this book is with empirical regularities of productivity performance. We will explore long-run trends in energy and labour productivity performance across a range of OECD countries at a detailed sectoral level. To what extent has the pursuit of decoupling energy use and economic growth within the OECD been successful over the last decades? Why do productivity levels differ across countries and across sectors? For the purpose of answering these questions we will document stylized facts, decompose long-run trends and provide an extensive empirical convergence analysis of cross-country energy and labour productivity performance. The study concludes by integrating the insights from the small analytical models developed in this book, in an existing Dutch policy model of economy–energy interaction. The aim of this exercise is to investigate the possible relevance of these theoretical insights for applied economic policy analysis and to examine their impact on estimates of energy demand at a sectoral level. In the remainder of this chapter we briefly introduce the above-mentioned issues and the way they will be dealt with in the research reported in this book.

1.2 ECONOMIC GROWTH AND TECHNOLOGICAL CHANGE

Technological change is the main driving force behind economic growth. Although this message was already put forward by classical economists, most notably Schumpeter (1934), it was not until the 1950s that the crucial role of technological change in explaining patterns of economic growth attracted broad attention in mainstream economics. This development can be mainly attributed to the introduction of the neoclassical growth model, developed by Solow (1956) and Swan (1956), aiming to provide a theoretical framework for understanding geographical differences in patterns of growth of per capita output. In the model, aggregate output depends on capital, labour and labour-augmenting technological change. The model is an intellectual masterpiece, it fits the major stylized empirical facts (Kaldor 1961) and became the benchmark for what is now called the neoclassical theory of growth. However when Solow (1957) used the model for growth accounting it turned out that it was unable to explain growth rates of output on the basis of accumulation of physical inputs (capital and labour) alone. A large and persistently positive residual remained, which has become known as the Solow-residual. The remarkable conclusion was that something different from capital accumulation and an increasing labour force should be held responsible for most of the economic growth that has occurred. This 'something' was identified as 'total factor productivity growth' and has often been equated with 'technological change'. For this reason, the Solow-residual is often referred to as the 'measure of our ignorance' (Abramovitz 1986). Reducing this ignorance became the starting point of a quest for a better understanding of the process of technological change and nowadays many economists are still looking for missing pieces of that scientific Grail. Many things though have been learned in the meantime, and different schools of thought have contributed. An interpretative survey of this quest is provided in Chapter 2, with a focus on two recently emerged classes of models on economic growth and technological change. They are respectively labelled neoclassical endogenous growth models and evolutionary growth models. Both classes of models emerged out of dissatisfaction with the Solow–Swan growth model, in particular with its assumption that technological change is exogenous – suggesting that technological change falls like manna from heaven.

The recently developed class of neoclassical endogenous growth models moves beyond this unsatisfactory feature by endogenizing technological change. These models stress the fact that in the end, technological change is all about knowledge creation. In a growth perspective, this implies that economic growth is ultimately driven by accumulation of knowledge or human capital, thereby generating positive externalities (spillovers). The essential idea in the first endogenous growth models by Romer (1986) and Lucas (1988) is that knowledge is to be considered as a kind of renewable capital good, with capital being a broad concept including knowledge or human capital. Following this path-breaking research, many models have been developed that endogenize technological change, highlighting different dimensions of technological change and fields of application, including energy–economy–climate interactions (for example Goulder and Schneider 1999, Goulder and Mathai 2000).

The evolutionary growth models move beyond neoclassical endogenous growth models by criticizing not only some assumptions of the neoclassical growth models, but the whole neoclassical economic view on technological change as such. The foundations of the evolutionary economic view of technological change have been laid down in the seminal work of Nelson and Winter (1982), who argued that 'the weakness of the neoclassical theoretical structure is that it provides a grossly inadequate vehicle for analysing technical change. In particular, the orthodox formulation offers no possibility of reconciling analyses of growth undertaken at the level of the economy or the sector with what is known about the processes of technical change at the micro level' (Nelson and Winter 1982: 206). In sum, with the latter they meant that technological change is the result of search processes, which are inherently uncertain and guided by 'routines'. Therefore they analyse technological change in terms of strategies to optimize profits under the assumption of bounded rationality rather than to maximize profits under the assumptions of full rationality and perfect foresight. Nelson and Winter (1982) developed an evolutionary growth model along these lines, which they showed to be capable of reproducing the patterns of aggregate output, factor input and factor prices as addressed by Solow (1956) in his pioneering contribution to neoclassical growth theory. Following this work, many models have been developed, analysing technological change from an evolutionary point of view, emphasizing the role of uncertainty, learning, irreversibility and path dependency (see for example Dosi et al. 1988, and Freeman 1994 for a survey). Whatever one's opinion on these developments is, they meant a revival of the evolutionary tradition in economics, which goes back to Veblen (1898) and Schumpeter (1934), as a result of which evolutionary theories and models have become the most influential alternative to neoclassical theories and models on economic growth and technological change. As noted above, the current neoclassical view on technological change is not the same as it was in the days of Solow, and hence the question arises whether neoclassical economics is still 'a grossly inadequate vehicle' for analysing technical change. We deal with this question in Chapter 2, searching for the essential differences and similarities between the neoclassical and evolutionary economic view on technological change, both conceptually as well as in terms of modelling practices.

1.3 INNOVATION VERSUS DIFFUSION

In this book we adopt the widely used typology of technological change as has been provided by the Schumpeterian trilogy of invention (generation of ideas), innovation (development of those ideas through first marketing or use of a technology) and diffusion (spread of new technology across its potential market). However, as noted previously, the focus of this book is diffusion rather than innovation or invention. It is beyond doubt that the innovation of new technologies is at the very heart of processes of technological change. However the diffusion of technologies is at least equally important, costly and difficult as the innovation of new technologies (see for example Jovanovic 1997). It needs no argument that there will be very limited – if any – impact of technological change on productivity growth or energy-efficiency improvements due solely to the act of innovating new technologies, without them being actually adopted in economic processes. And of course technological change can only help in achieving policy targets with respect to the stabilization or reduction of greenhouse gas emissions insofar as new energy-saving technologies are embodied in capital goods that are actually adopted and used (for an overview see Jaffe et al. 2002). This is however less trivial than it might seem to be.

It is well known that the widespread adoption of existing energy-saving technologies that are available on the market could enable a significant reduction in energy use, especially in the short and medium run (for example de Beer 1998, IWG 1997). At the same time it is known that diffusion of new energy-saving technologies is a lengthy process, that adoption of these new technologies is costly and that many firms continue to invest in old technologies even when new and cost-effective energy-saving technologies are available. In other words, there exists a considerable gap between the most energy-efficient and cost-effective technologies available at some point in time and those that are actually in use, a phenomenon known as the energy efficiency paradox (Jaffe and Stavins 1994, Jaffe et al. 1999).

Recently economic models of economy–energy–climate interactions have been developed in which technological change is endogenous, emphasizing the role of knowledge accumulation in processes of technological change (see for example Grübler and Messner 1998, Goulder and Schneider 1999, Goulder and Mathai 2000, Nordhaus 2002, van der Zwaan et al. 2002). Despite the recognition of adoption and diffusion processes as the essential driving forces behind knowledge accumulation, until now most of these models are characterized by a macroeconomic perspective on aggregate knowledge creation, with much emphasis on innovation through R&D and learning-by-doing processes, the latter usually being a costless by-product of cumulative investment, installed capacity or abatement. Consequently these models ignore to a large extent the microeconomic characteristics of technology adoption and diffusion, such as the sluggish nature of technology diffusion resulting from all kinds of investment barriers – including the costs inherent to learning processes. Therefore we have chosen to focus this book on processes of adoption and diffusion of energy-saving technologies, with much attention on the interaction between microeconomic investment decisions and macroeconomic patterns of energy saving and productivity improvements. In doing so we build upon recent developments in economic theorizing on technological change that stress the role of knowledge accumulation (learning), knowledge spillovers, uncertainty and path dependency in driving processes of technological progress. Hence it is these issues that we will put forward as an important part of the answer to the question why diffusion of energy-saving technologies is often so costly, difficult and therefore slow.

1.4 SLOW DIFFUSION OF ENERGY-SAVING TECHNOLOGIES

Like any paradox, the energy-efficiency paradox suggests by definition a contradiction that seems to exist, and that might disappear if one takes a closer look. This book offers a closer look. In particular we provide a new explanation for the observed slow diffusion of energy-saving technologies and we further explore two explanations that have already been offered in the literature. In short, we suggest a new explanation by emphasizing the role of complementarities between technologies and we further explore the role of learning processes and uncertainty in determining investment decisions and, hence, diffusion patterns. Below, we briefly introduce the role of these different factors in explaining slow technology diffusion.

The Role of Complementarities

With technological complementarity we refer to the existence of imperfect substitutability between technologies. The idea that complementarities between technologies can explain the observed slow diffusion of cost-effective energy-saving technologies is based on the view that 'technological change is not a once-and-for-all-event but a continual process in which many different techniques coexist' (Chari and Hopenhayn 1991: 1144). Many new technologies pass through a life cycle in which they initially complement older technologies, and only subsequently (and often slowly) are substituted for older technologies. Not only at the macro level, but also at the sector level or even at the firm level, the picture of technological change is often one of continuous investment in both old and new technologies, depending on the technology and the type of production process (see for example Mokyr 1990; Rosenberg, 1976, 1982; Young, 1993b). Therefore we will argue in this book that the coexistence of multiple technologies is not only a by-product of past investment decisions – as is the case in virtually all vintage models – but also an essential ingredient of the process of technological change and a matter of deliberate choice. Since technologies differ often not only in terms of their energy productivity but also with respect to other qualities, there are returns to using a mix of technologies. In Chapter 3 we will develop a model in which we show that this 'taste for diversity' causes diffusion to slow down, because it provides an incentive to invest in older vintages, even if new technologies are available that are 'better' when considered in isolation.

The Role of Learning

Studying the interaction between technology diffusion and knowledge accumulation implies a crucial role for learning processes (see for example David 1975). We follow Rosenberg (1982: 121–2) in distinguishing three basic types of learning: learning in R&D stages, learning at the manufacturing stage and learning as a result of use of the technology. Throughout this book we refer to the first type as learning-by-searching, to the second type as learning-by-doing and to the third type as learning-by-using. In addition we distinguish information gathering as a fourth type of learning. Learning-by-searching refers to researchers engaged in (institutionalized) research and development processes, who learn over time to increase the efficiency of their search for innovations. Learning-by-doing refers to producers of a new technology, who learn over time to produce the technology at lower costs and/or to improve the quality of the technology. Learning-by-using refers to users of a new technology, who learn over time to increase their productivity as they gain expertise in how better to use the technology. Information gathering refers to potential adopters who learn about the arrival of a new technology on the market and shape their expectations by collecting information about its performance and its value for their own business. This information is obtained by, for example, observing others who have already adopted the technology and talking to technology suppliers and other experts.

These different types of learning are expected to have different effects on the speed of diffusion of new technologies. Concerning information gathering, the speed of diffusion of course depends positively on this type of learning by potential adopters about new technologies. However in principle the speed of diffusion depends negatively on learning-by-using. Since users of a technology explore the productivity potential of a technology by using it, they build up expertise which will get temporarily lost if they switch to a new technology, thereby creating a barrier for adoption of new technologies. The effect of learning-by-doing on the speed of diffusion is likely to be ambiguous. On the one hand, learning-by-doing leads to the emergence of improved versions of a new technology on the market, inducing adoption because of the improved quality of the technology. However learning-by-doing also creates an 'option value' for potential adopters to postpone investment if they expect new improved versions of the technology to become available in the near future, in order to gain this quality improvement. These different types of learning are included in the different models developed in this book, except for learning-by-searching, because it deals with the nature of innovation processes while we focus on diffusion rather than innovation.

The Role of Uncertainty

Technological change is intrinsically uncertain. When do new technologies arrive? What is their performance? Are they complements or substitutes for existing technologies? The very existence of uncertainty provides a barrier for technology adoption and this barrier becomes higher if investment decisions are at least partly irreversible. The latter suggests that firms can be 'prisoners' of past investments, which in combination with the existence of uncertainty provides an incentive to postpone investment in order to limit the likelihood of regret. In Chapter 4 we will develop a model in which we analyse the effect of this incentive on aggregate energy savings and the effectiveness of investment subsidies, in the presence of a learning process. Traditional investment theories (for example Stoneman and David 1984) suggest the presence of a 'double dividend' associated with subsidizing the adoption of energy-saving technologies that are subject to learning effects. Not only do subsidies induce immediate adoption to meet politically imposed targets, they also induce further technological progress since technology adoption induces the 'take-off' of learning effects. We will show that investment subsidies may give rise to a trade-off between early adoption of relatively inferior technologies on the one hand and late adoption of relatively superior technologies on the other hand. As a result, investment subsidies may be counter-effective in the long run since they might contribute to a lock-in into relatively inferior technologies.

1.5 INTERNATIONAL COMPARISONS OF SECTORAL PRODUCTIVITY PERFORMANCE

In their quest for understanding economic growth, economists have studied the role of accumulation, productivity and technology and their relation to one another. Broad consensus exists that long-run economic growth is caused by technology-driven total factor productivity growth, ever since the uncovering of the Solow-residual pointed to total factor productivity growth or technological change as the main driving force behind economic growth. Concerning the empirical work on the sources of economic growth, this led to the emergence of a growth-accounting tradition, measuring the contribution of various determinants of output and productivity growth (see for example Denison 1967; Maddison 1991). The empirical quest to understand productivity growth has long focused almost exclusively on labour and total factor productivity growth. However, during the last decades energy has increasingly been recognized as a crucial production factor fuelling economic growth, leading to increasing attention being paid to energy productivity developments and to the disentanglement of its determinants. In Chapter 5 we combine insights from both strands of the literature in a simultaneous exploration of energy and labour productivity developments.

A principal aim of this empirical analysis is to trace back macroeconomic developments to developments at the level of individual sectors. The reason for this lies in the fact that understanding trends and cross-country differences in technology-driven productivity performance requires the assessment of productivity performance in individual sectors, since aggregate productivity developments are also the result of structural changes. For this purpose we constructed a new database that merges energy data from the IEA Energy Balances and economic data from the OECD International Sectoral Database (ISDB) and the OECD Structural Analysis Database (STAN) at a detailed sectoral level. The new database covers the period 1970–97 and distinguishes 14 OECD countries and 13 sectors, including ten manufacturing sectors, services, transport and agriculture. Using this database we will document some stylized facts on energy and labour productivity growth in terms of both levels and growth rates across countries and across sectors. Moreover we will decompose aggregate productivity growth performance into a part that is due to shifts in the underlying sector structure and a part that is due to remaining productivity improvements. Finally, we will assess the relation between energy and labour productivity growth rates at different levels of aggregation.

Of course economies not only differ, they also interact. Hence productivity developments are not only determined by developments within a particular country or sector but also by what is happening in other countries and sectors. This raises the question of whether cross-country productivity differences are persistent or whether they will converge to similar levels, for example due to capital accumulation or technology transfers. The concept of productivity convergence has its roots in traditional neoclassical growth theory, with its central notion of a transitional growth path to a steady-state income. The Solow–Swan neoclassical growth model postulates convergence of per capita income, building upon the assumption of diminishing returns to capital accumulation at the economy-wide level. New or endogenous growth theory however yields a more diverse picture concerning patterns of convergence. In this view, cross-country convergence depends on the degree of international knowledge spillovers, allowing less productive countries to catch up with more advanced economies. At the same time, endogenous growth theory suggests that growth differentials may persist or even increase, since learning effects, externalities and market imperfections allow for economy-wide increasing returns to capital accumulation and the existence of multiple steady states. Consequently, the convergence hypothesis has become the subject of extensive empirical research and debate, concentrating on the question of whether initially poor countries indeed grow faster than rich ones. In this book we step back from this debate, but add to the existing empirical macroeconomic literature a systematic comparison of energy and labour productivity convergence at a detailed sector level.

1.6 OUTLINE OF THE BOOK

This book consists of four parts. Part I provides the motivation for the research carried out in this book and provides a short review of economic thinking about economic growth and technological change. Apart from the current chapter it also includes Chapter 2, which compares and contrasts neoclassical and evolutionary thinking. In Part II, containing Chapters 3 and 4, we develop two theoretical models of energy-saving technology diffusion, and the way in which microeconomic characteristics of investment decision determine the impact of environmental policies. Part III, containing Chapters 5 and 6, gives an empirical analysis of energy and labour productivity performance across countries and across sectors. In Part IV, containing Chapters 7 and 8, several elements of the previous chapters are integrated into an existing policy model, conclusions are drawn and some suggestions are made for policy-making and future research. The different chapters are introduced in more detail below.

Chapter 2 provides an interpretative survey of insights from a neoclassical and an evolutionary perspective on economic growth and technological change. We will compare a number of landmark models of both views along three central issues in the debate on technological change, namely the role of heterogeneity, uncertainty and path dependency. What are the essential differences and similarities? What are the recent developments in both traditions and what does this mean for their relation to one another? By answering these questions, this chapter lays the conceptual foundation for the second part of the book.

In Chapter 3 we develop a vintage model that is characterized by 'returns to diversity' of using a mix of technologies. The model is inspired by the product-variety theory which started with the seminal work of Dixit and Stiglitz (1977) and was later extended and applied by for example Ethier (1982), Grossman and Helpman (1991) and Romer (1990). We use the model to offer a new explanation for the observed slow diffusion of cost-effective