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TECHNOLOGY AND THE TRANSITION TO ENVIRONMENTAL STABILITY : CONTINUITY AND CHANGE IN TECHNOLOGICAL SYSTEMS

SUMMARY FINAL REPORT

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As of January 1994, the Innovation Studies Group became the STEP Group (Studies in Technology, Innovation and Economic Policy), a new independent research centre in Norway with Professor Smith as its director.

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I. OBJECTIVES

The project concerned the policy problems involved in inducing a technological transition away from hydrocarbon-based technologies, and other technologies producing significant greenhouse gas emissions. The objective of the project was to refine what we know about large-scale technological shifts, and to apply the results to the policy problems involved in changing our basic energy technologies. The project consisted of three interlined parts :

- a theoretical part on the conceptualisation of technological change, discussing stability and change in technological systems.
- a historical component discussing our historical understanding of change in complex systems of energy generation and use, focusing on large-scale technological transitions and the role of public policy.
- an applied component which analysed technological transitions towards environment-friendlier energy technologies, and explores policy measures to enhancing environmentally-beneficial technological change.

II. METHODOLOGY

The project was based on the concept of a "technological regime". A "technological regime" refers to the whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures which make up the totality of a technology. The essential idea behind a technological regime is that the ways in which technological change can and will develop are both structured and constrained : constrained by the available methods and techniques, by the consensus of engineering ideas about how to approach problems, and by patterns of infrastructures and consumer demand.

III. MAIN RESULTS

First, a theoretical exploration of the properties of complex technological systems or regimes, in which energy was used as an example. The project provided a general discussion of how technology has been understood - leading to a distinction between approaches which revolve around individual products/processes and approaches which emphasise the notion of a system. The importance of integration and links between technologies was emphasised, which implies the existence of structured technological systems. In turn, systems lead to questions of rigidity and lock-in. This leads to the development of the concept of *technological regime*, and a further discussion of the development and evolution of structured technology systems.

Second, there was a discussion of techno-economic factors which lead to self-organised stability, in regimes. The basic issue here was, why do some technologies become dominant ? Why is automobile technology dominated by the internal combustion engine rather than the steam engine as a power source, for example ? The team argued that dominant technologies are characterised by technological features which translate into sustained economic superiority. The most important of these features are :

- The existence of learning curves
- Economies of scale
- Interactive learning possibilities
- economies of scope.

However, there are also external factors which shape the dominance of technologies; these factors are strongly influenced by public policy decisions. The above discussion is therefore followed by a more extensive discussion of the relationship between technological regime dominance and infrastructure provision. The research examined the economic characteristics of infrastructures, and described the ways in which physical infrastructures (such as power supply systems, ports, roads etc.) and science-technology infrastructures (regulatory systems, technical institutes, universities, etc.) affect the formation and persistence of technological regimes. This discussion focused on the role of public policy in infrastructure decision-making.

Third, a brief historical description of the world energy system, emphasising the symbiotic relationship between energy resources, technology and economic development was carried out. This was followed by a discussion of energy technologies and the concept of a technological paradigm and regime that are used extensively throughout this research. Short-term and long-term technological solutions to limit greenhouse gas emissions were identified and discussed; in particular renewables - by looking at the cost-reduction potential of various renewable energy technologies and the importance of government policy to set a level playing field for market forces to operate in.

Fourth, a discussion was made of transitions in modern economic history (i.e., after 1750), with an emphasis on technologies of power supply and distribution. It focused on a discussion of steam power in the British Industrial Revolution, and the development of electrical power and use technologies in the United States in the late 19th century, emphasising the systematic aspect of such change. This emphasises the long time periods and substantial social changes associated with changes between technological regimes.

Fifth, there was a discussion of historical changes in shipping and shipbuilding technology : from wooden sailing ships to steel steamers, to tanker ships with diesel engines. It was demonstrated how - historically - technological change was intertwined with social and institutional arrangements (classification societies and brokers) and was shaped through years of development and perfection. At the time of their introduction, the new shipping technologies offered only few advantages over existing technologies, they were able to compete only in specialised markets. For example, early steamships were fuel-consuming monsters, prone to machine troubles, expensive to build and slow compared to advanced sailing ships. Their use was limited to passenger and mail transport where regularity rather than speed counted. Several decades of learning and perfection were needed before steam ships could compete with sailing technology in other areas. Similar points apply to tankers ships with diesel engines that depended for their development on one particular market niche (oil transport); and that required for their diffusion a wide array of organisational and institutional changes.

Sixth, a study was made of the role of corporate R&D in creating new technological regimes. The project looks into firms' R&D processes as an important determinant of technological trajectories. It studied how environmental concerns are changing industry R&D practices and looked at the motivation of firms to develop and use cleaner technologies. It also looked at the possible contribution of three areas of revolutionary technological change - information technology, new materials and biotechnology - in alleviating environmental problems. This was followed by a discussion of empirical studies of environmental R&D, with a focus on the way in which industry perceives the environment, and how the environmental challenge is being met (both technically and organisationally).

Seventh, a study was carried out of the development and diffusion of windpower as an example of an alternative energy supply technology. The team looked at technical design issues, and how the existing energy infrastructure (the electricity grid), together with public policies, have shaped the development of windpower in the last two decades in three different countries: the UK, Denmark and The Netherlands. The role of other actors (especially environmentalist groups and universities) was also discussed. Current obstacles to the wider diffusion of wind turbines in Western Europe were identified - like public resistance, land-use policies, and energy pricing practices.

Eight, a study was made of energy-efficient technologies and practices in the construction industry. The project looked at the factors influencing the transition to a more energy-efficient building stock, focusing on the various trajectories of research, available technological solutions, building practices and government policies. It was found that the rate of change is far from rapid due to a combination of factors. These included the fragmented nature of construction industry, with its broad heterogeneous range of actors, the regulatory framework which governs it, and low-responsiveness of consumers to price signals.

And finally, a discussion was elaborated of the general issues for public policy of making a swift and smooth transition away from hydrocarbon-based energy technologies, towards a more environmentally sustainable energy system - one in which renewable and energy-efficient technologies are used more widely. This discussion was structured around three possible energy technology scenario's : "business-as-usual", "a pale greening of energy" and "a clean break".

IV. SCIENTIFIC INTEREST AND POLICY RELEVANCE

(I) scientific interest and novelty

The present energy system based on fossil fuels gives rise to a range of environmental problems - from photochemical smog, acid rain to greenhouse warming. The implication of fossil fuels as causing many of the world's environmental problems suggests that a sustainable environment requires - at least in part - new technologies for energy supply, conversion and end-use. At this moment, many public and private decision makers are thinking about how to achieve a smooth transition away from fossil fuel-based energy technologies, and many sensible proposals have been made - like more government R&D for renewable energy and energy conservation, carbon taxes, etc. What is missing, however, in the policy debate is a framework for understanding change in complex technology systems, especially how the dynamics of technology interact with the socio-economic system from which it emerges. In this research a framework was provided.

(ii) policy relevance

This research was about the transition path to sustainable development, focusing in particular on so-called greenhouse gas emissions and the processes of technological change which are necessary if the world economy is to achieve environmental stability. The central idea of this study was that a sustainable environment will require new technologies for energy supply and use, and therefore that the solution to the greenhouse problem is highly contingent on the ability of policy makers to begin and sustain a technological transition away from hydrocarbon-based energy supply, conversion and end-use technologies (towards the use of renewable or electric vehicles powered by batteries or fuel cells) or the replacement of car commuter traffic by interactive telecommunication systems allowing for activities like telework and teleshopping.

The problem of inducing such shifts in complex technological systems poses a formidable task for policy makers, as it involves not only a change in technology, but also quite fundamental changes in production, organisation and the way in which people live their lives. One way of dealing with this problem is to let market prices reflect the negative environmental costs, to let prices speak the "environmental truth". This is exactly what economists suggest policy makers should do: to rationalise energy markets by internalising the environmental costs of pollution. Such an approach is not wrong, but we must be looking at what is missing. It fails to recognise the way in which society is locked-in to particular technologies; how the market favours technologies that are within the hydrocarbon regime, and is based against technologies that require a new infrastructure, skills, plant design, etc. Certainly, a carbon tax and tradable carbon rights will have a role to play in the wide array of necessary GHG policies, but it is not likely that such measures will be sufficient to bring about radical change in energy technologies and practices, unless they significantly raise the costs of using fossil fuels, something which is unlikely in the political reality of today. To encourage sustainable energy technologies that are not part of the hydrocarbon regime, a more integrated and coordinated policy is probably needed, a policy that would engage in experimentation and make use of the cumulative and self-reinforcing character of technological change.

Elements of policies of managing a transition to a sustainable economy were identified. One such policy is niche management, the creation and control - through public policy - of market niches for some technology options with potentially high environmental and social benefits. These market niches may be an important stepping stone for the further evolution of radically new energy technologies. It helps suppliers to better understand user needs, to identify and overcome critical problems, to achieve cost reductions in mass production, and, perhaps most important, to create a constituency behind the new product (firms, research institutes, public agencies, users). The creation of a market niche for radically new technologies with a low environmental impact should be considered as a learning experiment, not just for suppliers and potential users of these technologies but also for public authorities that want to achieve a smooth transition towards a more environmentally sustainable energy future.