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People, Land, and Food Production: Potentials in the Developing World

Mahendra Shah and **Günther Fischer** of the Food and Agriculture Program present the results of the first assessment of crop-specific food production and population-supporting potential in the developing world. This study was carried out by the Food and Agriculture Organization of the United Nations in collaboration with IIASA for the United Nations Fund for Population Activities.

Potential for food and agricultural production is determined primarily by soil and climate conditions and by the management of the land. Unwise use will result in degraded land and decreased production and productivity. There are limits to the viable levels of food and agricultural production obtainable from any given land area, and hence limits to the population that can be fed from any area.

Development of land resources to meet the food and agriculture needs of populations should be based on ecological, social, and economic factors. Many development policies in the past have largely ignored the ecological issues. The major contributions of this study are the development of a methodology to determine the capacity of soil and climate resources to provide the food needs of populations on a sound environmental foundation, and the application of the methodology to developing countries. The resource data bank generated by the study provides ecological-technological information for the formulation of policies and development of agricultural land resources in relation to the size and distribution of populations in developing countries.

The study provides a first approximation of the food production and population-supporting potential for 117 countries in five regions of the developing world: Africa, Central America, South America, South-East Asia, and South-West Asia.

Resource Data Base

Our starting point was the creation of a computerized land and climate resource base for each country. Within each country, land units of 10,000 hectares – agroecological cells – were classified by temperature regimes, number of days in the year suitable for plant growth, and soil characteristics. Not all of the land is available for cultivation, of course, and the study allotted land for nonagricultural uses on the basis of population distribution. Present and planned irrigated areas are treated separately in the study.

For each of the land units, the production potential of the fifteen most widely-grown food crops was assessed by using crop production models linking the agroecological cell characteristics to the photosynthetic, phenological, and soil requirements for each of the crops. Livestock production from grassland was also considered. Soil erosion and related productivity losses, harvest and post-harvest losses, seed types, power, fertilizers, and pesticides corresponding to each crop, level of farming technology, and each land unit were also quantified.

The total potential production (including production from planned irrigated areas) from all agroecological cells in a zone with a particular length of growing period in a country was translated to calorie and protein equivalents. Recommended calorie and protein requirements per capita for each country were applied to determine the population that could be fed from the zone's potential production.

Three sets of results corresponding to the following three alternative levels of farming technology were obtained:

Low level: Traditional seeds, no fertilizer or chemicals, no soil conservation, and continuation of existing cropping patterns;

High level: Improved seeds, recommended fertilizers and chemicals, full soil conservation measures, and most productive cropping patterns;

Intermediate level: Mix of low and high levels.

Results

Of the 117 countries studied, fifty-seven nations do not have the land resources to meet the food needs of the populations projected for the year 2000 at the presently practiced level of farming technology, even if they were able to use all their arable land resources by then. If we assume that by 2000 all developing countries could achieve the intermediate level of technology for all their potentially productive land, then thirty-six countries would not have the land resources to be self-sufficient in food. Even at the high input level, the land resources of nineteen countries could not supply the needs of their projected populations from their own food production.

The study assumed that all land resources were used for food production; in reality, land is also required for nonfood crops (cotton, tobacco), other food crops (beverages, vegetables) and forests (timber and fuel). If, at a minimum, one-third of the land is required for "other" agriculture, then additionally six, seven, and eight countries at the low, intermediate, and high levels of farming technology could not supply the needs of their projected populations from their own agricultural production. Most of these countries are in Africa.

"Critical" Countries

Countries which cannot meet the food needs of their populations from domestic production are referred to as "critical" countries. For some of these countries, it will be necessary to develop other sectors of the economy to earn foreign exchange to finance food imports. Continuing the presently practiced low level of farming technology, twenty-seven countries in Africa do not have the land resources to feed their future populations from their own food production. With the exception of the oil exporters, Algeria and Nigeria, and the medium-income countries, Tunisia and Morocco, most of these countries are the least developed and lowest-income countries in the world (gross domestic product less than US$ 300 per capita).

Africa has a very large area of potential rainfed cropland – 789 million hectares, not including marginal land – but only a fifth of this is being presently cultivated.

It is reasonable to assume that most African countries could reach at least the intermediate level of technology over the next two decades. Even then, however, twelve countries in Africa would still be critical despite using all their arable land resources for food production only. At the high level of inputs, only four countries in Africa would be critical: Western Sahara, Cape Verde, Rwanda, and Mauritius.

Ten countries and territories in Central America would be critical in the year 2000 if the presently practiced level of farming technology were to continue. Three of these could comfortably aim at achieving an intermediate level of technology by 2000, leaving seven in critical condition: Antigua, Barbados, El Salvador, Haiti, Martinique, Netherlands Antilles, and Puerto Rico. Barbados and the Netherlands Antilles would remain critical even at the high level of farming technology. Of the 74 million hectares of potentially cultivable land in this region, about a half is now being farmed with technology about a third of the way towards the intermediate level.

There are no critical countries in South America. In this region only about 15 percent of the potentially arable land area of 819 million hectares is in use at present, with technology about a third of the way towards the intermediate level.

In South-East Asia more than 92 percent of the potentially cultivable land area of 294 million hectares (not including 226 million hectares of marginal agricultural land) is already being used, with farming technology about halfway towards the intermediate level. In the year 2000, five countries would be critical if presently practiced farming methods continue. But it is heartening to see that by reaching the intermediate level of farm technology by the year 2000, only Bangladesh and Singapore would remain critical. In the case of Bangladesh – a low income and least-developed country – further expansion of irrigation and some food imports appear to be the only options. Singa-

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- to promote international cooperation in addressing problems arising from social, economic, technological, and environmental change
- to develop and formalize systems analysis and the sciences contributing to it, and to promote the use of the analytical techniques needed to address complex problems
- to create a network of institutions in the countries with National Member Organizations and elsewhere for joint scientific research
- to inform policy advisors and decision makers about the applicability of IIASA's work to such problems

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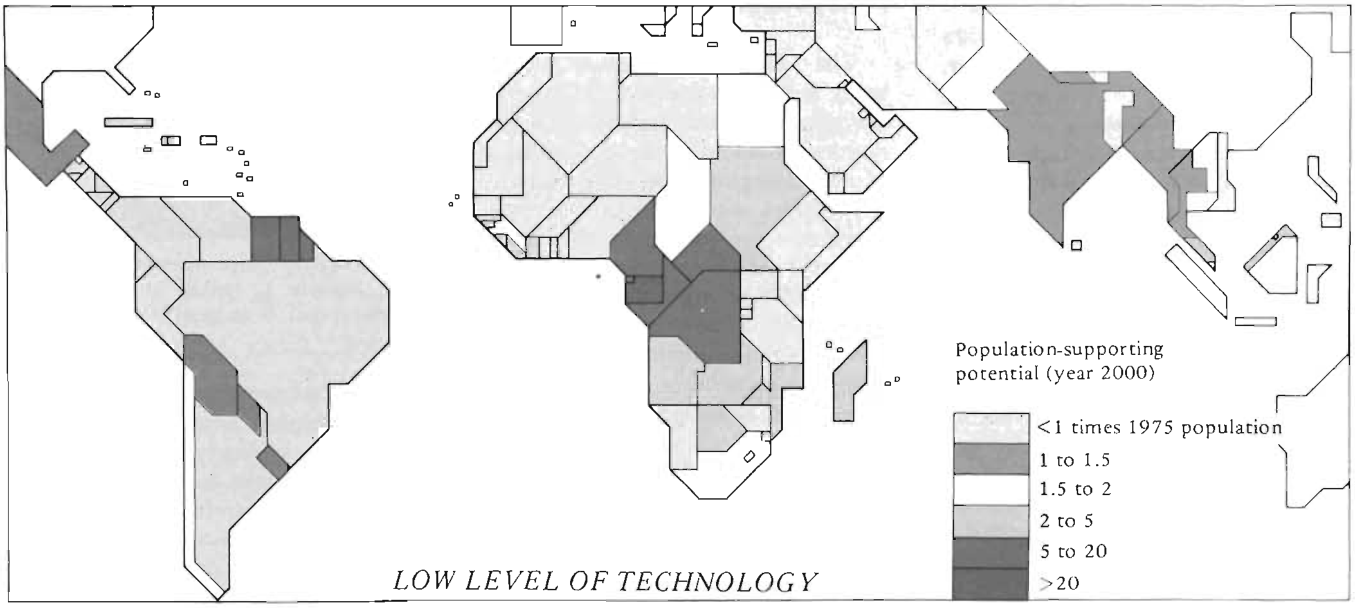
Population-supporting
potential (year 2000)
<1 times 1975 population
1 to 1.5
1.5 to 2
2 to 5
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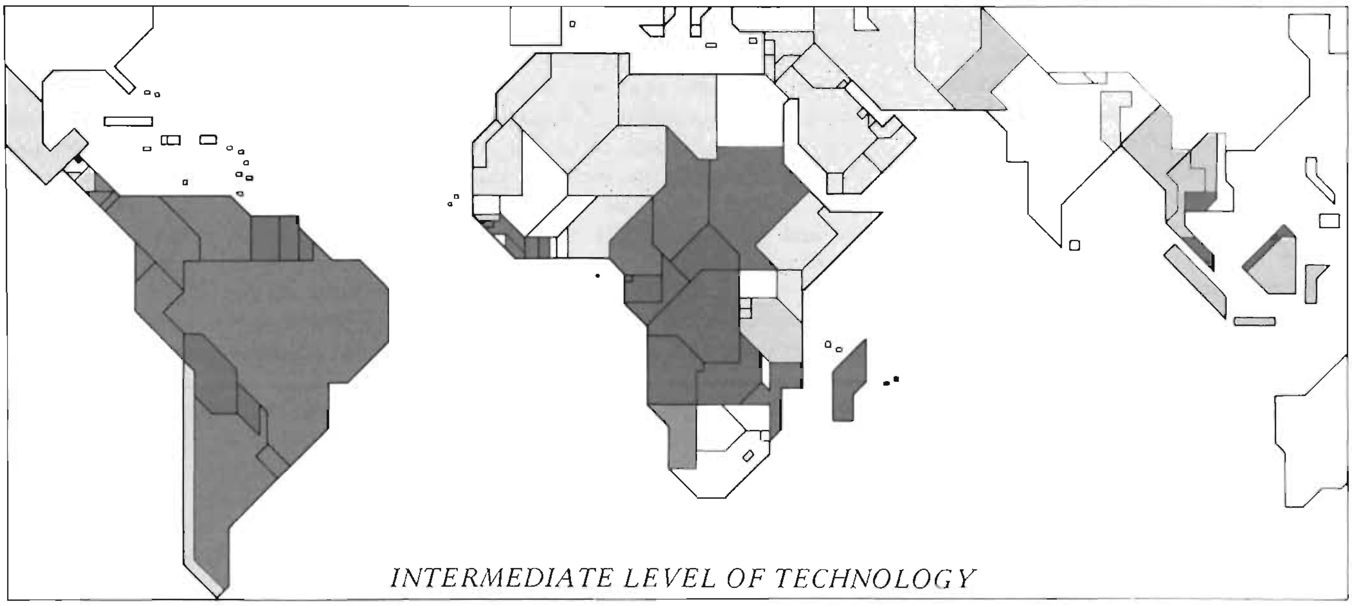
LOW LEVEL OF TECHNOLOGY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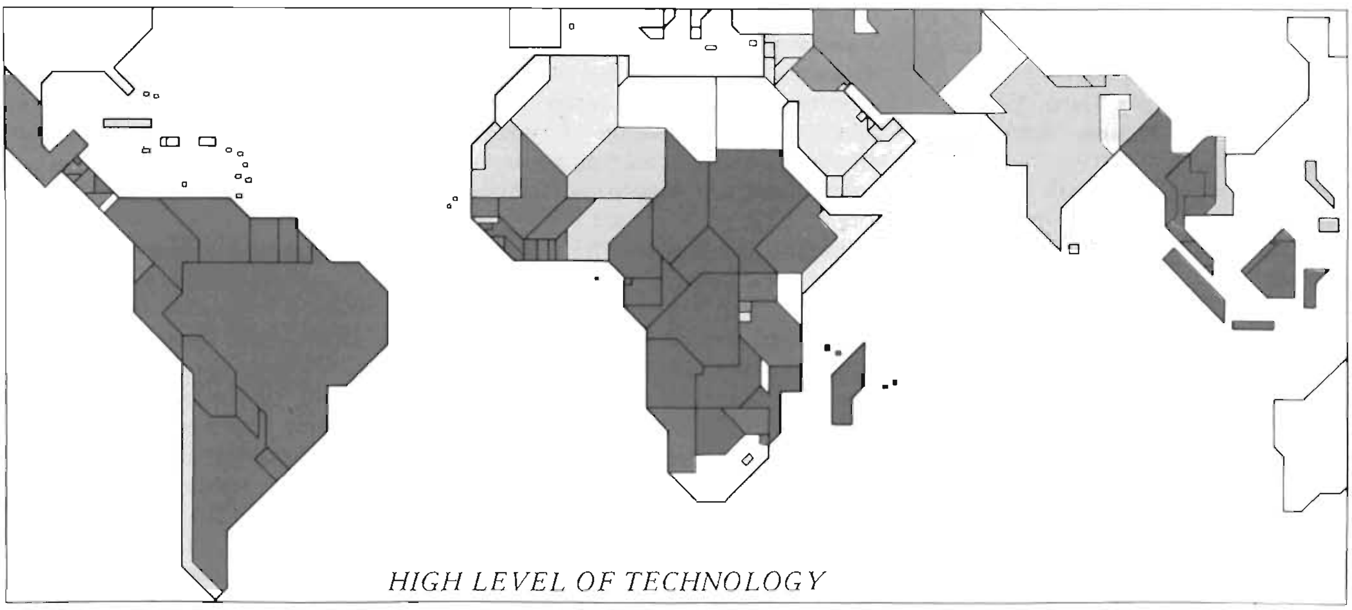

HIGH LEVEL OF TECHNOLOGY

pore basically does not have any land resources for agricultural production but, as a prosperous free trade center, it has the ability to import all its food and agricultural needs.

Much of the land resource base of South-West Asia is unsuited for rainfed agriculture – of the total land area of 679 million hectares, only 49 million hectares hold rainfed agricultural potential. Some further irrigated production may be possible, although in some areas – the Tigris and Euphrates region and Iran – irrigated land resources are likely to be fully used by the end of the next decade. All countries in this region are critical except for Turkey, Iran, Iraq, and Syria; the latter three countries being not critical only at the high level of farming technology. Some of the countries in this region are endowed with rich oil resources and could import their food and agricultural requirements as well as rapidly developing some further irrigation. Critical countries such as Jordan, Lebanon, Yemen Democratic Republic, Yemen Arab Republic, and Afghanistan (especially the last three least-developed countries) will have to develop means to secure foreign exchange to finance food imports.

"Surplus" Producers

Some countries have the land resources not only to meet all the agricultural needs of their populations in the year 2000, but also to export, provided they are able to develop their potential sufficiently.

Angola, Cameroon, the Central African Republic, Madagascar, Mozambique, Sudan, and Zaire have the highest potential for food and agricultural production in Africa.

In Central America, Cuba, Mexico, Nicaragua, and Panama have the highest potentials.

All the countries in South America have extensive arable land resources and thus the potential to produce large surpluses.

In South-East Asia, even at the presently practiced level of farming technology, Indonesia and Malaysia have the highest surplus potential relative to their projected populations. At the intermediate and high input levels, Burma, India, Pakistan, and Thailand join this group.

In South-West Asia, only Turkey, at intermediate and high levels, would have surplus production potential.

Policy Relevance

The major contribution of our study is the first approximation of the environmental and technological production potential of the land resources of developing countries. The study not only shows where and how improvements can be made but also identifies areas where food production will not be able to meet the needs of the population. These results give rise to some important population and agricultural policy questions.

Population Distribution. Historically, man has migrated whenever the need arose. For example, more than 60 million Europeans migrated to the Americas and Australia during the last one hundred years. Such international migration opportunities are no longer open to the developing countries, although the pressure on land and resources in some of these countries is many times greater than was the case in Europe. The possibility of migration across national borders in search of food, for example in western and central Africa, is also becoming more and more politically restricted. The situation within developing countries is no better. Typically, there are large inequalities in the standards of living between and among rural and urban populations in different parts of the country.

From a national government's viewpoint, the concern is to formulate policies and bring about an appropriate distribution of food and population in relation to agricultural land resource endowments in different parts of the country. The quantitative results of the study, for example the total potential production and data on the per capita and per hectare value of potential production in each zone, would enable formulation of equity-oriented policies concerning food, income, land, and population distribution. If land resources are limited in particular areas, the need for nonagricultural development to provide income for food imports can also be assessed and suitable locations investigated. In many developing countries there is a massive migration from the rural areas to a very few urban centers and there is an urgent need to locate and develop new urban growth centers.

The study results also showed that current population densities were highest in the cooler and drier areas, which have much lower potential population-supporting capacities than warmer tropical areas. Humid environments are ecologically sensitive and sustainable agricultural development will require careful planning and appropriate technology. People also have an aversion to residing in these humid areas due to a prevalence of human, animal, and plant diseases. A separate study conducted by IIASA for the UN Food and Agriculture Organization (FAO) assessed the potential in terms of income generation and population-supporting capacities of all the tsetse fly-infested areas, as well as areas into which such infestation may extend in Africa. Animal and human trypanosomiasis in these areas is a significant constraint to development in thirty-seven countries. Results identify priority areas for the implementation of tsetse control measures so that migration into – and development of – cleared areas with high agricultural potential can occur to reverse some of the recent declining food production and consumption trends in some African countries.

The study core team comprised G.M. Higgins, A.H. Kassam, L. Naiken of FAO and G. Fischer (right), M.M. Shah of IIASA (left).

Population Size. Much has been written – and argued – about the need for a reduction in population growth. There are those who think that development itself will lead to a reduction, as was the case in the present-day developed countries. Others think that we cannot afford (and we do not have the time) to wait for this.

The national governments of some of the countries identified as critical in the study will have to face squarely and tackle the issues of fertility reduction and lower population growth rates, as a number of countries have already done. This is especially true for those countries that may have neither the soil and climate resources to produce domestic food and agricultural requirements nor other resources to secure foreign exchange for imports. *Investment.* The development of the primary food and agricultural sector in many countries will require a mix of land-extensive and input-intensive investment strategies. The results for food production and population-supporting potential, obtained in the study on the basis of using all available land resources at each of the three levels of farming technology, provide information for assessing the investment mix required for land expansion, soil conservation, and improvement of farming technology to meet the food and agricultural needs of future populations. In many developing countries a disproportionate share of the available investment funds are channeled into agriculture and, in many instances, to large-scale development schemes. With the nonagricultural sector's difficulties in being rapidly able to absorb an increasing share of the growing population, it will be essential to efficiently channel agricultural investments according to the needs and development possibilities of various agricultural areas and rural populations in a country.

Technology. The study quantifies the volume of potential food production and related crop mix and inputs required: fertilizers, pesticides, power (human, animal, and mechanical), and seeds. This information, together with an assessment of presently used farming technology, provides realistic targets in space and time for the upgrading of farming practices.

If the crop mix does not match the food consumption mix of the population, then policies would be required to change the crops and/or to bring about changes in dietary preferences and/or to import the necessary food items. For instance, in some African countries, in spite of a large potential for the production of sorghum and millet, there has been a shift away from consumption of these cereals to the consumption of wheat. The production of wheat is ecologically infeasible in most parts of tropical Africa, necessitating increasing imports from overseas.

Data on the crop production potential and the required inputs provides the information for the location and the development of processing and storage facilities (crop and fertilizer), extension services, and so on, and for the formulation of relevant agricultural input policies. The study results provide a benchmark against which the desirable and feasible levels of food self-sufficiency and related farming technology can be assessed. This in turn would enable realistic planning of agricultural-technological development.

Conservation. The issues of environmental preservation and conservation are especially important in ensuring sustainable production. Farmers and governments require information on present and future crop productivity losses caused by soil erosion to justify and apply conservation measures. Soil erosion and the resultant crop productivity losses in the absence of conservation measures are quantified in the study. These results reveal that large productivity losses could occur from unchecked soil erosion in many developing countries. More recently, the methodology for estimating soil erosion and crop productivity losses has been refined on the basis of theoretical and empirical consideration of some 160 sets of experimental data from various countries. This will provide the basis for the formulation of relevant soil conservation policies in developing countries.

Agricultural Research. The study identifies and assesses the likely increases in production of specific ecologically-suitable food crops. These results provide information for the identification of particular regional agricultural research needs. For example, research on ways to improve the yields of sorghum and millet production in the drier areas and root crops in the wetter areas would be useful for a number of countries.

International Cooperation. Historically there has been little agricultural trade among the developing countries. There is considerable scope, necessity, and interest in evolving trade links. The study results, for example, show that within certain geographical groups of countries, regional food and agricultural self-sufficiency would be feasible. This may entail strategies not only for trade development but also for sharing natural resources, even through population migration.

International Aid. The study results provide opportunities to assess the level and type of international aid required. A developed country giving aid to developing countries is typically faced with the question of whom to give aid to and in what form. The study identifies countries and areas within countries by whether their own land resources could provide self-sufficiency in food and agriculture. A number of countries could achieve greater self-sufficiency through a combination of improving farming technology, developing irrigation, and implementing soil conservation measures. For such countries it is important to channel aid in terms of inputs, capital, and know-how. There are also a number of countries that do not individually have the land resources to produce all their food and agriculture needs; here integrated aid packages may be directed toward groupings of countries in viable economic regions. Some countries may have other resources that could be developed through aid and technology transfer to facilitate earning foreign exchange for food and agricultural imports. Finally, there may be a small group of countries that have very limited possibilities; for these, sustained direct international food aid is required.

Such considerations would help to identify aid projects and, with additional feasibility studies, ensure that aid is better directed, more focused, and efficiently utilized.

The most fruitful avenue for further extension of the study presented here is the refinement of the methodology and the physical resource data base for detailed country planning studies. A first such case study – of Kenya – is presently being carried out.

The development of the food and agriculture sector in any country has to be planned within the national and international setting, since this sector is embedded in the national economy, and nations are interdependent through trade and cooperation within the international economy. Searching for national and international policies for food and agricultural development is at the core of IIASA's Food and Agriculture Program.

The coming two decades and beyond will see an ever increasing demand for food. The ecological, technological, social, and economic issues will have to be explicitly considered and integrated in an interdisciplinary planning framework if we are to succeed in providing for the well-being of future populations on a sustainable basis.

Further details and data are available in *Potential Population-Supporting Capacities of Lands in the Developing World*, FAO/IIASA/UNFPA Technical Report of the Land Resources for Populations of the Future Project. Rome, Italy, 1984.

Diversion of Water Resources into the Caspian Seabed

Grygory Voropaev describes the scientific work and the decision-making process leading to the water diversion projects underway in the Soviet Union.

The Soviet Union possesses an enormous reserve of fresh water. The annual volume of surface river flow is about 4,700 cubic kilometers, while estimated reserves of underground water amount to 350 cubic kilometers, which exceeds the present consumption of water in all branches of the economy by 15-18 times. However, there are at least three aspects of water distribution that give rise to concern. First, the spatial distribution of water resources is distinctly inhomogeneous. A major share, 84 percent, is concentrated in Siberia, the Far East, and the northern regions of the European part of the country. The southern regions of the European part, Central Asia, and Kazakhstan — 75 percent of the country's population and almost 80 percent of the production forces — contain just about 16 percent of the water resources available in the country. Second, the main consumption of water is for agricultural irrigation, which will impose major requirements upon water resources in the future as well. All arable lands that require irrigation are situated in the southern regions where water resources are already nearly exhausted. Finally, the largest lakes and inland seas are also situated in the southern regions. These are the Caspian Sea, the Aral, the Sea of Azov, the bays and firths of the Black Sea, and Lakes Issik-Kul, Balkhash, and Sevan, whose hydrologic and hydrobiologic regimes and even existence depend upon the amount, the regime, and the quality of fresh water inflow. In this respect, these water bodies can be looked upon as major consumers of fresh water resources, with all inflow being irreversibly consumed (mostly through evaporation from their surfaces).

This mismatch of water resources with respect to the distribution of consumers has given rise to suggestions concerning large-scale interzonal redistribution of river flow. It can be noted that the first suggestions and projects for territorial redistribution of river flow in the country were brought up as early as the last century and were actively advanced in the 1950s. However, the main purpose at that time was quite different. Projects were intended to provide a better transportation system and increase the production of hydroelectric power. New approaches to the problem of water supply by territorial redistribution of river flow date from just two decades ago. Today engineering solutions have been found and research completed concerning partial diversion of northern rivers and lakes of the European part of the U.S.S.R. to the Caspian Sea basin. One of the questions that received the most attention was the problem of predicting possible ecological consequences that the proposed partial diversion of river flow from the northern rivers might entail.

Engineering Solutions

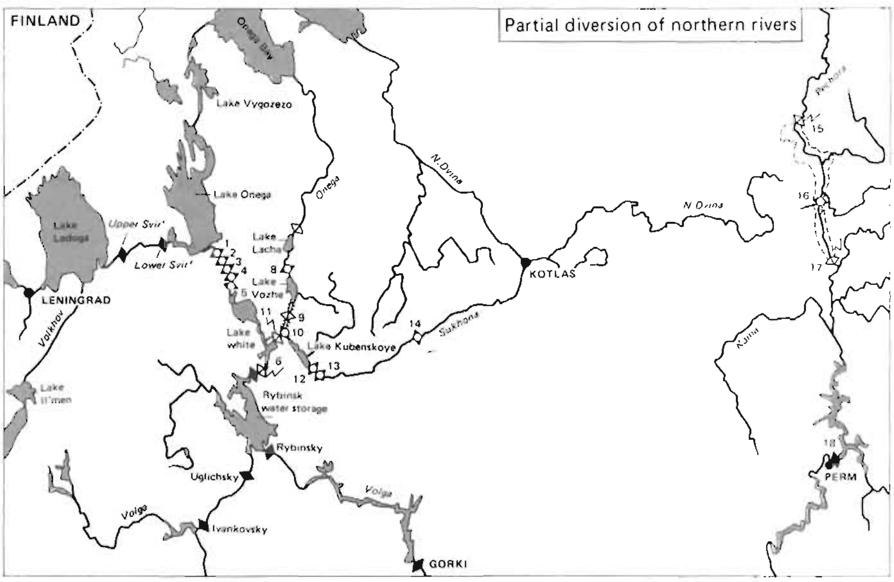
Studies of the problem took into account the engineering solution developed by a technical institute on the basis of technological and economic comparisons of different proposed plans. During the design process, many problems were addressed including the evaluation of water consumption development, choosing a scheme for the development of water systems and the diversion routes, the location of hydrotechnical installations, etc. The recommendation was to transfer, on average, up to 19 or 20 cubic kilometers of water annually by the year 2000, the whole project being divided into three stages.

Upon the completion of all three stages of diversion, some 19 or 20 cu km of water will be transferred southward annually, thus allowing the irrigation of 4.5 million hectares of land, the production of about 2,000 million kilowatt-hour (kwhr) of peak power annually at the cascade of the Volga-Kama hydroelectric power stations, and the stabilization of the water budget of the Caspian Sea to keep its water levels close to 28.5-29 meters under average hydrometeorological conditions.

Research Problems and Methods

During research for this project several new problems were encountered including an evaluation of the possible effects the planned river diversion projects might have on the climate of both the U.S.S.R. and neighboring countries; long-term (up to several decades) prediction of environmental conditions over the several million square kilometers of territories affected by the partial transfer of water from the northern rivers and by its southward redistribution and utilization; evaluation of possible ecological consequences of river diversion including changes in the productivity of aquatic and terrestrial biological systems in the respective regions; finding measures to prevent possible negative consequences of partial southward redistribution of river flow; and estimation of the maximum permissible volume of diversion from the northern rivers and minimal additional volume of water required in the southern regions up to the end of the century.

Because of a lack of experience and the absence of a proven methodological approach to solving similar complicated problems, special attention has been paid to methodological studies. Extensive use was made of systems analysis, the mathematical simulation of natural and combined natural and technical systems, field experiments, expeditionary and stationary observations, and statistical analysis of available information. More than one hundred national scientific institutes participated in the studies during 1976-1982 under a common scientific program.



◆ Hydroprojects at: (1) Vytegra, (2) Bjelousovsky, (3) Povinkinsky, (4) Savinsky, (5) Pakhomovsky, (6) Sheksninsky, (7) Kargopolsky, (8) Svidsky, (9) Ukhtominsky, (10) Porozovitsky, (11) Kirillovsky, (12) Upper Sukhonsky, (13) Lower Vologodsky, (14) Kamchug, (15) Mitrofanovsky, (16) Komsomolsky, (17) Fadinsky, (18) Kama.

hydroprojects with pumping stations

hydroprojects for water head accumulation and release

hydroprojects with hydroelectric power plants

connecting canals

The methodological approach was based on the following considerations: water resources, as a natural element of the biosphere, critically affect hydrologic and thermal regimes of land, water bodies, and the atmosphere, the bioproductivity of the aquatic and terrestrial environment, and the living conditions of human society. At the same time, anthropogenic effects on natural processes in the biosphere reveal themselves mainly in the regime of bodies of water. Both the spatial and temporal scales of anthropogenic intrusion due to the planned diversion of rivers are exceptionally large. In fact, these measures involve natural processes at all levels of circulation of matter and energy fluxes in the biosphere. On the other hand, the diversion of rivers would take place with a general background of constantly increasing anthropogenic pressure on the environment. All types of mankind's economic activity clearly give rise to definite changes in the regime of terrestrial water resources and the character of the respective natural processes, which makes the separation of the effects of river diversion measures upon natural processes so difficult. The aquatic environment in the rivers and lakes to be diverted was therefore studied and predicted both under the conditions of planned diversion and without any diversion.

River Diversion and Climate

A partial diversion from the northern rivers will result in less inflow of fresh water into the Arctic Ocean. This fact gave rise to a hypothesis concerning possible changes in the thermal regime and circulation of moisture in the region, as possible climatic consequences of diversion projects. Similarly, the transfer of additional volumes of water to the southern regions and its utilization for irrigation will lead to higher evaporation and thus can change the thermal regime and moisture circulation over huge territories, which, in turn, might influence climatic processes. These considerations inspired special studies of heat and mass exchange over continental and oceanic regions in the north, possible changes in meteorological conditions in the regions of water removal and in the thermal budget, agro-climatic resources and redistribution of water exchange budget elements in the regions that receive additional volumes of water.

It was found that partial redistribution of river flow, even on a much larger scale than planned, should not entail large-scale changes in the heat budget and atmospheric circulation. Changes of local character are possible and could be detected in aquatic and terrestrial environments over short distances (not exceeding several scores of kilometers) or up to a thousand kilometers in the atmosphere.

According to our studies, the effects of river diversion on climatic processes cannot even be detected if the annual volume of diversion is less than 20 cm km. This is true even with respect to possible amplification of such effects due to the long-term influence of the project and possible feedbacks.

Environmental Changes in the Region of River Flow Diversion

As now approved, the volume of diversion at the project's first stage amounts to 5.8 cu km per year; 1.8 cu km taken from the Onega River (Lacha and Vozhe Lakes) and 4 cu km taken from the Upper Sukhona River. All of this water goes to Lake Kubenskoye. The inflow into Lake Vozhe is mostly used to provide the 1.8 cu km taken from the Onega. The normal water level of Lake Vozhe will be slightly lowered while that of Lake Lacha will remain close to natural conditions, though the periods of high water levels will be shortened. The drainage of neighboring territories will be increased, which is favorable for their agricultural utilization. The changes will involve the seasonal distribution of streamflow and water levels at all reaches of the Onega, up to its estuary. The streamflow at the source will be decreased two- or three-fold during the dry season, water levels will be decreased, and the inflow to the estuary diminished by 10 or 15 percent during dry years. The warming effect of fresh water will become less pronounced, and the dates of the formation and the breakup of the ice cover will be changed by 5 and 7 days respectively. Water temperature will drop by 1.5°C during extremely dry years, while the ice-cover period will grow slightly longer.

Professor Grygory Voropaev, Director of the Institute of Water Problems of the Academy of Sciences of the U.S.S.R., is also Chairman of the State Expert Commission of the State Planning Committee.

A partial removal of flow from the Onega will cause higher concentrations of pollutants in the river. However, the hydrochemical regime of Lakes Lacha and Vozhe will not be affected. The removal of water from the system of lakes that includes Lacha, Vozhe, and Kubenskoye will entail changes in the system of currents and a definite reconstruction of their hydrobiological systems, especially in Lakes Lacha and Kubenskoye. The loss in fish production could be rather high, up to 80 or 90 percent.

In order to take 4 cu km of water from the Upper Sukhona, the Kamchug hydroelectric power station will be constructed to pump a part of the flow into Lake Kubenskoye, while the Sukhona will be transformed and its flow reversed. The water levels of Lake Kubenskoye will become controllable and the diminished flow from the river to the lake will allow control of the length of the flooding interval and water depth over the Sukhona Plain, thus improving the hydrological regime of floodlands along the river. The maximum discharge will be changed only slightly, while the average discharge will be diminished markedly, especially downstream from the Kamchug hydroelectric power station. Discharges during the winter and summer dry periods will decrease substantially causing difficulties in navigation and timber rafting. Heat transport to the mouth will be decreased slightly and the average dates of ice cover formation and breaking up of ice cover will be changed by three days. Injection of water to Lake Kubenskoye will result in substantial intensification of water circulation in the lake, though the quality of water might suffer and the oxygen regime might become worse in winter time. Fish production on the Sukhona, insignificant even now, will become still lower.

During the second stage, 3.5 cu km will be taken from Lake Onega annually. This will cause a respective decrease in the flow of the River Svir', the inflow into Lake Onega, and the flow of the Neva River. The water levels of Lake Onega, now at the normal level of the upper Svir', will remain practically unchanged though the exchange of water masses will intensify. The frequency of minimal flow occurrence for the Neva and Svir' during dry seasons will increase. However, this will not affect navigation along the Neva. The analysis of year-to-year hydrology variations showed that this aquatic system would not undergo any substantial change. Partial diversion of flow might result in a slightly higher mineralization of water in the Neva and Lake Ladoga. The hydrochemical regime of Lake Ladoga will not deteriorate.

During the third stage, 9 or 10 cu km of water are to be taken from the Pechora River. This will be done by constructing the Mitrofanovsky water storage reservoir and the Komsomolsky and Fadinsky hydroelectric power stations. The water is to be released through the Kolva to the Kama and further to the Volga The water storage reservoir will cause major changes in the hydrology of the Pechora. Its flow downstream of the dam will be diminished by as much as 40 or even 70 percent, depending upon the volume of flow in each particular year. About 5,000 hectares of an overall 40,000 hectares of meadows will not be flooded during moderately wet years. At the beginning of the dry season, water levels will fall by 2.5-4.0 meters or even more under unfavorable ice and streamway conditions. Navigation along the river and its tributaries will deteriorate drastically. The influence of the water storage reservoir and the water diversion will be felt to a lesser degree downstream where more tributaries are feeding the flow, but it will remain substantial even at the river mouth where water levels will drop by 0.3 meters on average, the flow will diminish by 5 or 10 percent, water temperature will drop by 0.5° or 1.0° C, and the dates of the formation and the breakup of the ice cover will change by 5 or 7 and 2 or 3 days, respectively. About 5,000 hectares of agricultural land will be flooded and the flow of several large tributaries will be affected by the high water levels of the reservoir. Migration of fish and navigation along the mainstream and tributaries will be cut off.

Water storage reservoirs and diversion of flow will affect the hydrochemical regime of the river so that the quality of water will worsen. Changes in the regime of water levels in the river, disappearance of floods on the Pechora, deterioration of water quality, diminished flow, construction of dams — all these factors will change drastically the fishery conditions that now exist along the Pechora and in the Pechora Bay. The largest shoal of salmon in the European part of the country, which supplies up to 60 per cent of the total catch, will probably be affected quite substantially along with other species of fish. Additional volumes of water entering the Volga through the Rybinsk water storage reservoir and the Kama River will not entail major changes in the hydrology of these streams. Changes in ice conditions at the high and lower reaches of hydroelectric power stations will probably be the most pronounced effects of the project on these rivers; water temperature will drop by 2° or 3° C in summer and increase by 0.5°-1.0° C in winter. Polynia — areas of open water in sea ice — will occur more frequently in winter, and humidity and fogging are bound to increase.

Hydrochemical conditions in the Rybinsk water storage reservoir might get better, with a lower concentration of salts, nutrients, and oil pollutants. The chemistry of the Pechora will be affected only slightly, though the quality of its water will not be improved. No substantial negative impact of diversion on fishery production of the

Volga water storage reservoirs and the river as a whole is expected.

Environmental Changes in Southern Regions

The southern regions where the additional volumes of water will be utilized include the Caspian Sea and the Sea of Azov, the Volga-Akhtuba floodlands and the Volga estuary, and new irrigated lands in northern Caucasia and along the Volga. As mentioned above, the major goal of the river diversion scheme is the conservation of the unique fish production in the Caspian and Azov Seas under the conditions of growing water consumption and diversion of water resources in their basins. At the same time, our studies showed that substantially larger volumes of additional water resources were required to achieve this purpose. If, however, the volume of diversion were increased over 20 cu km per year, the environmental changes could hardly have been predictable. Their evaluation might only be possible by making use of the experience gained at the initial stages of the river diversion scheme and through additional special studies that cannot be done in less than ten or fifteen years.

These considerations made it necessary to choose only one of the two seas as the major recipient of water transferred to the southern region. For many reasons it was decided that more importance should be given to the conservation of the water budget of the Caspian Sea. First, the present water level of the Caspian Sea is close to the equilibrium state which corresponds to the present-day water budget, specifically to the inflow into the sea. Any additional diversion of water from the basin will make the level drop quickly even under average climatic conditions, thus diminishing its fish catch. Second, the Caspian Sea still is and always was the largest producer of sturgeon in this country and in the world. It may remain the largest producer of sturgeon in the future with a simultaneous increase in the catch of other species. The Sea of Azov lost its former role as a major sturgeon producer during recent years. Its catch could not be restored, if at all, earlier than the end of this century. Third, the present water levels are closely interrelated with the economy of the region; both higher and lower levels are undesirable because they could cause definite economic losses.

The Soviet Government recently approved plans for the diverson of 5.8 cu km of water annually from the basins of the Onega and the Sukhona Rivers into the Volga River and for the construction of the Volga-Don Canal to transfer 5 cu km of water from the Volga into the River Don. This water will be used for irrigation in the northern Caucasus. Existing plans provide for the development of irrigation in the northern Caucasus and in the basin of the River Don rather than in the Volga basin. This part of the diversion project cannot possibly affect the water budget of the seas during 1981-1985. However, termination of the development of irrigation in the Volga's basin will result in a lower growth of water consumption in the basin and, consequently, in a more stable water budget and water level of the Caspian Sea during the forthcoming decade. Further increase of diversion volume up to 19 or 20 cu km per year, along with other measures aimed at reducing water consumption and controlling evaporation and outflow (by cutting off its northeastern shallows and controlling the outflow to the Kara Bogaz Gol) will help stabilize the water levels near the present elevation even under changing values of water budget constituents. The efficiency of all these measures will depend upon the natural variation in the amount of water during the forthcoming period.

Decision-Making Procedures

From our experiences we know that one should distinguish two stages in the obtaining and analysis of information and related decision making when one deals with the investigation of large-scale scientific and technological problems. The first stage is the making of a preliminary decision on the basis of the data obtained. The procedure consists of a step-by-step analysis of the problem. If at any point a negative decision is reached, then the source material is sent back for further development and revision. If the decision reached is positive, the projects proposed are included in the draft of a long-range plan of national economic development. At the same time, further studies are carried out to prepare more detailed information on the projects. The information is used at the second stage of investigating a large-scale problem.

The second stage includes scientific research, technological design, and discussion of the results, leading to decisions on the preparation of program implementation measures and a time schedule. Revised data make it possible to specify technical details and consequently to set up a construction timetable.

In both stages continuous contacts and joint efforts between scientists, engineers, and the public take place. Most of the information needed is prepared by design and research institutions and various specialized scientific and technological councils participate in the discussion. Decisions are made by the ministries involved.

The redistribution of part of the river flow from the northern basins to the Volga basin can serve as an example. Step 1: we formulated the problem of water transfer and specified the goals to be achieved by water transfer. Step 2: an integrated program of scientific research was developed. Over one hundred research and design institutions were involved. A scientific council on the problem was established. The results of these studies were widely discussed in scientific periodicals, newspapers, and by the public at large.

Then a decision was reached. The materials prepared in this process entered the U.S.S.R. State Planning Committee (GOSPLAN). The State Expertise Board within GOSPLAN scrutinized all materials submitted. In addition, a temporary subcommission of experts was set up, consisting of about 80 leading Soviet scientists. The recommendations they made were considered by the State Planning Committee and then by the Council of Ministers of the U.S.S.R. The final decision was made by the Council of Ministers.

Competing Technologies and Economic Prediction

W. Brian Arthur explores the dynamics of choice between objects with increasing returns — and finds that the economy can become locked-in to inefficient structures by insignificant events.

In 1890 there were three ways to power automobiles — steam, gasoline, and electricity — and of these one was patently *inferior* to the other two: gasoline. Yet today the entire automotive technology is based upon gasoline. It is possible, of course, that gasoline possessed hidden engineering advantages that were only slowly uncovered. But another, quite different explanation can be put forward.

Very often, technologies show increasing returns to adoption — the more they are adopted the more they are improved, and the more attractive they become. Aircraft designs, for example, improve greatly in structural soundness, maintenance costs, and payload capacity as they accumulate experience through actual airline operation. When two or more increasing-returns technologies compete for adopters, insignificant "chance" events may give one of the technologies an initial adoption advantage. Then more experience is gained with this technology and so it improves; it is then further adopted, and in turn it further improves. Thus, the technology that by "chance" gets off to a good start may eventually "corner the market" of potential adopters, with the other technologies gradually being shut out.

Whether the automotive industry is locked-in to a gasoline technology by historical small events magnified by increasing returns, or by the innate superiority of gasoline engines, is a matter that would require careful historical weighing of evidence together with detailed engineering analysis. If we take the increasing-returns explanation as valid however, we can see in this example four key features of the dynamics of markets where increasing returns are present.

First, the technology that "wins" a market does not necessarily have to be the "best" or most efficient. In the case of the automobile, the steam (Rankine) cycle is thermodynamically more efficient than the gasoline (Otto) cycle. Given as much development as the gasoline engine has undergone over the last ninety years, it is quite possible that a steam engine could have been more economical. (There are several recent steam prototypes that achieve better fuel mileage and have lower exhaust emissions than current gasoline power sources.) In the dynamics of choice under increasing returns, even when individual choices are perfectly rational, there is a potential economic *inefficiency* of outcome.

> "Every steam carriage which passes along the street justifies the confidence placed in it; and unless the objectionable features of the petrol carriage can be removed, it is bound to be driven from the road, to give place to its less objectionable rival, the steam-driven vehicle of the day."
> William Fletcher, *Steam Carriages and Traction Engines*, 1904, page ix.

Second, an industry (or economy) can get "locked-in" to a technological path that is difficult to get away from. As more and more people choose one technology from a group of competing technologies, that technology becomes more attractive. The other technologies become "frozen out" of the market and often disappear. To reestablish them, a widening changeover gap would then have to be closed. In cases with increasing returns, there is a potential *inflexibility* where ultimate "market shares" cannot always be easily altered as a matter of policy.

Third, even with hindsight, the reasons why a particular technology came to be adopted are difficult to pinpoint. Exact causality is hard to ascribe. Where increasing returns are present, it is often a mistake to explain adoption by the "superiority" of the technology, as is traditional. There is a *non-ergodicity*: historical "small events" are not averaged out and "forgotten" but may well decide the path of adoption shares.

Fourth, even if we know all the preferences and possibilities of those choosing, the outcome — the share of the market taken by each technology — is often impossible to predict in advance. If small events can decide the outcome, and if these are in some sense "too small" for the economist's notice, then with increasing returns there is a *non-predictability*: knowledge of supply and demand usually does not suffice to predict theoretically the share of the market that each technology will take. Of course, with increasing returns we may be able to predict that one technology will come to dominate, we may be able to give odds on each, but we cannot with accuracy say *which* technology will dominate.

Dynamics of Choice Under Increasing Returns

As one possible, simple model of an adoption process with increasing returns, imagine two technologies, A and B, competing with each other to fulfill a particular economic purpose. They compete in the sense that adoption of one will displace or preclude the adoption of the other technology.

Imagine manufacturers — economic agents — having to choose between the two technologies. Once he has chosen a technology, each agent stays with it and his payoff is not affected by future changes. The agents fall into two groups or types, R and S, with equal numbers in each type, but differing in the use to which they put the technologies. Let us say R-agents, initially at least, prefer technology A, and S-agents prefer B.

Now assume that payoff or returns

Stanley Steamer
Reproduced from N. Taylor, *The Stanley Steamer and Other Steam Cars.*

to adopting A or B increase linearly (at a given rate) with the numbers who have chosen A or B respectively. And assume each agent's moment of choice is subject to small, but unknown, events, so that, to us as observers, choice order looks like a binary sequence of R- and S-agent types, with the probability that an R or an S stands in the *n*th position in line equal to one-half.

This is a well-defined, neoclassical model of choice: two types of agents choose between A and B, each agent demands one unit inelastically and the supply-cost (or returns) are known. The only unknown is the order in which the agents choose; this is subject to "small events" below the notice of our model. What happens to the market share of the two technologies?

Initially at least, if an R-agent arrives at the "adoption window" to make his choice he will adopt A; if an S-agent arrives he will adopt B. Thus the difference-in-adoptions between A and B moves up or down by one unit depending on whether the next adopter is an R or an S, that is, it moves up or down with probability one-half. This process is a simple gambler's coin-toss random walk. There is only one complication. If, by "chance" a large number of R-types cumulates in the line of choosers, A will then be heavily adopted and hence improved in payoff. In fact, if A gains a sufficient lead over B in adoptions it will pay S-types to switch over. Then both R- and S-types will be adopting A, and only A, from then on. The adoption process is locked-in to technology A. Similarly, if a sufficient number of S-types by "chance" arrives to adopt B over A, B will improve sufficiently to cause R-

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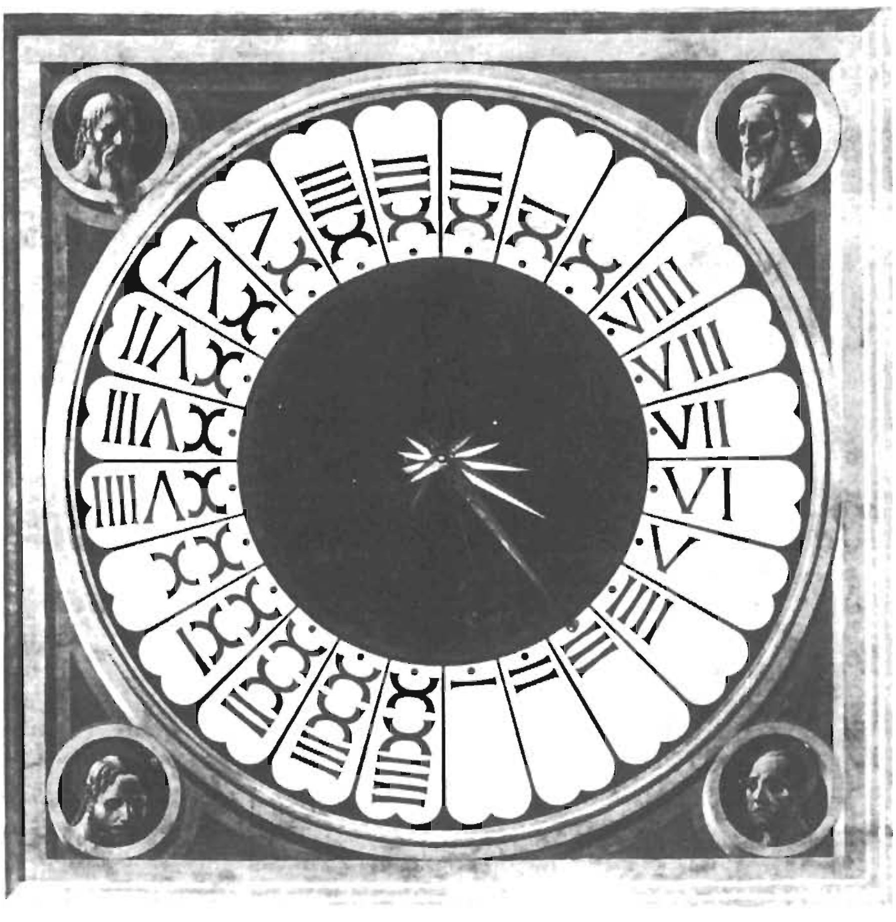
types to switch over. The process will then lock-in to B. Our random walk is really a random walk with absorbing barriers on each side, the barriers corresponding to the lead in adoption it takes for each agent-type to switch its choice.

All this is fine. We can now use the well-worked-out theory of random walks to "prove" the properties I pointed to earlier. The important fact about a random walk with absorbing barriers is that absorption occurs eventually with certainty. Thus in the model I have described, the economy *must* lock-in to one of the two technologies, A or B. But *which* technology is not predictable in advance. Also, the order of choice of agents is not "averaged away"; on the contrary, it decides the eventual market outcome. Thus the process is non-ergodic. Nor is it flexible. Standard policy measures of favoring one technology over another by tax or subsidy merely shift the barriers. But if the process has become locked-in, the leading technology is constantly improving, so that after a certain time any given boost to the payoff of the excluded technology will not be sufficient. Further, it is easy to construct examples in which this "greedy algorithm" of each agent taking the technology that pays off best at his time of choice may miss high rewards to the future adoption and development of the excluded technology. Economic efficiency is not guaranteed.

These results are drastically altered in the standard textbook diminishing-returns case. Here technologies, as they become adopted, exert pressure on scarce resources, so that their returns fall with adoption. Hydroelectric power, for instance, becomes more expensive with increased use as the more suitable dam sites are taken up. It is easy to show that the market shares of technologies in the diminishing-returns case are governed by a random walk with reflecting barriers. Here the market for the two technologies is usually shared: the outcome is predictable, as it is the same regardless of the "small events" sequence; it can always be changed as a matter of policy; and it is always economically efficient.

Where technologies remain the same in payoff regardless of the numbers of adopters — the constant-returns case — the dynamics are governed by a random walk without barriers. The table summarizes the properties of the three contrasting regimes.



Clock by Paolo Uccello, Florence, Italy. Casa Editrice Giusti di Becocci

Implications

There are several implications of the increasing-returns mechanism I have sketched out here. If this type of mechanism is valid, we would expect past history to contain a "fossil record" of technologies that could have been as good as, or, given equal development, might have been better than, the technologies which were eventually adopted. One example is the direction of motion of the hands on the Uccello clock in the Cathedral in Florence, Italy. They turn anti-clockwise. The Uccello clock was constructed in 1433: it wasn't until after 1550 or so that the clockwise movement became standard.

Properties of the Three Regimes

	Necessarily Efficient	Necessarily Flexible	Predictable	Ergodic
Constant Returns	Yes	Yes	Yes	Yes
Diminishing Returns	Yes	Yes	Yes	Yes
Increasing Returns	No	No	No	No

We would also expect to see technologies which are patently inefficient but which we are "stuck with". The U.S. color television system, the driving-on-the-left convention in Britain (bad for car exporters) and the extreme longevity of the 1950s programming language FORTRAN are examples. The "standard" keyboard on typewriters is a case in point. Before 1873, early typewriters came with a variety of keyboard arrangements But in that year, Christopher Scholes, together with his brother-in-law, a schoolteacher, designed a keyboard to overcome mechanical problems with sticking key-bars. The first six letters on the upper row of Scholes' keyboard were QWERTY. The Remington Sewing Machine Company of New York starting mass-producing typewriters on the Scholes model – with the QWERTY keyboard. An international meeting in 1904 was supposed to decide on one keyboard among the many alternatives to become the standard. No agreement was reached, primarily because of opposition to any change from typing teachers. QWERTY keyboards are now used in all but 3 of the 45 nations with Roman alphabets and superior competitors to the QWERTY system – the Dvorak system and the Maltron system – have had trouble in gaining a footing.

Policy measures are generally straightforward in the diminishing-returns and constant-returns cases. Here it is usually best to leave the adoption process alone and let the market find its way to an efficient mix of technologies. But where competing technologies show increasing returns to adoption, the "fittest" of the technologies may not survive. The government may then need to step in, to encourage and protect infant technologies that, if sufficiently adopted and developed, may pay off handsomely. But there are difficulties. Eventual returns to a technology (think of solar energy, for example) are hard to ascertain; so that while there are obvious dangers and costs of missing out on a potentially superior technology, there are equally obvious costs to exploring large numbers of unknown technological paths.

The argument here implies that we should be careful in interpreting economic history. We usually look for reasons why a predominant technology was superior, and how this "innate" superiority eventually led to adoption. But this line of reasoning is valid only for cases of constant and diminishing returns. Where technologies exist potentially in ever more improved designs, superiority becomes a function of adoption or use. To return to our gasoline versus steam engine example, it is quite possible that gasoline was indeed innately superior. The matter has never been settled. But it is equally possible that a series of small events at the turn of the century gave gasoline a temporary lead that subsequently proved unassailable. In the North American case, we can, among other small events, single out an 1895 horseless carriage competition sponsored by the Chicago *Times-Herald*. This was won by a gasoline-powered Duryea – one of only two cars to finish out of six starters – and has been cited as the possible inspiration for R.E. Olds to patent in 1896 a gasoline power source, which he subsequently mass-produced in the "Curved-Dash Olds". Gasoline thus overcame its slow start. Steam continued viable as an automotive power source until in 1914 there was an outbreak of hoof-and-mouth disease in North America. This led to the withdrawal of horse troughs – which is where steam cars could fill with water. It took the Stanley brothers about three years to develop a condenser and boiler system that did not need to be filled every thirty or forty miles. But by then it was too late. The steam engine never recovered. Where increasing returns are present, it is often the missing "horseshoe nail" that decides the technological path that is followed.

I have argued that, with increasing returns, the later development of an industry or economy may depend on "small events" beyond the resolution of an economic observer or his model. Similar arguments have been applied in the last decade to the theoretical possibility of accurate meteorological forecasting. It has been proven that an observational net of weather ships would theoretically have to be finer than the radius of the smallest eddy for weather developments to be forecastable; otherwise these "small events" become amplified by inherent positive feedbacks into large uncertainties. Given the inevitable presence in the economy of increasing returns to adoption or to allocation, we can speculate that an econometric model that predicts perfectly accurately is not just a practical, but also a *theoretical*, impossibility.

The mathematics, and further development, of Professor Arthur's argument can be found in Working Paper 83-90, available from IIASA.

News from the Institute

Meetings

Traders and scholars explored East-West mineral trade between 1950 and 1980 at an Institute Workshop in preparation for the expected increase in such trade in the coming decades. The discussions brought out both the problems and the benefits so that appropriate policies can be designed in advance of this forecast sectoral change in global trade. A book is being prepared which will feature studies of trade in specific mineral commodities, such as phosphate rock and bauxite, trade patterns and policies of individual countries, and topics such as the role of state trading organizations and barter trade in this area.

Canadian, Finnish, Icelandic, and Soviet experts joined IIASA scholars to discuss climate impacts on agriculture and forestry in high-latitude regions. Preliminary findings from impact assessments on marginal agricultural land, with their related socioeconomic implications, were considered, as were various approaches, possible scenarios, and impact models. These cold-climate studies, plus investigations on semi-arid and high altitude regions, are IIASA's contribution to the UN World Climate Impact Programme.

Scandinavian modelers held the third Nordic meeting on forest sector modeling in Oslo, Norway to present and discuss their work in connection with IIASA's forest sector project. Their national and regional models are input to the global model being developed at the Institute for the analysis of trends in production, consumption, and trade over the next 50 years.

A series of meetings were held at the Institute with scientists from the several disciplines included in the IIASA decision support system for acid rain control strategies. Their expertise, in such fields as meteorology, forestry, limnology, soil chemistry, and atmospheric transformation of sulfur dioxides, will be used in the expansion and refinement of the IIASA system of models.

Pall Bergthorsson of Iceland reporting climate impacts on agriculture in high-latitude regions.

A meeting on the industrial restructuring of interdependent economies, held at Varna, Bulgaria discussed mechanisms to adapt national policies to international influences. The meeting was sponsored by the State Committee for Science and Technology of Bulgaria, IIASA, and the Bulgarian NMO, the National Committee for Applied Systems Analysis and Management.

The Bulgarian NMO and IIASA, with the participation of the United Nations Educational, Scientific and Cultural Organization, also sponsored a task force meeting in Albena, Bulgaria on children and computers, devoted to computer-based education: how it is being used at present and how it might be used in the future.

Another meeting at Varna, Bulgaria was hosted by the ELPROM enterprise, with the Bulgarian NMO and IIASA, to discuss management style and strategy in planning innovation, with emphasis on the electrotechnology industry.

European researchers met with Institute scholars to discuss regional collaboration in the new IIASA international gas study — the goals of which are to determine the technoeconomic feasibility of expanded gas use and the factors affecting the development of an international gas market.

New Titles

Natural Resources and Development in Arid Regions. Enrique Campos-López and Robert J. Anderson, Editors. 362 pp. Conference held in Cocoyoc, Mexico organized by the Applied Chemistry Research Centre of Mexico and the International Institute for Applied Systems Analysis, supported by the Mexican National Council for Science and Technology. Published by Westview Press: Westview Special Series in Natural Resources and Energy Management.

About one-third of the Earth's land surface is desert and semi-arid grassland, while desertification of fertile land is increasing. As almost 40 percent of Mexico is arid or semi-arid, there is particular interest and ongoing experiments in using such lands. A broad systems approach to link science and technology with regional planning and socioeconomic development is described in the analysis of general problems plus specific Mexican experiences.

Rubber-producing guayule, vegetable oil-producing jojoba, and fuel-producing *Euphorbia lathyris* are examples of multi-use botanochemical plant crops with minimal water and energy needs, whose production can be developed as income-producing natural resource assets which will not further degrade the soil. Solar energy installations for electricity and biogas generation, heating, drying, and refrigeration are also discussed.

The policy analysis undertaken for different scenarios of guayule production in Mexico is reported: a Technology Assessment using several techniques, methods, and models to examine economic, social, political, institutional, and organizational options and consequences.

Forest Sector Models. Risto Seppälä, Clark Row, and Anne Morgan, Editors. Proceedings of the First North American Conference. 365 pp. Published by AB Academic.

There is a major shift underway in the global pattern of the supply of wood raw materials, while technological advances are also changing consumption habits. Current efforts in several countries in modeling forest sectors and their interactions with national and international economies are presented and discussed.

Analysts and researchers from industry, government agencies, and the academic community report on various systems concept approaches used in operational models or potentially useful for certain problems and situations. Emphasis is on developing long-term supply response estimation capabilities and modeling international trade flows. One section of the book is devoted to the IIASA undertaking to construct a computer-based global model of demand, supply, and trade in forest products by linking national and regional models.

Modeling Growing Economies in Equilibrium and Disequilibrium. Allen C. Kelley, Warren C. Sanderson and Jeffrey G. Williamson, Editors. Duke Press Policy Studies, in cooperation with the International Institute for Applied Systems Analysis. 375 pp. Published by Duke University Press, Durham, North Carolina, USA.

This book describes recent work that amplifies the use of general equilibrium models in analyzing resource allocation among the various sectors of national economies. Advantage is taken of the fact that there are several socioeconomic mechanisms for reconciling supply and demand imbalances, such as market solutions, government regulations, and centralized planning bodies.

Discussions are focused on modeling economic development in market economies, developing countries, and centrally, planned economies. One section concentrates on the incorporation of demographic considerations, including work on forecasting the population and labor supply in Australia and a new approach to the two-sex marriage problem.

Among other models described are those dealing with Third World urbanization and city growth, estimates of disequilibria in Poland, a reinterpretation of economic growth experiences in Japan this century, and medium-term, multisectoral economic growth in a small open economy.

Research Reports

RR-84-1 Metropolitan Growth and Population Development at the National Level. P. Korcelli and P. Just. Reprinted from *Regional Development Dialogue* 4(1), 1983: United Nations Centre for Regional Development.

RR-84-2 Multiregional Demography: Four Essays. A. Rogers, Editor. Reprinted from *Environment and Planning A*, volume 15 (1983).

RR-84-3 What the Age Composition of Migrants Can Tell Us. L. Castro and A. Rogers. Reprinted from *Population Bulletin of the United Nations*, No. 15 (1983).

RR-84-4 Analytical Evaluation of Hierarchical Planning Systems. M.A.H. Dempster, M.L. Fisher, L. Jansen, B.J. Lageweg, J.K. Lenstra, and A.H.G. Rinnooy Kan. Reprinted from *Operations Research*, volume 29, number 4 (1981).

RR-84-5 Analysis of Heuristics for Stochastic Programming: Results for Hierarchical Scheduling Problems. M.A.H. Dempster, M.L. Fisher, L. Jansen, B.J. Lageweg, J.K. Lenstra, and A.H.G. Rinnooy Kan. Reprinted from *Mathematics of Operations Research*, volume 8, number 4 (1983).

RR-84-6 A Stochastic Approach to Hierarchical Planning and Scheduling. M.A.H. Dempster. Reprinted from *Deterministic and Stochastic Scheduling*, NATO Advanced Study Institute Proceedings Series, M.A.H. Dempster and J.K. Lenstra, Editors. Reidel: 1982.

RR-84-7 Information Systems for Regional Development Planning: A State-of-the-Art Survey. P. Nijkamp. Reprinted from *Environment and Planning B*, volume 10 (1983).

RR-84-8 Nonfuel Minerals – The Fear of Shortages and the Search for Policies. J.E. Tilton and H.H. Landsberg. Reprinted from *U.S. Interests and Global Natural Resources: Energy, Minerals, Food*. E.N. Castle and K.A. Price, Editors. Resources for the Future: 1983.

All IIASA publications can be ordered from the Publications Department, IIASA.

Guest's Corner

Food, Agriculture, and Systems Analysis

For some time now, there has been widespread recognition of the need for scientists from a wide range of specializations to work together. This is especially so if the aim is to work in a relevant manner on policies of sustainable and equitable development. Institutions have been established, nationally and through international cooperative efforts, to promote interdisciplinary research focusing on issues rather than on disciplines and using systems analysis in order to incorporate disciplinary knowledge appropriately. I would like to reflect on some of these, in the field of food and agriculture. This is an area of IIASA's activities which I know somewhat better than other work and it has been active long enough to discern some of the more generic problems of systems analysis. Identifying the latter may hold some lessons for other endeavors of IIASA in the years ahead, even when only in terms of the modesty which, I think, should characterize the judgments about our own scientific capability for interdisciplinary research.

The issues regarding food and agriculture are wide-ranging and complex. The fact that a significant part of humanity lives permanently on an inadequate diet raises questions concerning both national and international policies. Analysis may lead to structural improvements; policies must address the instability of world and national markets, the technological choices for agricultural development, and the environmental implications of both continued poverty and hunger and alternative agricultural development patterns.

How the strands of the issues come together can be visualized by looking, for example, at the Thai farmer who grows cassava. Ten years ago this farmer belonged to the lowest-income group of farm families in Thailand, working on an area of land that could hardly meet subsistence needs. His position has improved after a market for cassava meal (tapioca) opened up in Western Europe, where it is a highly competitive substitute for feedgrains. Feedgrains are relatively expensive because of European Community internal price policies for grains. The high levies on imported grains do not, however, apply to cassava. Growing exports of cassava has improved the income position of a significant group of poor farm families, it has boosted Thailand's export earnings, and it has kept meat and pork prices to consumers in the EC countries lower by not feeding the animals domestic or other imported grains. However, it has also reduced EC grain imports originating largely in North America and, in recent years, has contributed to a European surplus of grains which competes with North American grains in third markets and reduces world market prices. In order to maintain the incomes of American and European farmers, lower prices entail higher subsidies and cause fiscal and financial problems. At the same time, it is known that the continuous growing of cassava in poor soils in Thailand heavily reduces soil fertility if the nutrients are not replaced.

What are the solutions? Clearly, every country concerned has its own prescription, usually serving its own immediate interests. Taking the issues beyond the level of national interests, one may ask what the alternatives are if sustainability and equity are the professed objectives. This is where systems analysis is needed, providing a longer term perspective and assessing both the costs and the benefits to all concerned in alternative scenarios. However, looking at the tools now available for that kind of analysis, we are still far from the needed capability. This by no means wants to belittle what has up to now been achieved by IIASA's program and by all those who work with it in an extensive collaborative network. But it should be recognized for what it is, in comparison to the systems analysis tools required to answer some of the issues raised.

The FAP modeling system now nearing completion primarily follows the economist's approach to agricultural and food policy. Could it have been more than that? Could it have integrated the physical resources available for agriculture and the potential for their upgrading, as well as the technological choices for agricultural development within one analytic framework, together with the behavioral modeling of farmers, consumers, and governments? The answer, at least looking at the time and the resources that were available within the network, appears to be negative. This judgment stems not just from looking at the efforts at IIASA, but even more at those of the Centre for World Food Studies in the Netherlands. The Centre, from 1977 onwards, strived much more explicitly for an integrative approach which was to include the resources, the technologies, the behavior of actors, and the environmental feedbacks from alternative patterns of agricultural development.

The Centre's efforts have not as yet produced a system which permits the integrated analysis aimed for. Again, one should not belittle what has been achieved, but the stumbling blocks have been larger than was – or could have been? – expected. Some of these are of a kind that are very hard to deal with, as they are rooted in the character of the work customarily done in particular fields of science, which complicates interlinkage of analytical tools. Such differences between scientific approaches can become major barriers when attempting to develop one modeling system integrating different fields of science. Reluctance to change one's own approach to accommodate interdisciplinary linkage frequently is defended on grounds of the desire to preserve respectability amongst colleagues in one's own discipline.

Given that kind of experience, IIASA may have been right not to venture out into systems analysis of food and agriculture much further than in fact it did, in the absence of ready tools to be applied. There is still the question, however, to what extent IIASA could be supportive of work on tools and methods going on elsewhere, or whether IIASA's own experience over a broad range of disciplines could be molded into more integration across disciplinary barriers. For systems analysis to be what it purports to be, these issues require attention not only for IIASA's own programs of work, but also in its activities to select its collaborative partners and to evaluate the potentials of their work programs.

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