Tyndall°Centre
for Climate Change Research

Modelling technological change

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This is the final report from Tyndall research project IT1.19 (Etech: Technology and the economy-energy system in an integrated assessment of climate change). The following researchers worked on this project:

Dr Jonathan Köhler, Tyndall Centre, School of Environmental Sciences, University of East Anglia and Department of Applied Economics, University of Cambridge

Dr Terry Barker, Dr Chris Hope and Dr Haoran Pan, University of Cambridge

Dr Frans Berkhout, SPRU, University of Sussex

Professor Ken Green, Dr Paul Dewick and Dr Marcela Miozzo, Manchester School of Management, UMIST

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Introduction

This project (ETech; Tyndall code IT1.19) formed one of the initial exploratory projects (Round 1 of Tyndall project funding) looking at particular modelling issues for a next generation Integrated Assessment Model (IAM). At this stage, December 2000, it was considered necessary to build an economic model and that technological change should be a focus of the theoretical and modelling work.

Structure of project and participation

The ETech project had three activities: technology change analysis, scenario definition and model building. It was decided at an early stage to concentrate on a long-term analysis to 2100, with an additional capability of modelling shorter time periods and to work at a global level. From the initial project meetings, the structure of the project was developed as follows.

There would be an analysis of what future technologies might become important over the next 20, 50 and 100 years and how these would change economic structure in terms of sectoral activity (in Input-Output terminology) and greenhouse gas emissions. This would be complemented by a development of the IPCC Special Report on Emissions Scenarios (SRES) to provide more detail on technological change and some baseline assumptions for the model building. These two activities would provide a baseline structure and set of scenarios for a global, dynamic, non-equilibrium model which would incorporate endogenous technical change.

The project had the following participants from three Tyndall partner institutions:

- Dr Terry Barker, Dr Michael Grubb, Dr Haoran Pan and Dr Jonathan Köhler, Department of Applied Economics (DAE), University of Cambridge.
- Dr Frans Berkhout, SPRU, University of Sussex.
- Professor Ken Green, Mr Paul Dewick and Dr Marcela Miozzo, Manchester School of Management, UMIST.

DAE Cambridge undertook the model building, UMIST undertook the technology analysis and SPRU provided the scenarios structure.

Specific project objectives

This project concerns technology and the construction of an economy-energy-emissions model as a component of the Tyndall Centre's integrated assessment framework. The project establishes the theory and data of such a model with an emphasis on the treatment of technology. In particular, the project:

- considered how to model technological change, its drivers and its effects at a sectoral level and at different spatial scales over a time scale of 5 to 100 years.
- constructed a prototype model including technical change suitable for inclusion in an integrated assessment framework at the global level (but so that it can encompass the EU, UK, regional and local levels at a later stage).
- identified policies required to influence technical change in directions favourable to climate change mitigation.

Methods and activities

Technology analysis

The initial analysis of possible/likely technological changes that will influence industrial structure was based on three main types of activities.

1) A review of theories of long-term technological change. The ‘long-wave theory’ (Freeman and Louça, 2001) points to the need to identify the key elements of future so-called ‘techno-economic paradigms’. The key elements of such paradigms are associated with a ‘cluster’ of inter-related radical and incremental innovations (product, process, technical, organisational and managerial) that have a pervasive effect throughout the whole economy. We know that the key elements of all previous techno-economic paradigms (there have been five, according to most commentators) developed in the techno-economic paradigm that preceded each one. This suggests that we might be able to identify the key elements of future paradigms within industries that are in their infancy today.

2) A review of the technology forecasting literature. From this, we can already guess at which technologies are going to be important in the next techno-economic paradigm. Information and Communications Technology (ICT) is an obvious example. Biotechnology, for example, has the potential to create many generic platforms with a pervasive effect across a wide range of industries: pharmaceuticals, health care diagnostics, agriculture, food, materials technology, environmental monitoring. There are many overlaps between biotechnology and information technology; the former could not have grown so fast without the mature IT system facilitating distributed working for product development.

Nanotechnology is also a fledgling technology that has had its birth within the ICT techno-economic paradigm. Developments in nanotechnology could maintain the ICT revolution beyond Moore’s Law, increasing chip performance through nano-manufacturing using novel materials such as nanotubes. Nanotechnology could facilitate biotechnology developments through the application of nanocomputers to further understand, for example, the biological cell. Nanotechnology might have an impact on all areas of manufacturing, using nanoparticles to improve basic material properties. Nanotechnology's radical, pervasive impacts seem some way off, most likely after 2050; nevertheless, one can point to early developments in nanofabrication, nanoelectronics and nanomedicine.

Materials technologies are historically pervasive, but it is difficult to attribute developments in materials technology to any one technology or sector, particularly when there has been considerable convergence between the technologies and when the trajectories of automation are applied across different industries. For example, there are materials technologies being developed using knowledge and applications of biotechnology (e.g. in the application of genetic modification techniques to the production of biomass for energy, food and chemicals applications) and nanotechnology (e.g. carbon nanotubes) in addition to developments such as memory plastics.

In summary therefore, the likely technological developments of the next few decades are, we suggest, concerned with i) *the manipulation of organisms (and constituents thereof),* ii) *information,* and iii) *materials*.

3) Small-scale brainstorming sessions. These involved academic analysts concerned with technological and locational change to explore two issues: a) the likely effects of the technological changes identified on specific industrial sectors, and b) the likely global geographical distribution of these changes.

The analysis was conducted using an industrial sector classification system - based on previous work by Pavitt, Soete and Miozzo (Dewick *et al.*, 2002a) - that is based on technological relationships between sectors and that can be used to group industrial sectors in a way that allows longer-term forecasts to be made.

Scenario development
Berkhout (2002a,b) set out four scenarios for economic and political development in four global regions. These scenarios form the background against which scenarios for industrial and technological development are generated within the ETech project, which aims to develop a world macroeconomic model with which to investigate policies for climate change and sustainable development. The four scenarios developed were therefore 'building blocks' to be used in framing and interpreting the economic model. The model has been designed to run for the period until at least 2050 or 2100.

We drew on the Special Report on Emissions Scenarios (IPCC, 2000) developed for the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) in setting out the E-Tech scenarios. While there are many competing futures scenarios frameworks, the SRES scenarios are at the heart of the IPCC's TAR, will be retained for the IPCC Fourth Assessment, and are well recognised by both scientific and policy communities. A distinctive contribution of the E-Tech project, as compared with the modelling exercises that underlay the SRES scenarios, is that it seeks to take a neo-Schumpeterian approach (Freeman and Louça, 2001) to modelling the impacts of technical and structural change on greenhouse gas emissions from economic activities.

Modelling
There were two aspects to the modelling: the building of a pilot global model – E3MG (Barker *et al.*, 2002) - and the development of a theory of long-term technical change. The economic model was based on Cambridge Econometrics software and previous preparatory work on a global model. The pilot version has the EU, the USA and China separately identified, with some global aggregates identified. It is a dynamic (through time) disequilibrium model, with parameters for co-integrating equations econometrically estimated using the Engle-Granger technique (Engle and Granger, 1991) where data are sufficient. The model contains an Input-Output (IO) structure of 20 sectors to 2020, with less detail further in the future and provides the capability of considering individual countries and a changing IO structure (Pan, 2002c). Three levels of industrial aggregation are used: 20 sectors to 2020, 12 sectors to 2050, and 5 or so to 2100. Future issues that to be addressed are the incorporation of international capital flows – Foreign Direct Investment – and international technology transfer.

The endogenous technical change modelling, which feeds into changes in the IO structure, was based on a numerical interpretation of Freeman and Luca's (2001) theory of Kondratiev waves of long-term technical change. This work is reported in Köhler (2002a,b; 2003).

Progress and continuation in ETech+

A follow-on project has been funded in Tyndall Round 2 - ETech+ (Tyndall code T.12) - which will continue the work of ETech to further develop the technology analysis and the modelling work.

Technology analysis
This work has been mostly completed. The analysis of new technologies and their implications for sectoral structures and carbon dioxide emissions is reported in Green *et al*., 2002) and Dewick *et al*. (2002a,b). The changing spatial structure of economic activity is reported in Miozzo *et al*. (2002).

Scenario development
A draft report of the scenarios has been completed (Berkhout 2002a,b).

Modelling
The modelling work is well underway, but has been delayed for two reasons: 1) the staff member for the economic model did not start work until 1 September 2001, a delay of seven months, and 2) the theoretical work involved in developing a very long-term model of endogenous technical change was initially underestimated. The pilot economic model is expected to be built and tested by the end of December 2002 as part of ETech+.

The modelling demanded a heavy time investment. First, it took several months to understand the working mechanism and main components of the existing model in its European version, for the reason that the model was written in FORTRAN with over hundred subroutines and in specially designed languages such as IDIOM and MREG to deal with simulation, estimation and data management. Second, data collection was extensive because of its time-series nature. Most data on EU countries and China have been collected before (Pan, 2002a,b), but collection of USA data alone, which actually are mostly available and accessible through the internet, took three months including one month of assistance from a research assistant. Finally, estimation of the over two thousand econometric equations took another three months.

The theory of long-term technical change has been developed in outline, but the method by which this will be incorporated into the economic model has yet to be decided. These delays have meant that the technology policy analysis has not yet been undertaken. This is now a major area of activity for ETech+.

Future work in ETech+
Both UMIST and DAE Cambridge have been funded to take their work further, while SPRU will take part in the workshops and discussions of both ETech+ and scenarios activity in the Tyndall Centre in general.

Cross-Tyndall issues

Implications
The ETech project has provided a relatively rapid start to the development of the economic component of the CIAM (Community Integrated Assessment Model) that forms the flagship project of Research Theme 1 of the Tyndall Centre's research activities. The approach of disequilibrium modelling at a global level with a detailed consideration of endogenous technical change and the impacts on economic sectoral structure is a new and innovative approach to modelling the economics of climate change policy. The flexible structure of the model will in the future enable a more regionalised analysis of individual countries to be incorporated into the modelling where there is data available and this is considered important to the modelling activities. As a first priority, it is intended to generate results for the UK.

Scenarios
The scenarios work undertaken for ETech have been made available to other Tyndall projects, so that where relevant, they can take account of, and undertake scenario based work that is consistent with, the ETech scenarios.

Tyndall Centre links

The main links outside the immediate ETech project members have been with the RT1 research fellow and with Research Theme 2. The incorporation of the ETech model into the CIAM will require further close liaison with RT1's CIAM and also integrated assessment process activities, as well as with the SOFTIAM project (Tyndall code T2.15) for interface definitions.

Links outside the Tyndall Centre

As a part of the RT1 activities, especially the Blueprint project (Tyndall code IT1.3), contact has been established with various other European researchers working on the economics and energy technology modelling as a part of integrated assessment models of climate change. These contacts are reported in the Blueprint project (Warren, 2002). The contacts with PIK, ICIS, Professor Morita in Japan and other members of the European Climate Forum will be developed during the course of the ETech+ project.

Policy relevance

This project, together with the developments in the ETech+ project, will both form part of the CIAM. This is specifically intended to provide analysis of climate change policies and technology policies relevant to greenhouse gas emissions in particular. The policy plans are further elaborated in the Blueprint project final report (Warren, 2002). They are focussed on providing timely inputs to the next round of the Kyoto process for 2012-2020 and to the IPCC Fourth Assessment.

Wider relevance

This analysis has advanced the science of integrated assessment of climate change policy in several ways. Long-term technology assessments and the functional classification of industries have been developed in a way that is relevant to economic modelling. The IPCC SRES scenarios have been developed in a way suitable for consideration of technology dynamics for sectors other than energy generation. The modelling work is applying new approaches to energy-environment-economy modelling and the modelling of endogenous technical change.

Project outputs

Journal articles

Berkhout,F. (2002b) Technological regimes, path dependency and the environment **Global Environmental Change**, 12, 1–4.

Green,K., Shackley,S., Dewick,P. and Miozzo,M.(2002) Long-wave theories of technological change and the global environment **Global Environmental Change**, 12, 79-81.

Köhler,J. (2003) Long-run technical change in an energy-environment-economy (E3) model for an IA system **Integrated Assessment** (in press)

Conference papers/working papers/reports

Berkhout,F. (2002a) ETech Scenarios: technology, industry and environment futures Unpublished manuscript, SPRU, University of Sussex

Dewick,P., Green,K. and Miozzo,M. (2002a) Technological change, industry structure and the environment **Tyndall Centre Working Paper 13**, Tyndall Centre, UEA, January 2002

Dewick,P., Green,K. and Miozzo,M. (2002b) Technological change, industry structure and the environment Paper presented to the *10th Greening of Industry Conference*, Göthenburg, Sweden, June 2002.

Köhler,J. (2002a) Long-run technical change in an energy-environment-economy (E3) model for an IA system **Tyndall Centre Working Paper 15**, Tyndall Centre, UEA, April, 2002

Köhler,J. (2002b) Long-run technical change in an energy-environment-economy (E3) model for an IA system *iEMSS proceedings: Integrated Assessment and Decision Support*, Lugano, vol 3, pp.139-144.

Miozzo,M., Dewick,P. and Green,K.(2002) Globalisation and the environment: the long-term effects of technology on the international division of labour Unpublished manuscript, School of Management, UMIST

Pan,H. (2002a) A method for long-term projection of Input-Output structure with specific layers of technology Unpublished manuscript, DAE, University of Cambridge

Pan,H. (2002b) Note on the completion of EU data Unpublished manuscript, DAE, University of Cambridge

Pan,H. (2002c) Note on the re-arrangement and new collection of China data Unpublished manuscript, DAE, University of Cambridge

General references

Barker,T., Köhler,J. and Pan,H. (2002) **E3MG manual** DAE, University of Cambridge, Cambridge.

Engle,R.F. and Granger,C.W.J. (eds.) (1991) **Long-run economic relationships** Oxford University Press, New York.

Freeman,C. and Louça,F. (2001) **As time goes by** Oxford University Press, Oxford.

IPCC (2000) **Emissions scenarios. A special report of Working Group III of the Intergovernmental Panel on Climate Change**. Cambridge University Press, Cambridge, UK and New York, NY, USA, 599 pp.

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The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

Research at the Tyndall Centre is organised into four research themes that collectively contribute to all aspects of the climate change issue: Integrating Frameworks; Decarbonising Modern Societies; Adapting to Climate Change; and Sustaining the Coastal Zone. All thematic fields address a clear problem posed to society by climate change, and will generate results to guide the strategic development of climate change mitigation and adaptation policies at local, national and global scales.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

The Tyndall Centre is a partnership of the following institutions:

- University of East Anglia
- UMIST
- Southampton Oceanography Centre
- University of Southampton
- University of Cambridge
- Centre for Ecology and Hydrology
- SPRU – Science and Technology Policy Research (University of Sussex)
- Institute for Transport Studies (University of Leeds)
- Complex Systems Management Centre (Cranfield University)
- Energy Research Unit (CLRC Rutherford Appleton Laboratory)

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Warren, R. (2002). **A blueprint for integrated assessment of climate change**, Tyndall Centre Technical Report 1.

Gough, C., Shackley, S., Cannell, M.G.R. (2002). **Evaluating the options for carbon sequestration**, Tyndall Centre Technical Report 2.

Köhler, J.H. (2002). **Modelling technological change**, Tyndall Centre Technical Report 3.