Development of Large Irrigated Areas

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Abstract: This paper is a synthesis of studies in various irrigated areas in Spain. Agricultural development in large areas where major irrigation projects are carried out by the government is a complex problem. The change from dryland to wetland crops needs irrigation water, but many other factors are necessary for farmers to take advantage of all the possibilities irrigation can provide. The use of a new factor, according to the principle of the "package of practices," requires that simultaneously other factors be changed. One of the most important factors that determine the rate of adoption of irrigation is the increase in returns; the greater that increase, the greater the stimulus for change from dryland to wetland crops. Availability of credit to acquire the means of production needed for the intensification of crop farming is essential if farmers do not waste such funds. Another factor is the existence of marketing organizations, especially for marketing agricultural products. And the agrarian structure of the zone has an influence on the process of irrigation adoption, especially the size of farms. Farmers' level of education, professional training, initiative, and dynamism, and the uncertainty involved in the change to wetland farming, whose technical and economic aspects are not familiar to farmers, have a great influence on irrigation adoption. The importance of these factors is manifest in the high rate of irrigation adoption in areas where some irrigated parcels existed prior to the irrigation project

Introduction

The introduction of irrigation in large areas, where major irrigation projects have to be carried out by governments, faces many problems as a consequence of the radical change in the pattern of farming produced by the adoption of wet farming. Some large irrigation projects have been resounding failures because farmers were reluctant to substitute wet-farmed for dry-farmed crops, even though doing so would have been economically rational behaviour. But the attitude of farmers towards irrigation is also influenced by many noneconomic factors.

In most large areas brought under irrigation, the irrigated area increases slowly. The full use of the investment takes place only after a long period of years, and the insufficient use of water in the meantime impedes the achievement of a satisfactory economic return on the investment. Irrigation development requires not only irrigation water but a whole series of essential factors of production, and to which farmers must have easy access.

The introduction of irrigation implies that all the elements that make up the economic reality of a given area and their mutual relationships are bound to be modified, giving the area a new economic structure. This profound transformation of agriculture produces radical changes in the way of life of the agricultural population in the area.

The provision of water to farmers, a critical factor for agricultural development in an area, is only one of the elements in the package of practices necessary to ensure a rapid area development.

The conversion to wet farming includes construction of irrigation works—channels, ditches and drains, roads—and levelling of plots. To achieve conversion, additional means must be available to farmers—technical services, credit, and marketing facilities for inputs and outputs—as well as profitable and dependable prices for those products. Apart from the provision of these factors and above all else, farmers' motivations and attitudes determine the use of water and all these factors. Farmers' behaviour can be influenced. Farmers can be encouraged to adopt irrigation by reducing uncertainty and creating and increasing incentives and motivations for such adoption.

Research on the development of irrigation is of great interest in countries like Spain because in some irrigable areas substantial possibilities exist for making better use of the productive potential and of speeding the adoption of irrigation by farmers in the areas to be brought under irrigation. The importance of this subject, as far as Spain is concerned, is shown by the fact that half of the crop production comes from irrigated zones, and the area with no existing works, but potentially irrigable, is approximately half the size of the area presently under irrigation.

With the object of determining the influence of the different factors affecting irrigation development when water is made available to farmers, several studies have been carried out on the progression over time of irrigation in zones with different characteristics. We have analyzed the process of irrigation adoption in eight zones in different regions of Spain (where the rate of adoption has been variable) as a function of the diverse factors affecting the process. The changeover was extraordinarily rapid in one of these zones (El Páramo) in the province of León, and very slow in another (Tierra de Campos). Both are in the same region, the Duero Valley, very close together but their characteristics affected the adoption of irrigation extremely differently.

The data from these observations have permitted us to establish that the evolution of irrigation in a zone follows the path of an S-shaped curve. The data also permitted us to formulate various hypotheses about the factors that influence irrigation development.

An Explanatory Model of Irrigation Adoption

In a zone provided with water by building an irrigation network, the irrigation process is the result of the behaviour of the different economic agents involved, especially farmers. Farmers' behaviour can be determined by means of a model based on the optimization of an objective function (Boussard and Petit, 1966). Our approach consists in establishing a set of hypotheses about relations in the real world and the confrontation of these hypotheses with data collected in different zones.

In a zone with an irrigation network (where the different parcels can be irrigated), we can take as an index of irrigation development the progression over time of the annual crop value relative to the potential crop value reached in the area when irrigation and yields have attained normal levels, considering a period of adaptation as does Bergmann (1973). More simply, we can take the progression of irrigation measured by the proportion of the area irrigated each year. This is the index we use here.

We assume that the proportion of the area irrigated in a given year is a function of the years, t, elapsed since the irrigation network was completed, and of the values corresponding in that year to a set of variables, $x, y, z, ...$, that measure the factors influencing the behaviour of farmers towards the use of water. We formulate this relationship by the following expression:

$$P = f(t, x, y, z, ...) .$$

But we assume that the evolution of the values of that set of variables over the years is a function of their values in a given year. Then, for a particular zone, the values of $x, y, z, ...$, will be those of the variables in the first year. We can now formulate the following expression:

$$P = F(t) .$$

Since (in the zones we have studied) the values of P over the years are acceptably adapted to an S-shaped curve, we assume that the evaluation of P is related to t according to a logistic function. This relationship is normal in the development of the adoption of innovations, and the change from dry farming to wet farming is an innovation. The rate of growth of P will thus be related to the area irrigated, P, and the area that is not yet irrigated, $(1\text{-}P)$, as follows:

$$(1) \qquad dP/dt = bP(1-P) ,$$

b being the factor of proportionality and varying from 0 to 1.

This expression represents the aggregate behaviour of all farmers. We suppose a stimulus and a brake exist to an increase in wet-farmed-crop area, given respectively by P and $(1\text{-}P)$.

By integrating *(1)* we obtain the following logistic function:

$$(2) \qquad P = 1/[1+e^{-(a+bt)}] ,$$

in which the value of a, the constant of integration, corresponds to the value of P when $t = 0$.

Representing the function with P in vertical and t in horizontal coordinates, the parameter a determines the position of the curve relative to the time scale origin so that a variation in a shifts the curve in a horizontal direction. The rate of adoption of irrigation, given by the slope of the curve, is a function of b as expressed by *(1)*, with the shape of the curve depending on that parameter. Then the curve is defined by b and its position by a. The function is symmetric with respect to the inflection point and asymptotic to the abscissa axis and to the $P = 1$ straight line for $t = -\infty$ and $t = \infty$, respectively.

For an irrigable zone, we have, through a series of years $(1, 2, 3, ..., n)$, the proportion of irrigated area in each year: $(P_1, P_2, P_3, ..., P_n)$. To adjust the logistic function to those data, we transform the function *(2)* into a linear function. By least squares, we estimate directly the parameters a and b in the transformed linear function:

$$log_e[P/(1-P)] = a + bt \, .$$

In adjusting the logistic function for a particular zone, the years in which irrigation development does not take place in a normal way should not be considered (i.e., the early years when farmers are not yet familiar with the possibilities of irrigation or its results and techniques). When farmers do not have this information, they are not able to behave in a normal way. By the same token, irregularity occurs at the end of the process because some parcels are poorly adapted to wet crops, and some farmers do not accept irrigation.

Because of differences in acceptance of irrigation between different zones, we will have in each zone a different logistic function. Those tendency functions are differentiated in the *b* parameter, which is a function of the factors on which the process of irrigation adoption depends.

We now consider a set of zones brought under irrigation. For each zone, by adjusting the logistic function, we determine the *b* parameter. At the same time, we measure in each zone the values of the variables ($\alpha_1, \alpha_2, \alpha_3, ..., \alpha_n$) corresponding to the factors that, in that zone, influence the behaviour of farmers. For zone *i* we have the value of *b*, and the values of the α's ($b_i, \alpha_{i1}, \alpha_{i2}, \alpha_{i3} ..., \alpha_{in}$). Since in each zone the *b* parameter is a function of the α's, we can (by an adjustment of the cross-section type) estimate the relationship between *b* and the set of variables considered, obtaining the degree to which each variable affects irrigation development.

For a given zone destined for irrigation, we use this estimated relationship to calculate the value of *b* as a function of the values of the set of variables in the zone. The value of *b* allows us to foresee its future development and to plan the measures for encouraging and motivating farmers to introduce irrigation, intensify the production system, and adopt the most advantageous cropping patterns.

In El Páramo, the irrigation progress was extraordinarily rapid. Before the irrigation network was set up, a sizeable number of parcels were under irrigation. Farmers knew wet-farm labour was abundant because the irrigation project was carried out in the 1960s before the rural exodus. The farms were small so that the irrigation permitted their conversion into economic units. The increase in returns by substituting wet farming for dry farming crops was important.

Before the irrigation project in Tierra de Campos, wet farming was practically nonexistent. The area had experienced an important rural exodus and had limited labour. Farms were for the most part large enough for farmers to live on farming income without intensification of farming through irrigation. The increase in returns by irrigation was, therefore, less.

Irrigation Development Hypotheses

The achievement of agricultural development in an irrigable area requires the availability not only of irrigation water but also of many other factors, including the willingness of farmers. The progress of irrigation will depend on all these elements, a dependence that we formulate in the following hypotheses that have been deduced from our experience and from the observations we have carried out.

- *The increase in yield that can be obtained with the adoption of irrigation is one of the most important economic aspects.* Irrigation represents an important change involving risk. The more economically interesting the change is, the more farmers will be willing to take the risk. The greater the increase in returns by substituting wet-farmed for dry-farmed crops, the greater will be the stimulus for irrigation and the faster the rate of progression of that innovation.
- *Availability of funds necessary for transforming a farm into wet crops is essential.* Farmers may use their own funds if their farm incomes are relatively high, but the greater part of funds must come from external sources. The existence of external sources, the ease with which credit can be obtained by farmers, and farmers' willingness to make use of credit are elements that measure the influence of this aspect of irrigation adoption.
- *When the size of farms is smaller than that corresponding to the family farm, the intensification of farming through irrigation is a means of improving the agrarian structure.* In this situation, farmers will take advantage of irrigation to increase the economic size of their farms so that they are able to live on their farming incomes. This and other structural aspects (such as the fragmentation of holdings) are taken into consideration in large irrigation projects in Spain (Garrido, 1970). We must also consider the labour required for the intensification of farming. An abundance of labour favours irrigation development and is one of the reasons why farms of family or smaller sizes adopt irrigation

more rapidly. The shortage of labour in the irrigated area will be an obstacle to irrigation, especially for farms larger than family size.

▪ *Farmers' level of instruction and training in wet agriculture and in farm management has a decisive importance in agricultural development of an area brought under irrigation.* Research, education, and extension will contribute to irrigation development. To encourage the adoption of irrigation by improving farmers' training, programmes such as agricultural experimentation, extension of irrigation techniques, and setting up of pilot farms should be implemented. The existence of irrigated areas in a zone before a large irrigated project is undertaken has proved to have a positive impact on the adoption of irrigation in the areas in Spain studied by Cavero (1976). Wet farming developed in the area before the project is proof of farmers' interest in irrigation; this, and the know-how thus acquired by farmers, are two elements that speed irrigation development.

▪ *A marketing structure to furnish the inputs for the new agriculture and to purchase (in a reliable and satisfactory manner) the outputs is an essential factor.* Farmers produce an agricultural commodity when they think it possible to sell it at a reasonable price. Normally, dry crops have a more stable market than wet crops, and, for that reason, the measures to stabilize prices at a profitable level and to secure the purchase from farmers of the production yielded by the irrigated area will favour irrigation.

▪ *Dynamism, initiative, values, and attitudes towards economic progress are important elements in irrigation adoption.* The changes that affect farmers' way of life are decided by farmers themselves. Their views and opinions must be taken into account to reduce the incidence of failures. When the living standards are low, the stimulus for irrigation adoption will be greater. An index of all these aspects can be made up considering diverse elements, one of the most important being the age level of farmers. Young farmers are more willing to assimilate new techniques, are more innovative, and have more desire to improve their income levels.

▪ *Resistance to change from dry farming to wet farming is due in great measure to the uncertainty involved in carrying out a different farming activity.* Various elements of uncertainty accompany wet farming in an area in which farmers grow dry crops. Technical uncertainty about the yields of the new crops and their growing techniques and economic uncertainty often derive from poor knowledge of the data used in forecasting costs of and returns from crop farming. The attitude of farmers towards risk for a given level of uncertainty will influence the adoption of irrigation. The change is not as simple an innovation as the use of a new crop variety (e.g., a new hybrid maize). A study of irrigation in large areas in Italy (Istituto Nazionale di Economia Agraria, 1983) found that the relationship between irrigated and irrigable area is 0.68, and that slowness in irrigation adoption is because irrigation causes notable cultural transformation with substantial change in the production process in farms.

The rate of adoption of irrigation by farmers in a large area in which works have been undertaken by the government can be explained by the above factors. The measurement of these factors and the extent to which they can be affected by government actions for speeding irrigation adoption is not easy. Among the factors are economic and technical elements that can be quantified, but other elements are of a social type, and their measurement is more difficult.

Note

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References

Bergmann, H., *Guide for the Economic Evaluation of Irrigation Projects*, OECD, Paris, 1973.

Boussard, J.M. and Petit, M., *Problèmes de l'Accession a l'Irrigation: Étude Économetrique d'une Petite Region*, Institut National de la Recherche Agronomique, Paris, 1966.

Cavero Cano, J., *Análisis de los Factores que Determinan el Desarrollo Económico del Regadío de Tipo Extensivo en España*, Ph.D. thesis, Escuela Técnica Superior de Ingenieros Agrónomos de Valencia, 1976.

Garrido Egido, L., *Ordenación de Áreas Agrícolas y Reorganización de la Propiedad: Transformación en Regadío de Zonas Parceladas*, Serie Monográfica IRYDA, No. 20, Ministerio de Agricultura, Madrid, 1970.

Istituto Nazionale di Economia Agraria, *Indagine sulla Irrigazione*, Societá Editrice il Mulino, 1983.

Discussion Opening—*Som P. Pudasaini*

Whilst Mwangi correctly lists the efforts to increase yields and cropping intensity, better distribute larger holdings, develop irrigation and drainage facilities, and improve arid and semiarid agriculture as important and complementary measures to solve the stated problems, I have strong reservations with his final conclusion that those efforts help "...little in solving problems of land scarcity, employment, and food production...." Overemphasizing the role of population control undermines the importance of agricultural innovations and other factors in solving Kenya's problems. Land-augmenting and labour-intensive technological packages (such as HYV seeds, fertilizers, irrigation, and drainage) and crop intensification would make significant contributions to solving the problems of land scarcity, employment, and low productivity, particularly in countries with low yields and low cropping intensity. Similarly, the introduction of appropriate agricultural enterprises and development of a dry-farming system would help generate increased output and jobs from semiarid and even arid regions. If one argues that these innovations cannot be implemented due to higher costs, limited labour, and weak organizational capacity, no guarantee exists that the same problems would not affect the implementation of population programmes.

Mwangi's paper also does not adequately deal with issues such as environmental problems (deforestation, soil erosion, and desertification) and their impacts on agriculture, the institutional changes necessary to induce small family norms among masses, or the need for expanding small and agro-based industries to create more jobs. Consequently, a more balanced strategy emphasizing population control, agricultural development, and expansion of cottage and agro-based industries, along with due emphasis on the development of the nonfarm sector, may be crucial to solving the problems of Kenyan agriculture.

Whilst the declining self-sufficiency ratios for wheat, rice, and coarse grains in African countries between 1966-68 and 1978-80 may support Shah *et al.*'s contention that the cause is sluggish domestic production rather than the push by exporters through attractive aid offers or the availability in the world market, why production of and area under wheat has not expanded faster than other grains if the producer price for wheat was more favourable than for other grains is not clear. The question becomes even more unclear when the paper shows that more potential wheat area exists in Africa and, importantly, that wheat is superior to coarse grains as a food commodity. Looking at the provision of inputs and technical services to farmers to grow wheat and at the risks and uncertainties in growing a relatively new crop (wheat) to get a better picture of why expansion in wheat cultivation has not been as fast as that for other grains may be as important as looking at the producer price differences between wheat and coarse grains.

The authors have worked out the maximum rainfed wheat potential based on both agroclimatic suitability and economic viability, but why estimates of wheat production potential under irrigated and irrigable conditions are not presented is not clear. Since wheat cultivation is more profitable and its adoption velocity faster under irrigated conditions, such estimates would offer a better picture of the total wheat production potential for Africa.

The magnitude of future imports of wheat by African countries depends on the wheat and other crop production situation in the respective countries. Consequently, explicitly considering the future domestic food production possibilities and wheat import links together is important. I feel that the paper does not adequately look at the future wheat and other crop production possibilities in Africa resulting from potential technological innovations.

In Garrido's paper, the development of proper drainage facilities, adequate and timely supply of water, and demand for new crops grown under irrigated conditions should be added to his list of factors affecting adoption of irrigation. Whilst Garrido states that the evolution of irrigation follows the path of an *S*-shaped curve, the specific factors that affected irrigation development and the magnitude and direction of their effects were not indicated. Similarly, whilst the paper presents a detailed discussion on how a log-linearized logistic type model can be used to explain the adoption of irrigation and to determine the influence of various factors, it neither empirically estimates the model nor suggests how to identify and measure various factors to be included in the model as independent variables. Consequently, the paper fails to provide any clear view of the process of adoption and irrigation or of the influence of various factors affecting it. Nevertheless, the treatment of the model in the paper offers a preliminary basis for developing a better theoretical framework. At the end of the paper, a number of interesting hypotheses are also presented. However, none are actually tested in the paper nor are any suggestions made on how to go about testing them.

The paper would be quite useful if the author could include some more specific information on what the previous studies suggest about the validity of the model, factors affecting irrigation adoption, and validity of the stated hypotheses. Also, some discussion of the problems encountered in the past in persuading farmers to adopt irrigation, costs and benefits of irrigation to farmers, input and output prices, and marketing arrangements made could also be added. Possibly, the empirical estimation of the model and tests of the hypotheses could be included.

Discussion Opening—*Alaa El-Menoufy*

Three excellent papers have been presented in this session. The authors have been remarkably successful in drawing attention to the main obstacles facing progress of agricultural production in Kenya, realizing wheat self-sufficiency in Africa, and the development of irrigated areas in Spain.

The papers by Mwangi and Shah *et al.* are designed to revive a discussion about the treatment of agricultural problems generally; e.g., at the continental level or at the regional level. This may lead to conclusions unsuitable for direct application. The nature of agriculture in Africa is extremely varied in the different areas of even a single country. The main question is: Are we capable of mastering, at the same time, all the environmental, social, institutional, technological, economic, and commercial factors that are involved in determining the best ways of increasing agricultural production or realizing wheat self-sufficiency at the continental level or even at the national level? Although Shah *et al.*'s paper concluded that self-sufficiency in wheat is feasible for Kenya to attain, we find that Mwangi's paper had recorded that, since 1980, growth in Kenyan agricultural production for all commodities, except sugar, has failed to keep pace with growth in demand, resulting in huge imports of food.

The paper by Mwangi stressed the very high population growth rate as the single most critical issue in Kenya's development. But how did India realize self-sufficiency in food crops? Also, the author described the possibilities of increasing yield and land reclamation in Kenya, which, from my point of view, are the only way to increase food production in all African countries. Furthermore, the suggested strategy of opening up new lands through clearing of forest may merit further discussion.

In Shah *et al.*'s paper, an attempt is made to determine the wheat production potential in African countries by presenting the comparative advantage of wheat production under an income strategy and a food strategy. Not enough attention was given to the competition between food crops (for domestic consumption) and export crops. Agricultural activities in African countries, although not all at the same stage of development, have been oriented towards exports. According to the principles of comparative advantage, emphasis may be given not only to food security or increasing farmers' incomes, but also to the necessary increase in export earnings. Furthermore, the economic analysis used to estimate wheat consumption in this study apparently neglected the possibilities of significantly altering the consumption pattern as a result of migration from rural to urban areas in the African countries. In Egypt, a clear, sudden increase in per capita consumption of wheat and wheat flour was observed. In this relatively short time interval (until the year 2000), more productive resources will be allocated for the production of export crops, and the wheat problem in Africa may be solved through increasing wheat imports.

Garrido's paper deals with the effects of social and economic factors on development of large irrigated areas in Spain. The importance of these factors is clearly observed not only in developing irrigated areas but also in the dissemination of new technology to different types of farms. The human obstacles are the more serious difficulties that face the adoption of new production patterns or use of new technology. Establishing an advanced agricultural system amongst farmers who are resistant to technical change is not an easy task because change requires technical knowledge and a will to modernize. In this case, support of the government is certainly required; but how can we overcome the antipathy of farmers to government intervention (as every kind of economic intervention is political in character)? The economic incentives are not enough to encourage farmers' participation in the development programmes. The adequate programmes must, in principle, attempt to satisfy farmers' desires. Finally, seeing the data and results of the empirical estimation of the logistic function used for different zones would be useful.

General Discussion—*Julio Hernández*, Rapporteur

Land reform, population growth rate, and social services were not mentioned in Mwangi's paper. Mwangi should have taken marketing problems into consideration instead of focussing exclusively on production. The industry-agriculture relationship is important, as well as land productivity.

Regarding Shah *et al.*'s paper, cereal demand will increase due to increased income and increase in livestock demand. Dependence on wheat is an urban problem. The distribution process should be taken into account. Analysis of shocks to wheat supply and demand is needed.

Regarding Garrido's paper, the shortage of labour will handicap the development of irrigation, but evolution of the farm firm towards a more commercial operation will generate a surplus of labour in rural areas.

Participants in the discussion included S. Belete, I. Minde, B. Roux, and J.S. Sarma.