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THE IPTS REPORT

Produced by IPTS and issued in Cooperation with the European S & T Observatories Network

- **Strategies on the Future of the Chlorine Industry**
- **Towards Greener Refrigeration Technologies**
- **Climate Change Research: Facts, uncertainties and responses**
- **Intelligent Software Agents: Perspectives for business**
- **Economic Growth Theories and Technical Change**

JUNE 1996

EUROPEAN COMMISSION
Joint Research Centre

This Report is addressed to the decision-makers involved in 'managing change', seeking distilled, selective presentation of technoeconomic intelligence and prospective alert on under-discussed facets of a topic, rather than a deluge of data and encyclopaedic reviews.

This Report stands as the most visible indication of the commitment of the IPTS to Technology Watch, its main priority and mandate. In this context, the Report aims to focus on issues of projected pertinence for decision-makers, exploring *prospectively* the socio-economic impact of scientific and technological developments. On the one hand, such exploration implies signalling on issues which are not yet clearly on the policy-makers' agenda, but can be projected to draw attention sooner or later. On the other hand it implies alerting actors about underexplored aspects of an issue on the agenda, aspects which, though under-appreciated today may have substantial consequences tomorrow.

The Report benefits from a validation process, underwritten by networks of renowned experts and Commission services, making this Report a product of not only the IPTS but also of its collaborating networks inside and outside of the Commission. The process of interactive consultation used guarantees the validity of the points highlighted, the relevance of the topics chosen, and the timeliness of their examination.

There are many publications excelling within their discipline. The Report takes the extra step, prospectively exploring interdisciplinary repercussions, often drawing surprising connections. Moreover, sharing the Commission's priorities, the Report is still the product of a research institute, and can be a neutral platform for dialogue on issues of relevance and a nexus for facilitating debate.

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CORRIGENDUM: CO-AUTHORS FOR ARTICLES IN IPTS REPORT 04

We would like to note the names of the co-authors of the following articles in the 04 Issue:-

- Incentives for Innovation in Electric Power Utilities: Pietro Moncada Paternò Castello & Antonio Soria
- Producing High Value-added Molecules in Crops: A sustainable alternative for agriculture: Mario Demicheli & Patrice Laget
- Brief Note: Mario Demicheli & Pietro Moncada Paternò Castello

In this issue we are inaugurating our Letters-to-the-Editor section with an interesting response to our article on the potential of hydrogen (issue 03). We welcome letters, which should be short and to the point. Following standard practice, *the IPTS Report* reserves the right to edit letters (depending on considerations such as space, intelligibility, etc).

The first article in this issue is triggered by a recent appearance of studies from authoritative sources that seem to come to different conclusions regarding projections for chlorine and the chlorine industry. On the one hand, a very large percentage of the sales of chemical products are linked to the use of chlorine; on the other hand chlorine has been charged with negative environmental and health impacts. The article presents the arguments and the studies, and concludes that a policy initiative taking these projections into account would be useful, if for no other reason than for bringing industry into a constructive dialogue and for providing a framework for decision-making.

The second article examines the trends in refrigerants/coolants following the Montreal protocol. It suggests that the shift from chlorofluorocarbons (CFCs) to hydrogenated CFCs (HCFCs) is a transitional solution since HCFCs still deplete the ozone layer (though less perniciously than the CFCs). It also argues that more environment-friendly, but costlier, solutions may fail to be adopted by poorer regions, if the right incentives are not in place. Moreover on the technical front, ammonia is making a comeback as a coolant, as scientists are tackling some of the associated safety/cost concerns. Similarly, research on hydrocarbons suggests their strong potential as coolants, provided that safety concerns are addressed.

The third article was triggered by the recently released second assessment report of the Intergovernmental Panel on Climate Change (IPCC). It examines the state of scientific knowledge, and more particularly it identifies areas of uncertainty regarding observations, impacts and appropriate methodologies that need to be addressed. It suggests that policies need to integrate the existence of uncertainty in their formulation, allowing for adjustments along the way; that the full range of impacts (environmental, social, economic, etc). should be taken into consideration; and most crucially, utmost attention should be given to 'win-win' measures which can improve both environmental impact as well as economic efficiency. It will open the way to future articles focusing on more specific aspects of the uncertaintly issue (eg. the global carbon cycle).

The fourth article examines the advances and potential of 'intelligent agents' in the emerging information society. It suggests that their economic impact will depend on which link in the economic chain controls the rules under which these agents operate; the reaction towards them by vendors, users, etc., the possibility of their abuse/misuse; and their ability to have an impact on international trade flows.

Finally, the last article contrasts standard growth models and new endogenous growth models regarding their view of technology. It presents some of the evidence for and against each, and suggests some of the implications of the theoretical debate for technology policy.

Hydrogen as Automotive Fuel: The Bridge to CO_2-free Transportation

Comments on the article of Dr. Hernández entitled

"Alternative Fuels for Automobiles: Hydrogen Potential and its implications"

appeared in the April 1996 edition of the IPTS report

The initiative taken by Dr. Hernández to dedicate an article to the potential of hydrogen as a candidate fuel for automobiles is a laudable one. It complies perfectly with the remit of the IPTS as a "Technology Watcher", by drawing attention on an energy system for which little or no interest can be traced in national or EU R&D programmes, at the very time when very ambitious programmes have been or are about to be adopted by such powers as Japan or the U.S.

This being said, the author runs the risk of giving a partial, or even uncertain view of the potential of hydrogen as a fuel by concentrating primarily his attention on the end-consumer technological problems. Various studies have shown that the use of hydrogen, produced by classical processes, in automobiles with combustion engines is globally more polluting than the direct use of fossil fuels, even if it may help to relief "hot spot" pollution of urban streets with busy traffic. On the other hand, fuel cell electric drive systems with their improved overall efficiency can reduce the global emissions below those levels related to the use of fossil fuels, while also having zero tailpipe emissions.

It is therefore of paramount importance to consider the entire energy cycle, from production of the fuel, through its transportation and storage, to its final consumption.

The promise of hydrogen as a clean fuel (local pollution and global greenhouse gases) makes its full sense only if hydrogen is integrated in a wider and longer-term vision, in which it provides, in parallel with electricity, another secondary energy carrier ultimately derived from renewable energy sources tapping the inexhaustable solar resource, although fossil fuels may serve as a transitional resource (e.g. chemical by-product hydrogen available at several locations in the EU). Vice versa hydrogen as an energy carrier offers a second opportunity, i.e. bringing renewable energies to the market place.

Recent developments and reductions in the costs of solar energy technologies have been substantial, and the price of hydrogen to be produced from renewables is likely to continue to decline gradually, over the coming decade, down to acceptable levels. If the external environmental and social effects of the use of conventional and other alternative fuels are taken into account, then the use of hydrogen as a fuel can be expected to become cost-effective even sooner, as has been shown by studies effected under the Euro-Quebec programme for the cities of Los Angeles, London and Munich.

There are no great technological breakthroughs of uncertain outcome that stand in the way to the hydrogen energy system. There are engineering challenges, as in every new technology, and in every new application, but they seem to be quite superable.

Hydrogen storage on board road vehicles is receiving different approaches, and the prototypes put into operation so far do not raise excessive difficulties in terms of range. Also different solutions are under investigation for the refuelling infrastructure, and no unsurmountable barriers (e.g. technology, refuelling time) are encountered even for ambitious concepts like cryogenic liquid hydrogen.

Even the safety issue has to be deflated, considering the results of various tests that have been conducted in various parts of the world, including those under the Euro-Quebec Project. Experts value the hazard potential of hydrogen to be no higher than that of present fuels, although safety properties and related risks may be different between the various fuels.

A specific safety philosophy has to be developed or further worked out. Let's add, en passant, that this subject lends itself ideally for international collaboration and exchange of information, and for the establishment of harmonzied rules and regulations. A first such initiative aiming at international standardization has been taken on the ISO level.

Although Europe has been a pioneer in the field of hydrogen, not only by launching the Euro-Quebec Project the first major project to address the issue in some of its various aspects, there are presently no follow-up programmes at the EU level, and the risk of missing the boat is not to be underestimated. For instance, additional demonstration projects are needed in order to solve practical questions related to the infrastructural implementation of technologies, the definition of compliance with administrative and regulatory requirements, for formation of public acceptability and the establishment of first niche markets.

What is also needed is a framework programme of the European Commission that would care for the implementation of a well structured and planned European effort that integrates and completes the numerous private and regional or national initiatives towards the global objectives.

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Assessing technologies for the European Parliament

Dick Holdsworth

Developments in the European Union during the 1980s and 90s which increased its involvement in research and innovation policy, as well as in closely related areas such as environment issues, have put science and technology on the European Parliament's (EP) agenda more firmly than ever before. As the effects of this began to be felt, the need was seen to equip the Parliament with its own technology assessment facility, providing a channel to independent sources of information and advice.

The result was the EP's adoption of the Linkohr Report on the establishment of an office of 'Scientific and Technological Options Assessment' on 10 October 1985 and the official launch of STOA in March 1987. STOA comprises a Panel of MEPS, appointed by the 20 parliamentary committees, and a unit in the Directorate-General for Research of the Parliament which executes the annual workplan and budget. The Chairman of the STOA Panel is Alain Pompidou (France, UPE), and the Vice-Chairpersons are Fiorella Ghilardotti (Italy, PSE) and Renate Heinisch (Germany, PPE).

STOA's recent work has included projects on the information society, nanotechnology, the car of the future and the future of the car, sustainable development in the Mediterranean region, water quality, biomedical technologies, aquaculture, pollution damage to monuments, telematics in transport, and floods.

The projects are proposed by the parliamentary committees to the STOA Panel, which decides on the content of the annual workplan. The projects inserted in the workplan are executed in cooperation with external contractors, who may be university departments, research institutes, laboratories, consultancies or individual researchers. The in-house team is deliberately kept small, since it is STOA's policy to make optimum use of the most up-to-date external expertise in the many different fields in which it is called on to operate. A core staff of nine, located in Luxembourg and Brussels, works on project management, budget, documentation and secretariat duties, while the presence of a fluctuating number of contract researchers, scholarship-holders and visiting scientists can increase the total size of the team to 15-20. The research budget for external contracts has, for some years, varied around the one million ECU figure. STOA identifies its contractors by publishing an annual call for expressions of interest in the Official Journal, Tenders Electronic Daily and in the press. In addition, it has operated a scholarship scheme for young researchers. The first scheme ended in December 1995. Plans are under consideration for the launch of a new European Parliament scientific scholarships scheme, possibly in 1997. The publications of STOA are primarily intended for the committees and Members of the European Parliament, but they can usually be made available to others at no charge upon request.

In addition to the studies prepared by contractors, STOA organises presentations to committee meetings and holds workshops, as well as assisting committees in the preparation of public hearings. Recently STOA presented its report on aquaculture to the Committee on Fisheries.

The current workplan includes a range of projects on Internet-related issues, such as multimedia in schools and the question of women and the Net. Other topics range from vehicle emissions to coastal erosion, as well as 'technological innovation and money'.

STOA has always enjoyed good relations with a number of Directorates-General of the European Commission, including the Joint Research Centre, and in 1995, with the support of Commissioner Edith Cresson, cooperation started on specific projects between STOA and the Institute for Prospective Technological Studies in Seville (IPTS).

STOA is one of the partner organisations in the European Parliamentary Technology Assessment network (EPTA), which was created under the patronage of the President of the European Parliament. This is a loose but effective grouping of the six organisations providing officially-recognised technology assessment services to parliaments in the European Union. The other five partners serve the national parliaments of Denmark, France, Germany, Netherlands and the United Kingdom. STOA is also a member of the European Technology Assessment Network (ETAN), set up under the specific programme on Targeted Socioeconomic Research.

In 1994 STOA was evaluated by an international team of experts, for whom the rapporteur was William Westermeyer, formally of the Office of Technology Assessment of the US Congress. This made a number of recommendations subsequently taken up in the Bowe Report from the STOA Panel to the President of the EP, Klaus Hänsch, and the Gutiérrez Díaz Report to the Bureau of Parliament. Two of the key points were the need for rigorous quality control procedures, and a reduction of the number of projects so as to permit greater depth of analysis. These and other measures are currently being put into effect.

The demand from parliamentary committees for technology assessment projects by STOA has demonstrated the need for this type of service in a modern parliament. STOA's mandate as an official organ of the EP was confirmed by the Bureau of Parliament in September 1995. It can expect to be kept busy in the years ahead.

Strategies on the Future of the Chlorine Industry

C. Hendriks and D. Papameletiou

Issue: Production and use of chlorine are of key importance for the chemical industry. There are a large number of chlorinated compounds on the market, and nearly 60% of the global sales of chemical products are directly or indirectly linked with chlorine. Besides its importance for the economy, chlorine has for many years been the subject of controversial debates because of adverse environmental and health impacts of many chlorinated organic compounds. As a result of these debates, there is currently a world-wide trend to study how many of the chlorine uses can be substituted by other substances.

Relevance: Recent studies coming from authoritative sources in Member States of the EU have reached important conclusions about the necessity and feasibility for replacing chlorine with alternative substances in most of its uses. The results of these studies may have significant repercussions for the chlorine industry in terms of its competitiveness, and its employment and environmental impacts, and they therefore need to be analysed closely with respect to their usefulness for policy making at EU level.

The debate on the future of the European chlorine industry has recently been fuelled by a study conducted by Prognos. This study examined the manufacture of chlorine and its uses in Germany and found that elemental chlorine could be eliminated in more than 50% of its applications over the next 15-20 years, at a net cost increase of only 1%. Another recent study by TNO and CML investigated the need for a move towards a chlorine-free society. On the basis of these results, the Dutch Ministry for the Environment concluded that the risks related to chlorine and the chlorinated compounds are largely manageable by already-established policies. A new policy on all chlorine compounds was therefore not recommended, although the Ministry recognised the need for combining existing policies with additional actions and instruments.

Growth of the chlorine industry and its negative environmental reputation

Since the beginning of this century, the chemical industry has expanded rapidly without the necessary scientific knowledge of the environmental chemistry, bioaccumulation, toxicity of chemicals, or of general environmental issues such as ozone layer destruction and long-range air transport. On the one hand this has allowed the chlorine industry to grow to its current size (see Box 1), on the other hand it has led to several prominent cases where widely used chlorinated products have had to be banned because of their ecotoxicity. DDT, PCBs and CFCs represent some of the cases which have contributed to the poor environmental reputation, not only of the chlo-

A 50% reduction in chlorine use is feasible over the next 15-20 years at 1% extra cost, according to the Prognos study

Box 1: Statistics on Chlorine Use

Chlorine production in the world in kt/year: 37 in 1900; 3,000 in 1950; 37,000 in 1995

Chlorine production in Europe (Euro-Chlor Federation) in kt/year: 800 in 1950; 9,000 in 1995

Chlorine use in Europe: 12,500 kt in 1995 (94% of this amount were produced and used in 83 identified locations):

- 34% recycled from used HCl (4,083 kt) and CHC* (223 kt)
- 66% from NaCl salt

Uses of chlorine in the world:	% of the market**	% annual growth rate**
Vinyl chloride monomer	34	+ 4.2
Phosgene	6.0	+ 2.5
Hypochlorite	2.5	+ 2
Titanium dioxide	1.8	+ 1.5
Allyl chloride	2.0	+1.8
Pulp and paper	9.0	- 6.0
Propylene oxide	7.0	+0.8
CHC (C1 and C2)	6.0	- 4.5
Chlorobenzene	2.0	- 0.8
Water treatment	5.4	+ 0.7

Employment: Europe: about 2 million jobs are related to the chlorine industry
Germany: about 0.5 million jobs
USA: about 1 million jobs

Turnover: Europe: 100 billion ECU per year are related to the chlorine industry

* CHC: chlorinated hydrocarbons ** cumulative previsions for the period 1994-1999

Reviews of chlorine use are no longer confined to environmental groups, but extend to governments and international bodies

rine industry, but also of the element itself. In the mean time, while the chlorine industry maintains that current scientific progress guarantees that similar cases will not be repeated, several environmental organisations have been advocating a complete phaseout of chlorine.

These organisations have been so successful in their campaign that we are now witnessing worldwide actions reviewing the scope of chlorine production and uses. Furthermore, these actions are not only limited to the initiatives of environmental groups such as Greenpeace, but are increasingly undertaken by governments, such as the US, German and the Dutch, and international bodies, such as the Oslo and Paris Commissions for the Prevention of Marine Pollution, the Barcelona Convention on the Mediterranean Sea, the International Whaling Commission, the World Wilderness Conference, and the USA-Canada International Joint Commission. All of these bodies are commissioning related studies aimed at analysing the current situation and screening policy options.

Current policy issues and related studies

One of the most significant contributions to the chlorine debate over recent years has been the "Chlorine-Free Campaign" of Greenpeace International. It claims to represent an international

movement calling for a complete phaseout of chlorine. Its argument is based on data relating to around 177 different organochlorines that have been found in the fat, blood, mothers milk, semen, and breath of the general population. This analysis has led Greenpeace to conclude that organochlorines can cause damage to human reproductive systems, from the womb to adulthood and it warns that "we are confronting a persistent, global pollution burden that results in a universal exposure on a multi-generational timescale".

Greenpeace has been playing a particularly active role in the US debate on chlorine, where it has questioned the effectiveness of applied policies and instruments. It claims that the discharges currently perceived as acceptable, slowly build up until they reach unacceptable levels, and that the capacity of the ecosystem to assimilate even very low dosages of pollutants that are either persistent in the environment or toxic, or both, is essentially zero. On that basis, the current risk assessment procedures and predictions of safe pollution levels based on "good science", which allow organochlorines to be regulated individually, are considered to be inadequate and are at the heart of the chlorine problem. Greenpeace therefore recommends a re-examination of each use of chlorine within a framework of a systematic phaseout strategy, rather than on an individual basis.

After being directly attacked on its risk assessment practices, the US EPA announced, in early 1994, its intention to develop a national strategy for substituting, reducing or prohibiting the use of chlorine and chlorinated compounds. Related actions have been carried out by the International Joint Commission (IJC), an environmental-policy group organised by the US and Canadian governments. The IJC focuses on water pollution in the Great Lakes region, which is partly associated with discharges of chlorinated substances from the pulp and paper industry.

In Europe, the Oslo and Paris Conventions adopted a legally binding agreement in 1992, requesting the reduction of discharges and emissions of substances which are toxic, persistent and liable to bioaccumulate, in particular organohalogen substances, to levels that are not harmful to man or nature. A ministerial declaration set a reduction target for the year 2000. In this context, the Third North Sea Conference, in 1990, agreed that chlor-alkali plants should meet low mercury emission standards by the end of 1996, and recommended a complete phase-out of mercury cell technology in chlor-alkali plants by 2010. At the Fourth North Sea Conference, held in June 1995, the Ministers re-confirmed the goals set in 1992 for the year 2000.

Recent amendments to the 'Protocol for the Protection of the Mediterranean Sea against Pollution from Land-based Sources', adopted by the Barcelona Convention, request the Contracting Parties to eliminate, to the fullest possible extent, inputs of substances that are toxic, persistent and liable to bioaccumulate. Priority is given to aldrin, chlordane, DDT, dieldrin, dioxins and furans, endrin, heptachlor, hexachlorobenzene, mirex, PCBs, and toxaprene.

Systematic discussion of the problems arising from the chlorine industry in Germany has been carried out by the Enquete Commission of the German Bundestag on the "Protection of Humanity and the Environment". The chlorine industry was selected not only because it is a key sector but also because it has been the subject of a controversial debate for many years. The Commission identified a fundamental need to keep the chlorine flows within closed, integrated production and application systems. Three chlorine production and application areas were selected for in-depth analysis:-

1) in the case of polyvinyl chloride (PVC), the members of the Commission did not agree on all points of the available German disposal strategies;

According to Greenpeace, the current risk assessment procedures and predictions of safe pollution levels are at the route of the chlorine problem

2) in the case of chlorinated hydrocarbon solvents, the Commission recommended their use should be minimised by ensuring leak-free processing cycles or by means of substitution;
3) in the case of propylene oxide (produced exclusively by the chlorohydrin process in Germany), the Commission suggested the examination of the oxiran process, an alternative chlorine-free production route.
As a general interim conclusion, the Commission expressed its unanimous support to a "partial conversion" of chlorine chemistry by using alternative technologies or substances, where this is ecologically necessary, and economically and socially acceptable.

In Germany, about 29% of chlorine use can be eliminated by switching to the oxiran process

In parallel to the work of the Enquete Commission, a more detailed study has been undertaken in Germany by Prognos on behalf of the BMFT and the Ministry of Environment, Energy and Federal Affairs of the Land Hessen. Based on previous results, this study concludes that around 50% of PVC currently used can be substituted with no cost increase, and about 70% with a very moderate cost increase. Concerning the use of chlorine in the production of propylene oxide, the study suggests that the alternative oxiran process is both economically viable and ecologically advantageous. On the basis of this substitution alone, the Prognos study estimates that 29% of chorine use can be eliminated in Germany. In the case of phosgene and polycarbonate chemistry, the study identified limited substitution opportunities which could lead to the elimination of about 20% of chlorine use in this area (14% of total chlorine use). Finally, concerning the epoxy resins, it concludes that 60% of the chlorine use can be eliminated by switching to an alternative low chlorine process for the production of epichlorhydrine, and through substitution of some of the resins by chlorine-free materials. In total, the study claims that 50% of chlorine use could be eliminated over 15-20 years at a net cost increase of only 1%.

In the Netherlands, a detailed study recommended actions relating only to specific chlorinated compounds

Another important study has been carried out recently by TNO and CML in the Netherlands. The study was set up as a substance flow analysis, covering about 99% of the flows of chlorinated substances in the Netherlands. It involved the compilation of an inventory of all emissions, waste generation, exports, imports and economical transactions, and an assessment of their environmental impact using data sources such as the Dutch emission registration database, LCA-databases, industrial data etc. The study concludes that, based on present knowledge about emissions and toxicological evaluation, there appears to be no inherent danger related to the chlorine chain, but that important uncertainties exist and require attention.

...with regards PVC the recommendations are moderate, suggesting its production and recycling be given further attention

On the basis of these results, the Dutch Ministry for the Environment decided against a specific policy for chlorine compounds in general, as existing government policy was considered sufficient for achieving emission reductions in the areas where chlorine presents the biggest environmental burden: climate change and water quality. However, the Ministry recognised the need for supplementary measures to reduce the risk presented by certain chlorinated compounds. Specific follow-up actions will therefore be taken concerning tetra-chloroethylene (dry-cleaning), di-chlorobenzene (mothballs and toilet fresheners), methyl chloride (paint stripper), and trichloroethylene (solvent). Concerning the use of PVC, the recommendations of the study are moderate, suggesting further attention be given to it or to its recycling. Further study is also expected on reducing emissions from hypochlorite which is used in household bleach, swimming pools, electricity power stations and industrial cooling-water systems. No final conclusions could be made on the emissions from the 1% of chlorine use in the Netherlands which is not monitored, and the study therefore suggests further investigation of the so-called "micro-chlorines" that might be formed in low quantities in production processes. These substances, which are formed in small quantities, are not yet covered in the emission databases and their environmental impact is not well understood. Some of them are believed to be persistent, toxic and liable to bioaccumulate.

An inventory of major accidents has been set up by the Major Accident Hazards Bureau (MAHB) of the European Commission, which runs a dedicated database called MARS. MAHB states that 10% of the 230 accidents reported by the Member States involve mostly chlorine as a pure substance released from fixed installations, in addition to a few cases related to chlorinated compounds.

The strategies and position of industry: short-term and long-term visions are needed

The visible part of industry's efforts is contributing to the debate with environmental groups and public authorities. Industry considers sound scientific criteria to be a firm priority for decision-making and is therefore reluctant to accept simplified interpretations of eco-toxicological events. Environmentalists believe this attitude is a systematic attempt to delay action.

A less visible part of industry's agenda, with long-term goals, is to develop alternative techniques and products that limit or eliminate chlorine use or abate the hazards from their use and final disposal. There are several cases of successful innovation in industry and clear evidence that the traditional markets for chlorine are shrinking, such as the chlorinated solvents and the use of elemental chlorine in the pulp and paper industry.

In the USA, the chlorine industry responded to the EPA's announcement about a targeted chlorine strategy by reinforcing its Chlorine Chemistry Council, which later disseminated a study by Charles River Associates advocating that chlorine and its products are indispensable to the US economy.

In Germany, industry's position is clearly reflected in the evaluation of the Prognos study carried out by the Association of German Chemical Industries (VCI). It argues that the study focuses too much on the German situation alone, while ignoring the influence of the global market which is especially strong in the case of chlorine. According to VCI, "conversion of chlorine chemistry" should only be considered in cases of urgent ecological or toxicological necessity. It goes on to state that such cases do not exist, and that the approach taken by the Prognos study for the ecological and economic assessment was invalid, and in any case was based on incomplete, erroneous, or partly outdated data. In reference to the economic viability of substituting the current propylene oxide production route by the oxiran process, VCI doubts whether investors would adopt this option even in new plants. In addition, VCI claims that the ecological risks of the oxiran process were not taken into consideration by the Prognos study. With regards PVC, VCI disagrees with the method and criteria applied by Prognos for evaluating the related ecological advantages of substituting PVC with other polymer materials.

At the European level, and in view of the emerging actions to phase out the use of chlorine, Euro Chlor, the Brussels-based federation of European chlorine manufacturers, has begun a campaign to persuade the public that chlorine is essential in many important human activities, and that industry has tried to reduce the potential risks as far as possible. It argues that there is a sustainable future for a number of chlorine uses which present no risk to the environment. In this context, Euro Chlor's top priority is to gather information on the health and environmental impact of chlorine-based products. A related database known as Co-ordinated Orbital Monitoring Programme Alarm Security System (COMPASS) is being set up to monitor worldwide scientific information on products containing chlorine.

R&D needs and priorities

Concerns have been raised recently over the possibility that chemicals present in the environment may mimic the action of the animal and human hormones, oestrogens. The hypothesis is that these chemicals may bind with oestrogen receptors to produce a variety of undesirable side effects on the reproductive system. However, it is generally recognised that we are a few years

The possibility that chlorinated compounds mimic oestrogens needs to be investigated further

away from understanding the underlying hypotheses, mechanisms or any structural activity relationship relating to oestrogen mimicry. Euro Chlor is working with CEFIC on this issue as it believes there is insufficient scientific evidence to implicate chlorinated compounds with any reproductive abnormalities. Other areas where further research is needed include associated endocrine problems; evaluation of the risk associated with chlorinated compounds in drinking water; so-called micro-chlorines; the metabolism of emitted compounds; and the combined toxicity of chemicals.

Generally, the need for improved procedures for "risk management in uncertainty" and "life cycle analysis" are expected to be a major issue in future debates. Research in this area is considered to be a clear priority.

Conclusions

The refinement of existing tools for risk assessment and management would certainly help to resolve the current controversy about the future of the chlorine industry.

The industry is defending, with all available technical and scientific knowledge and resources, the major traditional uses of chlorine in the plastics industry such as in PVC, propylene oxide and epoxy resins. In these cases, improvements in modern recycling and incineration techniques are considered as promising justification for further long-term investments despite the current controversial debate.

An EU Action Plan for chlorine would help harmonise measures between Member States and contribute to more constructive dialogue with industry

At EU level, a policy initiative concerning an overall chlorine strategy has not yet been planned. However, as several Member States and the USA are taking advanced positions on chlorine, an EU action plan would be desirable in order to provide a framework in which to harmonise measures of Member States, and guidelines for positioning the EU's interests in international negotiations. Furthermore, it would also help the chemical industry to enter a more constructive dialogue.

Regarding risk assessment and risk management of chemicals as products, the main tools in the EU are given by the Regulation 793/93 (Existing substances) and the Directives 92/32 (New substances) and 76/769 (Market and use limitation). The appropriate forum for discussions concerning product phase-outs or restrictions which would involve considerable changes in the internal market, is under Directive 76/769. In the context of this Directive, the Commission is now working on a proposal to limit some uses of chlorinated solvents.

The forthcoming Integrated Pollution Prevention and Control Directive (IPPC) could help tackle several problem areas of the "chlorine debate", such as the production of chlorine, propylene oxide, epoxy resins and the incineration of wastes. This Directive provides adequate instruments for the systematic assessment of the production routes that should be adopted as BATs (Best Available Techniques). By using rigorous BAT descriptions in future permitting procedures at EU level, will help the future evolution of the manufacturing technologies and capacities related to chlorine production and use towards more ecologically desirable solutions.

An early recognition of the trends for chlorine substitution is essential for analyses about the prospects and competitiveness of the European chemical industry. Although it is yet unclear how much funding either governments or industry are prepared to commit to the chlorine-research effort, it seems that industry, besides its public-relations campaigns to assure people that chlorine compounds are safe, has started to study substitution options for a number of areas where there is growing evidence that society is not prepared to accept scientific uncertainty and risks.

Keywords

Chlorine substitution, organochlorines, risk assessment

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Towards Greener Refrigeration Technologies

Mario Demicheli

Issue: Innovative refrigeration technologies, as well as frameworks for their adoption by industry, will be decisive in reinforcing the effectiveness of the Montreal Protocol for the protection of the ozone layer and its speedy application by all countries.

Relevance: Although some companies have already started to adopt greener refrigeration technologies, incentive and regulatory structures that make these changes affordable to poorer regions and to small companies are still lacking. On the other hand, the generalised use of alternative, non-chloro- or fluorinated refrigerants may entail potential risks, thus calling for the development of new safety standards.

Market overview

Developing country manufacturers are becoming significant players in a world market worth US$40-45 bn

Air-conditioning and refrigeration is a global industry. Refrigeration is essential for food preservation, modern healthcare and many industrial processes. In addition, modern living and work environments and transportation systems increasingly utilise air-conditioning.

In today's global marketplace, demand for air-conditioning and refrigeration equipment is estimated at US$40-45 billion. It is composed of both mature markets in North America, Asia and Europe, which require both new and replacement equipment, and newer, expanding markets in Asia, Latin America and Eastern Europe. The United States and Japan are the world's major producers and suppliers of air-conditioning and refrigeration equipment, but industries in Brazil, China, Korea, Taiwan and elsewhere have grown dramatically in the last decade (see Figure 1).

The Montreal Protocol calls for radical change in refrigeration technology worldwide

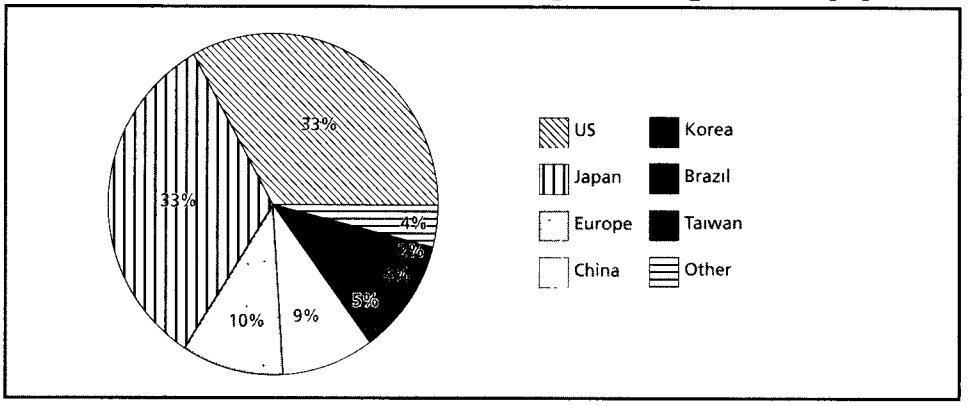
The forecast for 1996-2005 is very positive. With continuing economic growth in Asian and Latin American markets, the air-conditioning and refrigeration industry should expand to a $50 billion global industry. Manufacturers in Brazil, China, Taiwan and Korea will become significant equipment suppliers to the world market.

Efforts to protect the stratospheric ozone layer, in compliance with the Montreal Protocol on Substances that Deplete the Ozone Layer (MP), have necessitated a transition to new equipment using ozone-friendly refrigerants. The transition, which is already well under way in the industrialised nations, will also affect developing country markets early in the next century. Overall, prospects for a growing world economy bode well for the air-conditioning and refrigeration industry [1].

CFCs and ozone depletion

Additional scientific evidence has recently been reported confirming that CFCs are the dominant source of chlorine in the stratosphere [2]. The observations also support the assertion that the amount of chlorine is large enough to cause the

Figure 1: World market for air conditioning and refrigeration equipment



observed ozone change [3]. Among the adverse consequences of the ozone layer depletion are the increase in the incidence of skin cancers among humans, falls in agricultural yields, etc. [4].

Over decades the annual release of more than one million tons of CFCs was drawing chlorine concentrations in the atmosphere up several percent each year. The MP, restricting the use of chlorine-based ozone-destroying chemicals, was adopted in 1987. Chlorine peaked in the lower atmosphere by the end of 1994 and now is on the way down.

Signatories of the 1987 MP agreed to cease the production of CFCs by 1st January 1995. Some wealthy countries that signed the MP have moved from CFC use, mostly towards HCFCs which are still weak ozone destroyers and contribute to global warming. Subsequently, the fourth meeting of the parties, in November 1992, agreed a long-term target to cease the production of hydrogenated chlorofluorocarbons (HCFCs), weaker depletors but still causing strong global warming, by 2030 [5]. This relatively late date can be at least partially explained by the political clout of industry, with the aim of securing and protecting its established markets. The United States would be particularly hindered by a more imminent phase out of HCFCs due to its large air conditioning facilities [6]. On 1st December 1992 the *Financial Times* reported that Du Pont had invested $450 million in HCFC and HFC (hydrofluorocarbons) production, and was set to hit the $1 billion mark by 1995, with an expected recovery period for the investment of no less than ten years [7].

Transitional solutions

HCFCs are still weak ozone depletors

Industry refers to HCFCs and HFCs as "transitional substances", meaning that they will have to be replaced by more environmentally-acceptable substances sometime in the not-too-distant future [7]. However, in 1992 UNEP warned that investment in greener technology alternatives can be hindered by lasting prospects of conventional technology using transitional substances. Developing countries, especially, cannot afford the two-step approach for phasing-out CFCs, as proposed by the chemical industry [7]. Air-conditioning and refrigeration is, together with aerosol and fire protection, one of the major industry sectors using HCFCs and HFCs.

Towards low global warming potential and high energy efficiency

National governments, international organisations, industry and the European authorities now have an important role to play in making the switch to novel green refrigeration technologies a reality. The emphasis should be put on real alternatives; not transitional solutions.

Energy-related CO_2 releases compound refrigeration's effect on global warming

Changes in national regulations governing refrigerants are now being made by some countries. The implicit incentive of attaining cost-effective production is to be kept in mind while looking for new environmental technologies. Yet, in a proactive way, policies could be an additional stimulus for innovative companies, who might compensate for higher costs during the initial phase of development with a marketable "green" image.

In Europe, voluntary agreements should ideally play an important role.

Reduction in electricity consumption is an important issue for the EU. DGXI (Environment) and DGXVII (Energy) are working together in a Refrigeration Directive, whose main objective is to reduce energy consumption and increase the energy efficiency of household appliances. Needless to say, the generation of electrical energy used to operate air-conditioning and refrigeration equipment produces carbon dioxide, which is the dominant greenhouse gas. Consequently an air-conditioning or refrigeration system must be evaluated on the basis of both the global warming potential of the refrigerant released, and the indirect effect of energy used over time [8].

The availability of utility incentives and the opportunity to lower electricity bills should drive the end-user's decision to change to high-efficiency refrigeration systems or improve existing facilities. In other words, agreements could be reached by which a rebate from the local electricity utility would pay the cost premium of the equipment upgrade. This scheme has already been put into practice by a food distribution centre in Massachusetts resulting in annual electricity savings of about 440,000 kilowatt hours. The new evaporative system is approximately 15 percent more efficient than the conventional air-cooled system. [9].

...but in developing countries financial and technical assistance is needed

The importance of European consensus on the basis for implementation of agreements between national governments and industrial sectors arises, given the major role refrigeration technology plays in key economic sectors. Undoubtedly, voluntary agreements are preferable to regulation, wherever possible [10].

Developing countries may not be in a position to afford this change, however. The continuing provision of financial and technological resources to assist developing countries to eliminate ozone-depleting substances as well as the new insights provided by the scientific and technical communities are relevant to this point.

Ammonia-based refrigeration is enjoying a resurgence

Greener but safer coolants?

Ammonia

Historically, ammonia was used as a coolant in mobile and stationary installations. In the shipping industry the use of ammonia as a refrigerant for cargo ships carrying frozen foods peaked in the 1950s. At around this time CFC refrigeration began to be adopted and diffused quickly, mainly because of the inertness of these compounds not only towards the refrigeration machinery but also in the event of a leak. Thus, the low efficiency of this emerging technology was initially compensated by the use of cheaper assembly materials.

In the United States, ammonia refrigeration has recently been proposed as an alternative to refrigeration systems that employ ozone-depleting substances. In an effort to better inform the refrigeration industry of the basic concepts involved, the International Institute of Ammonia Refrigeration (IIAR) is preparing a series of educational videotapes [11].

Even in home refrigerators, ammonia was around well before CFCs and is still used for 81% of the chilling in refrigerated warehouses in the United States. German firms chose ammonia for two-thirds of their cold storage and food processing systems, a model increasingly copied by Nordic countries, Eastern Europe, and most developing countries. Ammonia is flammable and toxic at low concentrations. However, hermetically-sealed units, using corrosion-free materials, could rapidly become popular for water-coolers, air conditioners, and refrigerators. Moreover, ammonia is not persistent in the atmosphere – so its escape during maintenance and at disposal poses no significant environmental threat [12].

The UK's major port for fruit imports, Sheerness, which handles over 300,000 tonnes of fresh produce per year, has recently inaugurated additional cool storage facilities. The refrigeration system includes the UK's first screw compressors operating on ammonia. With a capacity of 20,000m^3 the new store can handle a throughput of 1000 tonnes of produce daily [13].

In comparison with HCFC-22, ammonia costs about a twelfth, and requires only 40% of the corresponding volume. However, because of ammonia's corrosive nature, expensive steel piping and storage vessels must be used. Also, upgraded compressors, a more elaborate refrigerant alarm system, a remote shut-off, and ventilation controls contribute to the cost premium [9].

In Japan, traditional barriers to the use of ammonia as a refrigerant in comparison with regular fluoron gas are: the fact that large quantities are required to achieve the same cooling power (of the order of several tons of ammonia for just a single refrigeration unit); the danger of leaks to the surrounding environment in the event of earthquake or through corrosion of cooling pipes; and its high cost [14].

Hydrocarbons

Governments and environmental groups have been pressing fridge manufacturers throughout Europe to use hydrocarbons because of their lower global warming potential. But hydrocarbons bring up new safety concerns.

The use of hydrocarbons in domestic refrigeration predates the invention of CFCs in the early 1930s. Looking at the situation predominating at that time in the United States, today's hydrocarbon refrigerators use 20-50 times less refrigerant under much safer conditions [7].

The flammability of hydrocarbons could be tackled through adequate safety measures in production and product design. The content of propane or butane in a domestic refrigerator is very small. Consequently, standards must be directed towards high-capacity commercial refrigerators.

Early in 1992, Germany introduced hydrocarbon refrigerators. Then, in 1994, India and China were being helped by Germany's development aid agency to build refrigerators using CFC-free technology. This technology, promoted by Greenpeace as "greenfreeze", utilises gaseous hydrocarbons. It must be pointed out that China and India account for over 50% of the total CFC consumption in the Third World [15]. Also in West Africa, national and international organisations have been working together in the conversion of existing refrigerators to run with hydrocarbons [7].

Hydrocarbons may offer a promising alternative, despite safety concerns

In February 1996, Elstar (Castle Donnington, UK), became the world's first commercial chiller manufacturer to switch entirely to hydrocarbon refrigerants. The converted production line will use Care 30® (Calor Gas) refrigerant, an hydrocarbon blend. These and other moves to "greenfreeze" technology indicate that solutions to at least some environmental problems are possible [16].

Bosch-Siemens Hausgerate (BSHG), Munich, one of Europe's largest refrigerator manufacturers, has decided to stop using HCFCs in the vast majority of its products. Instead, around 80 to 85 percent of its refrigerators will use pentane as an insulator and isobutane as a coolant. In the remaining 15 %, which will consist of frost-free models, the company will continue to use HFC134a as a coolant. Electrolux of Sweden, the market leader in the European refrigerator market, is thought to be developing models using hydrocarbon coolants and insulators. However, HFC134a producers in Europe appear not to be worried about a move by leading refrigerator makers like BSHG to hydrocarbon coolants. On the contrary, they are enjoying a booming market for this chemical product, since domestic appliances make up less than 5 % of the total world market [17].

Although HCFC and HFC replacements were initially favoured in the United States and Japan, the hydrocarbon option would have rooted in the United States. There, the refrigeration market appears to be sensitive to, and pervaded by, political concerns. As an example, the sales of OZ Technology, a company that markets hydrocarbon refrigerant blends, has fallen off since the Environmental Protection Agency (EPA) rejected its application for approval to market its product as a CFC replacement. Interested in the hydrocarbon refrigerant market, Exxon has offered assistance in OZ's legal battles with EPA. On the

More radical alternatives are likely to be found in the longer term

other hand, American equipment manufacturers, aiming at selling a new generation of equipment designed for the new HFC refrigerants, are seeking to amplify concern over flammability. EPA's officials, who are involved in a program to certify CFC substitutes, claim more formal risk assessment is required on flammability. In particular, distinguishing between hydrocarbon use in existing systems and retrofitted equipment will be crucial when considering their risk. In contrast, Germany's Ministry for Technical Co-operation (GTZ), which is supporting hydrocarbons and technology transfer to China, India, and other developing countries, maintains hydrocarbons can be produced locally in developing countries at far lower cost than imported HFCs or other fluorinated alternatives [18].

Future refrigeration technologies

As suggested above, research and technological development (RTD) could focus on real, safe-in-the-long-term alternatives rather than costly, transitional solutions. At the European level, the most important actions over recent years have been undertaken through the THERMIE and CRAFT programs. Some emphasis was put on integrated designs for reducing energy costs and on the use of naturally-occurring substances as refrigerants. Another point of interest is the development of a European absorption refrigeration technology, using ammonia/water, or very specific coolants such as lithium bromide. A key advantage is that absorption cycles can be designed for co-generation of power/heat and refrigeration. Major applications of these technologies are to be found in the food and air conditioning industries. Solar installations for co-generation of heat and cold have also been sought. In the United States, the intriguing alternative of hydrogen-based refrigeration is under development [19]. In the field of very low temperatures, both optical- and magnetic refrigeration technologies may have a strong impact in the future.

Keywords

Montreal Protocol, global warming, ozone depletion, refrigeration, CFCs, ammonia, hydrocarbons, hydrogen

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Climate Change Research -

Facts, uncertainties and responses

Astrid Zwick, Antonio Soria

Issue: The Intergovernmental Panel on Climate Change (IPCC) second assessment report indicates increasing confidence about possible confirmation of a discernible human influence on global climate. While there is evidence supporting the conclusion that human activities *are* modifying the carbon balance of the Earth's systems, the magnitude and timing of the associated climate change are less certain.

Relevance: It seems to be imperative to improve scientific knowledge and to reinforce research. However, policy decisions also rely upon future scenarios of socio-economic systems which introduce additional uncertainties. Meanwhile, the time constraints might not permit waiting until the uncertainties are resolved, although it is questionable which strategy should be pursued. The option of waiting and adapting to any type of change, under the so-called "business as usual" scenario, has sometimes been invoked. Precautionary measures are another option, ranging from those which help both in environmental and economic terms ('win-win' approaches), to those which focus solely on environmental improvement.

Climate systems are influenced by a combination of natural phenomena and human activities

State of scientific knowledge and related uncertainties

Apart from greenhouse gases, major components and forcing factors of the climate system are *global solar radiation*, the *oceanic circulation* and the Earth's *albedo* (the reflection of short wave radiation in relation to the incoming solar radiation). Present knowledge about the key forcing factors of climate is limited. This issue, however, is crucial, since the assessment of future anthropogenic carbon emissions requires a reliable accounting of the causes and effects of climate change. Therefore, the different forcing factors, and especially natural and anthropogenic forcing, have to be distinguished and analysed.

Natural solar radiation ('insolation') variations, due to external forcing, can be directly linked to climate changes. These changes might be partially attributed to periodic variations of the Earth's orbital parameters or to the periodically-changing sunspot activity on the Sun's surface (Berger & Loutre, in press; Schönwiese, 1994). Although their impact seems to be rather weak in comparison to the radiative forcing of the greenhouse gases, they may *trigger internal forcing mechanisms*, thus, amplifying their effect.

While changes in the Earth's orbital parameters occur on timescales that go beyond human history, Solar cycles, and especially long-term cy-

cles like the 80-year cycle, could have a more significant impact on climate in the near future (Cubasch, 1995).

Among the external forcing factors, *volcanic eruptions* have a significant impact, which, in addition, influence climate immediately by offsetting global warming. Yet, the time and magnitude of volcanic eruptions and their interactions with atmospheric processes involve further uncertainties, since their occurrence and their strength is unpredictable (McCormick, 1995).

In spite of this, it seems that the largest contribution to external forcing can be attributed to the greenhouse gases which act on a short time scale (i.e. decades) when compared either to solar cycles (centuries) or orbital parameters (millennia). Their effect on climate is particularly important, since human activities have significantly increased the atmospheric concentration of greenhouse gases within a short time.

Biological processes in the natural ecosystems play a major role in the *budget changes of the greenhouse gases* and, thus, complicate the estimation of their effects. There is evidence indicating that the uptake capacity of existing carbon sinks in the biosphere is flexible enough for a certain adjustment to increased rates of atmospheric CO_2 concentrations (Joos, 1995). How far this phenomenon can be extended may be proven by further investigations. A better understanding of the so-called "carbon missing sink mechanisms" may also provide corrections to the expected average temperature increase in the future.

The IPCC's second assessment report represented a down-correction of the anticipated temperature increase in comparison to its first assessment report (IPCC, 1990; IPCC, 1995). This down-correction is due to refinement of climate models and improvement of the input parameters. Among the latter, the negative radiative forcing of tropospheric aerosols, due to anthropogenic sulphur dioxide emissions, showed a significant effect. The effect of tropospheric aerosols could counteract global warming by about 0.1°C per decade (Mitchell, 1995). Unfortunately the role of aerosol impact on cloud physics is still uncertain, and in evaluating climate simulation results it has to be taken into consideration that, according to Kondratyev (1995), the anthropogenic aerosols represent only one part of the total aerosol content. This author also assumes that efforts to reduce urban smog and the effects of acid rain in Europe and North America will reduce aerosols over those regions, probably exposing them to the full force of global warming for the first time.

Greenhouse gases are a major driving force in climate change

A similar effect might be caused by aerosols derived from wind-blown mineral dust of degraded soils (Tegen, 1996). Its negative radiative forcing may reach values up to $1W/m^2$, a significant level compared to the positive radiative forcing of about $2.5W/m^2$ due to greenhouse gases. This estimation has to be further confirmed but reveals the low level of confidence in the quantification of climatic driving forces, as well as the possibility that new climate parameters or internal processes might be discovered in the future.

Radiation absorption by clouds is another sensitive topic in climate change research. Previous assumptions, estimating an absorption of solar radiation of about $6W/m^2$ by clouds, were extremely low compared to recent observations yielding about $25W/m^2$ (Cess, 1995).

The IPCC's estimates of temperature rises have been revised downwards

Oceanic oscillation and, especially the so-called "North Atlantic thermohaline circulation" constitutes an internal climatic forcing factor. Its mechanisms and reactions to external changes like *insolation or salinity variations* represent problems, since knowledge of its *past changes and rapid oscillations* is well established but understanding of its causes is lacking (Bond, 1995).

The issues above reveal that uncertainties are still present when quantifying forcing factors due to different estimations and assumptions or the lack of measurements. A better evaluation of these uncertain factors is crucial for a reliable assessment of the global warming problem.

Long-term monitoring and observation are needed to fill gaps in current knowledge

Methodological problems

Bearing in mind the preceding considerations, it seems that a systematic collection of *long-term instrumental* and *proxy observations* of climate system variables, as the IPCC (1995) emphasised, is mandatory. In fact, the study of the interaction of greenhouse gases with the climate system is one of the priorities of the EC's Environment Research Programme. New projects launched earlier this year focus mainly on the atmospheric budgets, fluxes, transformations of greenhouse gases into ocean and biosphere and their impacts on the climate system in order to improve climate models. The pioneering effort to perform measurements over long timescales, often considered as routine long-term monitoring, requires skilful perseverance.

The correlation of data sets constitutes a further problem. Data sets are often diverse and highly detailed, often reflecting laboratories' individual preferences. Measuring techniques are often not calibrated on the same basis, and tools and analyses are not standardised. Thus, the *handling and processing of data* needs to be improved.

Accurate risk assessment calls for a better understanding of natural phenomena

Despite the remarkable ability of the models to simulate climatic patterns, there are doubts whether such models adequately represent the *full range of natural phenomena* on the century timescale of human history, when compared with paleoclimatic data over the geological timescale. The modelling results deliver only some approximation to real world conditions. As a consequence, models of climate processes, especially feedbacks associated with clouds, oceans, sea ice and vegetation, need to be improved. The refinement of climate models could help *down-scale* climate projections to regional levels. Nevertheless, it has to be kept in mind that, while the underlying assumptions are based on limited knowledge of the climate system, to be reliable computer models need to be tested against observational data. Thus, validating computer models without sound long-term observations is considered unattainable, although a prerequisite for credible climate predictions (Levin, 1996).

Better observational data is needed to validate and further refine climate models

Uncertainty in impacts of climate change - some important examples

The contradictory scientific statements and uncertainties in the knowledge base make it difficult to *assess quantitatively* the possible risks due to anthropogenically-induced climate change. The impacts of climate change, such as changes in the hydrological cycles, shifting of vegetation belts, enhanced desertification, sea level changes, increase of extreme weather events, shifting of vector-borne diseases, are rather uncertain, particularly at the regional scale. Information is still too incomplete to provide an appropriate basis for political decision-making.

The expected *sea level rise* already poses some problems, since geological, tidal and meteorological factors can cause different regional changes, according to Sestini (1996): the natural processes in sea level dynamics need to be clarified. Whether natural or anthropogenically-induced, concern about its consequences is justified, notably because of the increasing occupation of coastal areas due to demographic pressure and economic development. Higher sea levels would affect many long-term coastal management projects (e.g. water resources, coastal engineering, fisheries, communications and energy planning, nature conservation) (Sestini, 1992). Therefore, research is needed to *identify high-risk areas*.

Similarly, a high degree of uncertainty surrounds the effects of climate change on agriculture, due to changes in the hydrological cycle and the shifting of vegetation zones (Harrison & Parry, 1993). Some regions in the northern hemisphere will certainly benefit from the warmer winters and longer growing seasons, as assumed by modellers. However, the potential losses to other regions, where water resources are already under stress, could be enormous. Fishery and forestry will have to deal with productivity changes and changes in the mix of species (IPCC, 1995). This implies that an *improvement of the impact analyses*, especially on a regional scale, is

needed in order to provide appropriate information for policy decisions.

Another area of uncertainty concerns the expected increase in natural disasters, like floods, droughts and heavy storms, and related health and social problems. *Economic losses from natural disasters* have increased dramatically over the past few decades, and have been most pronounced over the past seven years (Berz, 1994). If current trends persist, the average annual losses may double by the end of this decade, coming close to US$150 billion. The damage costs of some single "worst case" disasters may even be expected to exceed the US$100 billion threshold. This requires preparedness and mitigation measures by governments, NGOs, scientific institutions, industry and the media. Local and national authorities should be recommended to start reviewing hazard zones, land-use regulations, building regulations, warning services, information and disaster analysis. The records of insurance companies might be of value for evaluating disaster damage.

In summary, the extent and magnitude of climatic forcing factors are uncertain and their impacts are based on limited assumptions. Although science still cannot differentiate quantitatively between the share of anthropogenic influence and the range of natural variability, a number of potentially-alarming, anticipated impacts can already be perceived.

Going for a flexible response

Due to the scientific uncertainties, a clear-cut political response will be difficult. Policy-makers have also to weigh socio-economic factors alongside the environmental ones. An effective response depends heavily upon future economic circumstances and the institutional infrastructure, the future development of which under climate change is another area of uncertainty (e.g. implications of emission abatement).

How could possible decision-making look under these circumstances? Optimal decision-making requires the estimation of the likely effect of global warming, taking into account the expected degrees of damage and their respective probabilities for all the foreseen scenarios. An adequate policy should be able to modify the scenario probability values as well as the associated damages, diminishing the probability of the high damage scenario, and/or diminishing the damages associated to the most likely situations. Nevertheless, with the current state-of-knowledge, science is not able to provide well-defined values for these parameters. However, it is possible to integrate the uncertainty of the parameters mentioned into decision-making, so as to provide a flexible reaction. This is so because the mitigation actions necessary are certainly not a single-time move against uncertainty: rather they can be spread out over time so as to provide an optimal path of policies to be adopted given the current state-of-knowledge.

Policies need to be flexible, given the scientific uncertainties

This task is, of course, plagued with a number of difficulties. First of all, accurate values for the damages and their probabilities, as well as for the abatement costs, are required. In addition, damages and costs are often formulated via utility functions that are supposed to measure welfare as a function of per capita consumption. The choice of this function presents an additional problem, since it is impossible to know *a priori* what the preferences of future generations will be. Moreover, damages and costs have to be formulated in terms of their present value, so the selection of an appropriate social discount rate is also crucial. In this respect, the analyses of Cline (1992) and Nordhaus (1994) provide valuable insights on the methods and approaches to be followed. The conclusions emerging from these studies depend heavily not only on quantitative uncertainties in the causation chain (carbon concentration → climate change → economic impact), but also on the time horizon foreseen, and the decision-maker's degree of risk-aversion. The longer the time horizon analysis and the greater the risk-aversion, the more appealing seem to be the arguments in favour of an active mitigation policy.

The question of the costs associated to decision-making when information is lacking or insufficient is an unresolved issue in the global warming debate. As mentioned earlier, remarkable attempts to design the optimal mitigation paths have been made by taking into account the *current* state of scientific knowledge. Nevertheless, evidence is gained as time proceeds, so decisions will be taken at any time point using the information available. Some authors have suggested a multiple and stepwise approach, introducing gradual decision-making which adjusts itself as scientific knowledge reduces the variance in the different parameters. According to Manne and Richels (1992), the expected cost of deciding under uncertainty now may be higher than the costs of acting after having waited until further evidence is obtained.

A stepwise approach allows for adaptation to current knowledge

Turning to the greenhouse gas concentration targets, the IPCC's analysis (1995), based upon climate models, suggests an immediate stabilisation of the concentration of carbon dioxide at its present level, through an ***immediate reduction in CO_2 emissions*** of 50-70% and further reductions thereafter, until the year 2100. The IPCC justifies these emission targets by the fact that any eventual stabilised concentration is governed more by the accumulated anthropogenic carbon dioxide emissions from now until the time of stabilisation, than by the way those emissions change over the period.

Appropriate timescales for emission reductions are hotly debated

The IPCC's proposals have encountered some criticisms. Wigley *et al.* (1996) argue in favour of a ***learn-then-act*** policy similar to the one devised by Manne and Richels (1992), but using arguments on CO_2 concentration vs. cost-effectiveness. In this context, an interesting model has been developed by Wigley *et al.* (1996), involving a different approach in the ***reduction pathway*** analysis, which depicts a more politically and economically feasible situation. The model allowed a time of 20-30 years of moderate action in the early days, under a business-as-usual scenario, until a stronger reduction was pursued.

Over recent years, alternative emission reduction pathways have been taken up by a growing number of modelling experts (Russ, 1994). Such analyses have shown that the reduction pathway can be just as important as the concentration stabilisation level in determining the ultimate cost. For each stabilisation target, mild initial abatement pathways were found to be less expensive than those involving substantial reductions in the short term, and practically as effective. This line of thought has ***three advantages*** in terms of planning response strategies and reducing costs for options. Firstly, it seems that flexible responses would imply matching mitigation investments to future economic damages as they emerge. Secondly, since time is needed to reoptimise the capital stock, unanticipated changes in the stock for energy production, transformation and use would be inefficient and expensive. Finally, in terms of technical progress, the availability of low-carbon substitutes will probably improve and their costs reduce over time. The results of Wigley *et al.* (1996) did not elaborate the economical aspects of this issue. Thus, care has to be taken while evaluating its results. In addition, it is unclear how far pathway-related differentials (equivalent to ~0.2°C in global-mean temperature and 4cm in global-mean sea level change) translate into significantly higher damages, and if so, whether these are large enough to offset the reduced cost of a more economical transition away from fossil fuels. Detailed studies at a regional scale might bring answers to these questions.

The weight of this evidence, however, depends on several factors. There is broad agreement upon the need for immediate consideration of zero-cost mitigation policies. This is particularly urgent for those greenhouse gas abatement technologies which also provide benefits in terms of other environmental concerns and/or efficient use of scarce resources (a 'win-win' approach). Supporters of the *wait-and-see* approach should also consider that there is uncertainty in the expected information to be gained, and in the moment in time where scientific certitude will be

apparent. The time lag may be long enough to put the energy system into an irreversible path towards a high damage scenario. This point of view is developed in Hourcade and Chapuis (1995), where estimations of the duration of the 'window-of-opportunity' are delivered.

Arguments in favour of greater near-term abatement action are also invoked in Grubb *et al.* (1995). It is argued that the evolution of the global energy system is controlled by the inertia induced by capital stock and technology, as well as by adaptability to exogenous changes. With respect to the former, neglecting the greenhouse issue when considering today's capital replacement policy may have negative consequences if the global warming jeopardy turns out to be more severe after further evidence is collected. In this case, substitution of fresh, carbon-intensive capital stock would represent an additional economic burden to be afforded under pressing environmental circumstances. This is particularly the case for long-lived capital infrastructures, such as those in the transport sector.

Edmonds *et al.* (1993) underline that mitigation costs may witness a dramatic lowering, because of technological improvements, which should be carefully taken into account in designing the optimal mitigation policy. Nevertheless, as Grubb *et al.* (1995) remark, the technological changes should not be expected to occur in a natural manner, simply because of an autonomous trend towards better energy efficiencies and environmentally-friendly primary energy sources. On the contrary, technology deployment often concentrates on endogenous clusters of interrelated techniques, ultimately originating in a basic, once-radical technology innovation. It seems, therefore, important to make sure that today's innovations are already shifting towards a less carbon-intensive pattern.

Conclusion

Responding to uncertainty means emphasising further scientific efforts, but also pursuing possible response strategies flexible enough to optimise adjustment. A combination of systematic observations under standardised measuring techniques, data analyses and improved climate modelling might be recommended. Meanwhile, flexibility in the emissions reduction pathways would at least give more time to prepare for actions while science provides more progress in knowledge.

A political approach to the problem of uncertainty in the global warming issue may consider the following points:

Firstly, decision-making needs to accommodate uncertainty. This may be accomplished by adopting a stepwise approach: policy-makers should be given an appropriate framework that allows their decisions to be adjusted according to the information obtained in the future.

Secondly, policy-makers are concerned with sustainable development when trying to elaborate strategies which are not only environmentally sound but also economically feasible. Therefore, the advantages and drawbacks of each mitigation strategy should be made evident in these terms.

Thirdly, special attention should be paid to the panoply of zero-cost measures implying advantages not only with respect to a broader time frame, as the slow process of scientific knowledge develops, but also the replacement cycles for technologies and capital stock (so-called 'win-win' approaches). The elaboration of such measures could give rise to economically-beneficial strategies that are in accordance with both environmental protection and socio-economic development.

'Win-win' approaches are to be preferred

Keywords:

climate change, global warming, climate modelling, uncertainty, policy-making

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Intelligent Software Agents: Perspectives for business

Rob Meijer

Issue: As a consequence of developments in information and communication technologies and the rapid growth of the use of these technologies, the supply of information for end-users in increasing steadily. The access to relevant information and the efficient and effective use and control of this information is increasingly a problem for consumers and organisations. Intelligent agents may provide a valuable solution, at least for well structured transaction decisions, creating new business opportunities but also raising policy challenges.

Relevance: Intelligent agents have a profound influence on the structure of those value chains because they can bypass existing parts of the chain and change its way of working for all parties concerned (e.g. industrial process redesign). In that case it is very important which part of the chain has control of the functionality of the agent: the original supplier of the goods, the intermediary or the end user. Future policies will need to consider potential obstacles to market development, and barriers which may prevent the benefits of increased efficiency offered by these agents from being fully exploited. The potential impact of agents on international trade also demands attention: for example will an intelligent agent direct you only to American shops for audio CD's or also to European shops?

Introduction

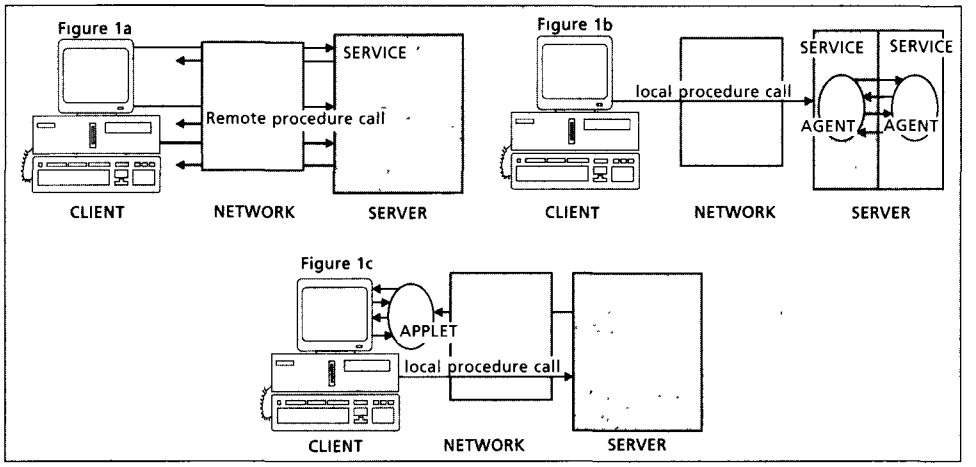
As a consequence of the growth in use of the Internet and the Worldwide Web (WWW), new applications, and even new markets, are being developed. One of the important developments creating new business opportunities are intelligent software agents. However, many commercial as well as non-profit organisations still seem to be unaware of the possible threats and opportunities for their core business. Applications of these agents in, for example, electronic commerce may have significant effects in the way end-users search and buy. Also, agents will influence substantially the way of doing business in the value chain.

Intelligent agents may change the way of doing business in the value chain

Intelligent (software) agents are small pieces of software that act autonomously in networks on a user's behalf. The intelligence of agents enables them to fulfil several tasks like information retrieval and even negotiating with other agents (for example, in making an appointment between several busy people, or booking travel). Currently, several (primitive) agents on the Internet can be actively used for electronic commerce. In electronic malls, like Shop Plaza and BargainFinder, agents are being used for electronic shopping.

Aspects of agents

Agents will cause the disappearance of functionalities, or their shift from computers or workstations to networks. 'The network will become the computer' (an idea promoted fiercely by Scott McNealy, Sun Microsystems) and will take over many of the functionalities into the 'network-centric computing model'.



Intelligent agents will enable a shift of functionalities from the computer or workstations to the network

Agents are of great help in communicating with other workstations. This communication is based on certain procedures. A traditional procedure is the "remote procedure call". It is based on the idea that messages (data) are sent on-line by a user to a server. Longer sessions require continued communication between client and server, which is expensive and not efficient (Figure 1a). Another procedure is "remote programming". In this procedure, the messages are agents. These mobile pieces of software are active off-line at servers where they execute their tasks, without continued feedback which is required by a remote procedure call (Figure 1b). A well-known language which supports this approach is General Magic's Telescript, designed for electronic commerce applications. Until recently, when its implementation in AT&Ts PersonaLink service was stopped, Telescript - which was designed for telecommunications networks - appeared to be the emerging standard. A new but already well-known language, that is dedicated to Internet applications and therefore has clear advantages, is Java and its derivative HotJava, which make software applications in a network accessible. In this case, a user only transports the required functionalities or small applications (applets) from a server and transports these to his own workstation (Figure 1c).

Currently, there are already many programming languages for intelligent agents. Since intelligent agent applications differ greatly, experts still rarely agree on the appropriate programming language for developing applications and we may expect a variety of developments.

According to Heilmann (1995), an intelligent software agent has several attributes such as autonomy, intelligence, mobility, communication and trustworthiness. The *autonomy* of an agent may vary and is based on the amount of interactivity required between a user and a server. The more advanced an agent the better it can cooperate and negotiate with other agents. The level of *intelligence* of an agent constrains the way of learning. There are several levels of intelligence ranging from accepting and executing a task to learning and adapting to an environment, establishing relations and anticipating a user's needs. An important requirement is *mobility*; agents have to be mobile and travel over networks. For executing tasks an agent needs access to (the servers of) other parties. Negotiating with other agents or gatekeepers can be part of this process. Finally, users only accept agents if they are *trustworthy* and execute their tasks in a reliable way. Here, issues such as quality, reliability and transparency of information - and information providers - come into play.

Agents are thus different from information robots - 'infobots'. They differ in their amount of intelligence and ways of reasoning. Agents are able to cooperate in complex situations while infobots only perform simple tasks. They also differ in the way they solve multidimensional problems and make decisions in complex situations with many relevant factors. Thirdly, an infobot only executes what a user commands it to do while an intelligent agent is designed to make tactical decisions. Lastly, infobots are less autonomous and stay on local workstations, while agents travel over networks.

Agents differ from 'infobots' in that they can cooperate and make decisions in complex situations

Current research areas are technology oriented (negotiation strategies, learning, architectures, programmability) as well as application oriented. Although public and private organisations are researching aspects of agents, the majority of research is being carried out in university settings especially in the United States, e.g. the MIT's Media Lab, Carnegie Mellon Institute, the universities of Washington, Maryland-Baltimore, Michigan and Stanford. Research and development in private firms is carried out by the General Magic consortium (Apple, Sony, Motorola, France Telecom, Philips) which uses agents in Personal Digital Assistants (PDA's); Microsoft uses agents for support (i.e. Tip Wizard, IntelliSense); IBM has developed some products with agent functions; and telecom carriers may use agents in the management and control of their networks.

Commercial applications

Agents have many different applications which can benefit service providers, distributors and users...

Agents can perform many functions: searching, filtering, negotiating, coordinating. The question is what applications have value for organisations. According to Heilmann (1995), the following groups can be distinguished:

1. **Watcher agents,** which autonomously look for specific information and can be used for collecting personalized versions of newspapers according to a readers interest;
2. **Learning agents,** which can learn to tailor their performance to the behaviour of their user;
3. **Shopping agents,** which are capable of comparing and finding the best price for an item. Retailers can protect themselves from this by giving their products unique names (hard to compare) or by blocking access to agents;
4. **Information retrieval agents,** which search in an intelligent way for information and are capable of reducing the information overload by finding documents (even when they do not contain any of the keywords contained in the search criteria) or by compressing or summarising documents;
5. **Helper agents,** which act without human interaction. In general these are used for network management and standard maintenance functions.

A useful way of describing the impact of agents in electronic commerce is by a simplified value chain which can serve as a generic model. The chain consists of suppliers, distributors and customers/users. In a limited way agents are already applied in selling audio-CD's and video films. Suppliers are producers of movies and/or music. Distributors are CD-shops, mail order, video rental shops. Other distributors like supermarkets and gas stations are gradually entering this field. As an example, three development patterns are described for use of agents in the retail sector (although it is also very useful in analyzing other sectors like print publishing, travel industry or insurance).

In the first pattern, users control their agents which can directly order a product and use services in the supplier's domain. The end-user has direct access to producers of audio-CD's or movies. Agents search databases and present the cheapest product. An agent is also capable of recommending other products or continuously

Table 1: Typology of agents on the Internet

TYPE OF AGENT	PRODUCT
Watcher agent	Fishwrap (MIT), Newshound, Personal View (Ziff Davies), Personal Journal (Dow Jones), JobCenter
Learning agent	Firefly, Similarities Engine, WegHunter, Open Sesame, InterAp
Shopping agent	BargainFinder, Good Stuff Cheap
Information retrieval	AplleSearch, PageKeeper, Homework Helper, Architext, ConText, Netsumm (BT)
Helper agent	LANAlert

searching for new products. For a user, ordering is very easy. This may become a terrifying scenario for owners of video rental shops since the market for rental videos is decreasing and they will now have to compete with suppliers. The second pattern arises when a distributor or a group of distributors controls the agents, allowing them to reinforce their position in the chain. Agents make it possible to deliver more customised products and services for the end-user; distributors have to cooperate and make their databases accessible for the agents they control. A client needs to trust the results of searching and comparing. Agents serve as an extra service for customers. In the third pattern, suppliers control the agents. By cooperating they are capable of delivering more products and services and become a one-stop-shop. They will also bypass the distributors. Producers and organisations which do the packaging work together and develop and control agents. A new organisation (e.g. a joint venture) may be suitable for this, using trustworthy agents that search and compare in a reliable way.

In April 1996, the Dutch Technology Research Institute, TNO, organised a workshop on intelligent agents that was attended by representatives of content providers in the business-to-business market, intermediate agencies such as travel agencies, and telecom operators. At the meeting there was a strong conviction that the use of intelligent of advanced intelligent agents will have a substantial impact in markets such as audio, video, information and news provision, finance and R&D, within a period of 3-5 years. Another interesting observation was that existing intermediaries will have a strong position because they know the business of 'being an agent'. For consumers, 'trust' is an important point in using agents. There will be limits to that trust: 'Will you ask an intelligent agent to do for you what you would ask your neighbour to do for you ?'.

Strategic issues

At the current stage in development and utilisation of intelligent agents, it is still unclear what the commercial potential precisely will be and how it will be realised. There are many interesting developments in the technology, but the claims about abilities of intelligent agents may be overstated. The agents currently functioning are of a relatively simple nature, dedicated to well-defined tasks. Even the availability of advanced intelligent agents does not guarantee full-scale utilisation, due to bottlenecks such as standardisation, reliability, market power and security. The analyses above indicate at least that there are multiple options for development patterns concerning the use of agents, each characterised by their own specific bottlenecks and opportunities.

the function of the agent will depend on which of these groups control it

A general issue certainly is standardisation. Without standardisation agents will have limited use and trustworthiness. There is a need for standardisation of directories, keywords, interfacing, access to servers and, of course, programming languages. For large-scale utilisation, these agents should meet conditions such as: gradual growth of networks and PDAs; existence of a reliable system for billing and accounting; trustworthiness; standardisation; and cooperation in developing agents. Distributors, suppliers and users will have to trust agents. Very important is a reliable billing and accounting system. Agents might obtain costless access to servers or might have to pay. Next to this, there is the issue of authentification and authorization. Without a reliable system agents have a very limited future.

Agents are forecast to penetrate the audio, video, information and news market in 3-5 years

For large-scale use of agents, distributors or suppliers will have to cooperate. They should develop agents for their industry and not end up in competition. Those who wait may be bypassed by competitors in another part of the value chain, who will benefit from shorter time to market. Bypassing of distributors by users or suppliers, however, will occur as yet only in a limited way. Only a minority of users are on-line while the majority of users are satisfied with the present distributors' service. Thirdly, it will be difficult to enter a market where distributors have specialised experience, invaluable brand names and strong client relations.

Standardisation is vital for user confidence and the trustworthiness of agents

This raises the issue of the impact of agents on market dominance and market development. On the one hand, one might suspect potentially new sources of market dominance, related to the new

The spread of intelligent agents raises questions of market dominance and market development. .

ways of control of access to users, distribution channels and information sources. However, so far it seems that, unlike more traditional networks based on economies of scale (such as reservation systems) which act as monopolies, there is room for differentiation and new entrants in the current innovative stage of development.

On the other hand, the development of markets may also easily be hindered. An interesting example was quoted recently in the British weekly journal, *The Economist*. For an agent to compare prices, vendors would have to present their prices in a comparable way. But not all of them would want to aid a process that has the effect of making their goods commodities, with the result that agents may be blocked. This may result in markets not developing because of the quality and incompleteness of suppliers and incomplete access to products and services. Of course, the rise of agents may very well result in new markets appearing, or in the introduction of market processes in areas where up to now other rules are functioning.

.for example, do agents developed in the US also shop in Japan and Europe?

A related issue concerns fair competition and trade. Will the intelligent agents that are currently being developed predominantly in the US also shop in Europe and Japan? Those agents can easily be used by European consumers, but if they are programmed to only visit American shops on the Internet, European service providers will be out of business. Perhaps the regulation of the use of agents will be a new topic for the next round of GATT, but establishing 'brand names' for agents will be a key success factor.

The security problem certainly is of major importance. Agents may look like viruses, or visa versa. Presenting itself as an agent a virus can get access to a server and do considerable harm. Currently there is no satisfactory solution to this. Even Java, which was developed with this problem (it is claimed Java applets cannot carry viruses), does not solve this problem satisfactorily, even firewalls being largely ineffective. This raises organisational issues such as control of access to the World Wide Web, and of liability.

The issue of liability is broader than the questions of who is responsible for an agent; what is the legal position of an agent; or what will happen when a server goes down. This issue is connected with the issue of 'trust'. The diffusion of agents will not result automatically in more transparent and efficient markets, due to information distortions and limited observability. Maybe we will need a kind of certification or 'brand name' for agents. In that case we would need to decide which party is authorised to do the certification, whether it is a task for governments or for consumer organisations ?

Keywords

intelligent agents, software, security, information society, electronic commerce

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Economic Growth Theories and Technical Change

Jaime Rojo

Issue: New growth theories focus their attention explicitly on the role of technological change in economic growth. They support the idea that countries could rely on their own dynamics to sustain growth. That is, through the use of adequate policies, developed countries could foster the processes of growth for their economies. This approach will rely on important aspects embedded in technological progress, such as human capital accumulation, R&D and innovation processes, learning-by-doing and externalities.

Relevance: The recent adoption by high level international organisations of recommendations derived from growth theory and a proliferation of associated empirical work are signs of the re-emergence that the field is experiencing. This observation presages a promising future for our knowledge of how growth mechanisms develop and interact, and on their impact on technology policy.

The development of growth theory

The field of growth theory has experienced a renewed interest since the mid-80s. What started as an apparently simple debate between two academic schools of thought, has proved to have very fruitful consequences. The related findings can facilitate a better understanding of the complex relationships guiding the processes of economic growth.

In the standard neoclassical model [Solow (1956)], the processes of growth were based on capital accumulation. The aggregate production function incorporated two conventional factor inputs, labour and capital. Growth was achieved by postponing present consumption for future consumption - i.e. by saving. To attain growth, economies increased their net investments and consequently their capital stock. By holding constant the level of population and the aggregate labour input, more capital per unit of labour was achieved, increasing overall aggregate output. As more capital was incorporated into production higher productivity and higher growth were achieved. But as a result of the process of capital accumulation and because of diminishing returns, at some point economies reached their steady-state growth equilibrium. At that point in the theoretical system, net investment equalled zero, meaning that gross investment just covered the depreciation rate. In the steady-state, growth was only determined by the rate of technological change (and the population growth rate). Paradoxically the rate of technological change was left unexplained, i.e. it was exogenous from the model. Technology was considered as a 'black box'. The natural rate of technological progress and the way it interacted with growth could not be controlled by the social planners.

This kind of model imposed certain limitations, focusing strongly on saving capacity, which nevertheless may not be the only factor determining the growth capacity of a certain economy. As noted by Gilles Saint Paul (1995), if the processes of growth of nations were supported only by their saving capacity, as can be derived from neoclassical theory, we should have observed the ex-Soviet Union standing nowadays as one of the world's leading economic powers. There must be other factors explaining nations' long-term growth capacity.

New theories have emerged which reconcile the neoclassical model with empirical evidence

Not necessarily antithetical to neoclassical theory, and sharing many points in common, new growth theories (Grossman and Helpman, 1991, Romer, 1988) and evolutionary theories (Nelson and Winter, 1982) have appeared in an effort to incorporate into the analysis those issues previously left unexplained.

New growth theories believe in the existence of high externalities to technology. In particular they focus on those effects that are supposedly altering the natural rate of technological change. These effects are regarded as fundamental in modifying the growth rate in the equilibrium.

These theories support the notions of 'knowledge-based economies' .

For this purpose, the new growth theories introduce behavioural equations in their models which mimic processes of sustained growth in the steady state. These equations reflect belief in the importance of processes such as learning-by-doing, research and development, spillovers, education, and human capital improvement. They accept the existence, at the firm level, of diminishing returns on factor accumulation, but at the same time they reflect the existence of increasing returns at the industry/market level. According to these theories, countries can enable shifts in the production function by investing in R&D, creating what are termed 'knowledge-based' economies (OECD, 1996). The externalities generated will permit firms to benefit from participating in a particular environment. This should explain why developed countries are doing better than predicted in terms of growth: they invest in R&D and human capital and they are using their investments for building up technological 'knowledge-based' economies. The returns from these investments find their counterpart in the long-run growth rate achieved by these countries.

....and 'national systems of innovation'

Technology is not a completely free good, some of the spillovers generated are retained within the national boundaries, supporting the idea of the creation of 'national systems of innovation'. There are spillover effects present in technology, but the diffusion and absorption of technology developed by others, i.e. a free-rider effect, is not total: this is due in part to regulatory barriers, such as restrictive intellectual property rights, and partly because of the still timid IT advances. There are, in this sense, benefits which derive from the non-replication of know-how, from agglomeration and access to a common pool of inputs, i.e. suppliers and subcontractors, and a skilled and diversified labour force [Krugman(1991)].

Results from econometric studies

We have not, until recently, witnessed a proliferation of empirical models which try to test the results implied by the theory. This has been in part due to the absence, until recently, of refined country data sets, c.f. Summers-Heston Penn World Tables (1988).

The original growth-accounting methodology posed some problems. Using an aggregated production function, this related growth rates (GDP per capita) to increases in productivity of two conventional factors, labour and capital measured in per worker terms. That quantity of growth unexplained by increases in the productivity of the two factors was identified as the total factor productivity (TFP). The TFP measured the rate of technical progress, remained unexplained and was only accounted for as a residual. This was problematic particularly because the TFP accounted for a half of the total observed growth. Recognising the limitation imposed by growth-accounting methodology, some authors tried to determine what factors explained technological

progress. They searched for correlations between the TFP and R&D-related variables - e.g. numbers of scientist and engineers; numbers of patents; degree of education in the population. A correlation between the variables was observed: the problem was that the direction of causation was not easily identifiable.

Fagerberg (1994) has made a compilation of recent approaches to test for factors affecting differences in growth rates across countries. He makes a review of different studies that use cross-country samples to apply multivariate tests to single-equation growth models. He observes that the type of variables used can mainly be aggregated into three different groups:

a) GDP per capita acting as an indicator of a country's capital-labour ratio (neoclassical model advocates) or of the degree of technological sophistication (new growth model advocates);
b) variables reflecting efforts to modify the 'technology gap', such as human capital investment and variables accounting for differences in national technological capacities
c) other socio-economic and political variables considered to affect growth, e.g. political framework, degree of openness to trade, population growth, operation of financial markets.

Barro and Sala-i-Martin (1995) have tested the neoclassical convergence hypothesis using cross-country data sets. They have also considered regional data sets, arguing that with these it is easier to make the necessary *ceteris paribus* assumption credible for the estimated parameters. Their analysis presents empirical evidence in support of the convergence hypothesis, that is poorer countries/regions will tend to grow faster than richer ones, catching up in the level of per capita income or product (known as b-convergence). They conclude that absolute b-convergence, i.e. without including other variables, is the norm. The observed speed of convergence, of around 2-3% per year for different data samples, implies a half-life (i.e. the time needed to eliminate one half of the initial gap in per capita income for the sample studied) of between 25-35 years.

It can be useful to summarise some patterns arising from the existing empirical literature:

Empirical evidence seems to support the new theories.

- **An observed slowdown in productivity in recent decades**, in what seems to be evidence of convergence of one economy to its own steady state, as predicted by the neoclassical model. Loayza (1994), using panel data for a sample of 98 countries, finds empirical evidence in support of an even higher rate of convergence.
- **Importance of the role of technological progress in overall production growth.** Almost half of the growth is accounted for by this factor. Different models have tested the significance of variables that account for different degrees of investment in human capital and how they positively interact with growth.
- **The rapid growth in overall production experience in the Dynamic Asian Economies**, i.e. South Korea, Hong-Kong, Singapore, Taiwan. Some authors point out that it is because they are catching up in the use of physical capital, and not because they are experiencing technological progress. The implication is that their growth will at some point come to a halt.

Overall, some support for the hypothesis of convergence is derived from the empirical literature. Nevertheless it is important to note some open questions.

. . .but important factors remain unexplained

- The outcome predicted by the theory has not been completely validated by the data. Some African countries starting with lower income levels have not experienced growth at all. On the other hand, some convergence has been detected empirically within some restricted clubs of developed countries, e.g. OECD countries. A neoclassical response to this critique is that neoclassical theory predicts that countries should converge to their own steady-state rate of growth, which need not to be the same for all countries and is, in any case, affected by the system's 'environment variables' e.g. saving capacity, political framework, trade capacity etc..

Box 1 New Growth Policies

Examples of policy recommendations implied by new growth theory:-

- Tax incentives for entrepreneurs and R&D activities
- Promotion of education and training capacities
- Improvement of labour mobility
- Creation of collaborative networks
- Facilitation of the access of SMEs to the innovation market
- Introduction of supporting institutions in the innovation market
- Creation of venture capital markets

- Those conventional factors used to measure output growth in the production function, incorporate embodied technological progress, which can not easily be separated.
- Even if the empirical models determine the significance of science and technology (S&T) variables in the growth process, it is clear that there might be some two-way causation. S&T causes growth, but the reverse causation could also be posited: a country that attains a certain level of growth will probably invest more in S&T. The process should therefore be modelled as a system of equations [Fagerberg(1994)].

Policy recommendations

The new theories have important lessons for policy-makers

In conclusion, this debate has brought to the forefront of the discussion, the attainment of long-run economic growth - a central objective for our politicians and public planners. The recommendations derived from growth theory are beginning to be discussed and adapted into policy actions, encouraged by highly influential, supra-national organisations (e.g. European Commission and OECD).

Public authorities have a key role to play in moderating national systems of innovation

It is important to point to the relevance of new growth theories in terms of applied policy-making. In particular, the importance given in these models to the role of technological change in promoting growth based on the effects deriving from research, learning and experience, what is known as the 'knowledge-based' economy, should be emphasised. R&D and innovation give rise to private benefits which are remarkably lower than the social benefits. In this sense the amounts devoted to R&D by private enterprises and, consequently, the rate of technological progress and economic growth, will be far below that dictated by the social optimum.

New growth theories develop from the premise that technology does not conform to a linear system approach. Rather technology develops as a complex system, where many factors interact in a race for a reward reserved for a few. Technology investment involves uncertainty but individuals are often risk averse, which may lead to underprovision of technology investment. The role of public authorities, according to new growth theorists, should be to alleviate such underprovision by lowering market risks.

Hence, results derived from new growth theories are providing the framework for active S&T policies with one final aim - fostering technological change and therefore economic growth. On the other hand, if, as seen by neoclassical economists, technology is a freely available good, it will not be necessary to devote public funds to S&T, since the rewards will be shared and diffused away from the national boundaries in which the investment is made.

The 'endogenous growth' theories give special prominence to public policies in creating the necessary environment for growth. Through their decisions policy-makers can alter or modify the rules of the game for long-term growth. Using some particular policies, that lower the existing barriers, they can, for example, alter the rate of technological change through an environment which facilitates innovation and diffusion, enhancing `national systems of innovation`.

The general idea behind all these actions is that the flow of ideas generated by science and technology diffuses more rapidly into society, to the benefit of enterprises, the labour force and consumers.

Those external effects present in technology are, by definition, not reflected in market prices. In this sense, some agents (basically the local, regional, national and EU authorities) have to stimulate tech-

nology, taking into consideration these strong externalities, so that the S&T investments reach socially-optimal levels. All of these observations point in the direction of supporting the transformation of developed economies into 'knowledge-based' economies. This transformation acts as the engine behind the observed growth in developed economies.

Conclusion

The analysis developed in growth theory reflects a macro approach. It can be seen as a framework within which to support further micro-oriented studies, and eventually policy considerations. Although it does not aspire to being the definitive statement on the determinants of growth, it provides insights on growth dynamics. More micro-economic oriented approaches (e.g. industrial markets/sectors, internal organisation of the firm), deserve separate future study.

There are also new approaches aimed at defining sustainable economic growth and development. These theories explicitly take into consideration the use of natural and environmental constraints in their models. In accordance with this line of thinking, the World Bank proposes a change in the role of national accounting to incorporate sustainable development indicators [World Bank, 1995]. Moreover the IPTS, in a report on sustainable development [Kyriakou, 1995], has highlighted situations where the inability of price signals to reflect the imminence of catastrophic thresholds is at the heart of the problem. On the other hand, the report also states that sustainable development promotes scientific and technical progress, not only as a means to resolve uncertainty and enhance substitutability but also as an engine of economic growth in its own right.

Sustainable development goals present new challenges

Keywords:

economic growth, technological change, 'knowledge-based' economies, neoclassical theory, new growth theory, convergence.

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