Technological and Institutional Alternatives in Asian Rice Irrigation

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Irrigation plays a central role in increasing land productivity in Asian rice agriculture, but the pace and character of irrigation development in the region have varied greatly. This essay reviews five sets of determinants of these variations: population pressure, geography, agrarian structure, cultural factors, and the role of the state.

Rice irrigation in Asia often requires action above the level of the individual farm, and societies vary considerably in the success with which they have resolved the attendant problems of co-operation and conflict. A comparative analysis underscores the limitations of technocratic solutions to these problems, and points to the potential merits of strategies based upon democratisation of control over water resources.

I
Introduction

ASIAN rice cultivation supports the highest agricultural population densities in the world. One reason for the strong positive correlation between population density and rice cultivation is that, compared with other cereals, rice is more capable of sustaining constant land productivity without the use of manures or fertilisers. As Masefield observes, "There are rice fields in Asia which have probably been continuously under the crop for centuries without any conscious input of plant nutrients by the cultivators, but which can still be relied upon, provided that water is available, to produce a steady half tonne of paddy per acre."[1] As the extensive margin of cultivation is reached, however, increasing demographic pressure generates a need for rising land productivity if per capita output is to be sustained. Given diminishing marginal labour productivity, this requires the use of additional inputs, or technological change, or both.

Irrigation plays a key role in increases in land productivity in Asian rice agriculture. It is highly complementary with other inputs, including fertiliser and fertiliser-responsive rice varieties; and with its distinctive requirements for prior investment, both in fixed capital and in the creation of institutional arrangements for water use by a number of cultivators, it acts as what Ishikawa (1967) terms the 'leading input', or limiting factor in the intensification of rice production. The development of Asian rice irrigation has been very uneven, with much higher levels of irrigation in some countries and regions than in others, and this has had far-reaching implications for human well-being. The character of irrigation development also varies in a number of important technological and institutional dimensions, including water source and power source; the capital-labour ratio in construction, maintenance, and operation; scale; the institutional arrangements governing water allocation; and the degree of farmer control.

This essay examines the variations in the pace and direction of irrigation development in Asian rice agriculture, and explores the reasons for these variations. The geographical scope is the Indian subcontinent, southeast Asia, and east Asia. Together, the countries under consideration account for 58 per cent of the world's irrigated acreage.[2] They are also the home of of 71 per cent of the world's rural population, and of 84 per cent of those living in what Ahluwalia, Carter, and Chenery (1979) define as 'absolute poverty'.[3] The aim is not to provide a comprehensive account of rice irrigation in this vast terrain, but rather to address a number of crucial theoretcal and practical issues within a comparative framework.[4] Section 2 briefly summarises evidence of irrigation's critical role in the growth of rice production in Asia. Section 3 documents the uneven pace of irrigation development in the region. Section 4 summarises some differences among alternative irrigation strategies, including socioeconomic features as well as the usual engineering and hydrological characteristics. Finally, Section 5 investigates the forces which determine the pace and direction of irrigation development. Five sets of determinants are considered in turn: (1) population pressure, (2) geography, (3) agrarian structure, (4) cultural factors, and (5) the role of the state. The conclusions are summarised in Section 6.

II
Water Control as Leading Input in Asian Rice Agriculture

In his 1967 book *Economic Development in Asian Perspective*, Shigeru Ishikawa argued that irrigation acts as the leading input, or limiting factor in the growth of land productivity, in much of Asian rice agriculture. He distinguished four successive stages of rice cultivation. In the first stage, land productivity is low and subject to sharp fluctuations owing to variable rainfall. In the second stage harvest fluctuations are stabilised by the development of supplementary irrigation. In the third stage, irrigation improvements make possible the introduction of a second crop; land productivity now rises through an increase in cropping intensity. In the final stage, a complementary set of inputs—irrigation, fertiliser, and highly fertiliser-responsive varieties—enable cultivators to achieve much higher yields per acre. Irrigation development plays the key role in the transitions between these stages; only when the final stage is reached does irrigation surrender its leading role to a 'combined leading input' of fertiliser, seeds, and improved techniques.

Ishikawa's schematic account must be adapted to fit the specific environmental and historical circumstances of individual Asian countries. In reviewing Japan's agricultural history, for example, Ishikawa concludes that irrigation's first role, that of compensating for deficient rainfall, was accomplished during the Tokugawa period (1603-1867), so that by the time of the Meiji Restoration, Japan had attained average yields of 18 quintals of clean rice per hectare—a mark yet to be achieved in much of south and southeast Asia.[5] Subsequent improvements in drainage and water control made possible the introduction of high-yielding rice varieties and improved cultivation techniques. In the years leading up to the Second World War, water control improvements and varietal breeding alternately posed bottlenecks to further yield increases. In the post-war period, Japan reached the final stage in which fertiliser, seeds, and improved techniques play the leading role.

In Japan, irrigation did not play the role of allowing the introduction of an extra crop, since the country's climate permits rice cultivation only in the summer months. In much of south and southeast Asia, by contrast, rice can be grown throughout the year.[6] For example, in Bangladesh and West Bengal three successive crops are distinguished by the cultivators and reported in government statistics. In such places multiple cropping is potentially of great importance. In addition, chemical fertilisers and fertiliser-responsive varieties are more readily available in south and southeast Asia today than they were in the early stages of Japan's agricultural growth, and hence follow more quickly upon water control improvements.

Data from Bangladesh and West Bengal strongly support the proposition that irrigation, or more broadly, water control, is the leading input in the region's agriculture. An inter-district analysis reveals strong complementarity among water control, fertiliser use, and the spread of high-yielding rice varieties (HYV's). This complementarity—which is to be expected on agronomic grounds[7]—implies that each input has its full effect on output only in the presence of the other inputs. Water control differs from fertiliser and seeds, however, in two crucial respects: first, it usually requires fixed investment prior to the current production period, and second, it often cannot be secured by individuals acting on ther own, but rather requires joint action by cultivators who till adjacent plots. These distinctive attributes of prior investment and indivisibility make water control the limiting technological factor in the adoption of the complementary inputs. An analysis of the relationship between water control and agricultural performance reveals that districts with more irrigation and (in the case of Bangladesh) less deep flooding experienced more rapid agricultural growth and had higher yields per unit gross cropped area. Statistical analysis indicates that water control variables explain approximately 80 per cent of the inter-district variation in average yields.[8]

The varietal breeding strategies pursued by international and national agricultural research centres have reinforced the positive correlation between irrigation and agricultural performance, by emphasising technologies suited to irrigated environments. To some extent, a reorientation of research towards rainfed conditions (for example, by breeding drought resistant and quickly maturing rice varieties) could weaken this correlation, and as Levine (1980) observes, there may be sound equity and efficiency reasons for doing so. Nevertheless, irrigation's leading role in Asian rice agriculture is likely to persist for the foreseeable future.

III

Uneven Development of Irrigation in Asia

The uneven development of irrigation in Asian rice agriculture is apparent from the data in Table 1. Relatively high levels of irrigation are found in the east Asian countries and in Sri Lanka and Pakistan; relatively low levels are found in Bangladesh, Thailand, the Philippines, Laos, Burma, Nepal, and Kampuchea. These data are imperfect, however, for several reasons. First, there is the practical matter of data quality. The FAO estimates are based primarily upon the official statistics of the various countries, the reliability of which is variable. Official estimates of irrigated acreage in Bangladesh, for example, appear to be biased upwards, reflecting optimistic assessments of irrigation capacity utilisation.[9] Such official optimism is by no means confined to Bangladesh, but its impact upon irrigation data may vary from country to country. Second, there is the definitional question of whether irrigated area refers to land which receives *any* irrigation, however inadequate, or only to land which receives *sufficient* irrigation. Ideally, one would like to have a breakdown of acreage according to its 'irrigation coefficient', the ratio of the quantity of irrigation water to total water requirement, which could range from zero to one.[10] Even then a problem would remain, since water requirements vary among lands and among crops, the cultivator's choice of which is itself partly determined by water availability. In practice, only the binary irrigated/unirrigated acreage breakdown is available, and the adequacy of water supply on land classified as 'irrigated' may vary considerably. Finally, there is the difference between gross and net irrigation estimates. The data in Table 1 represent the net irrigated area (land irrigated at some time during the year) divided by the net sown area (land cultivated at some time during the year), since these are the only figures reported by the FAO. If, alternatively, gross irrigated area were divided by gross cropped area (both of which count the same land more than once if it is multiple cropped), one would have a measure of the percentage of crops irrigated. The net and gross measures will be equal only if the irrigation intensity—that is, the number of crops irrigated per net irrigated acre per year—equals the cropping intensity. In practice these often differ, and the magnitude and direction of the divergence vary, depending primarily upon whether irrigation sources provide water throughout the year or only seasonally. These qualifications must be borne in mind when examining the data.

Table 1 also reports rice acreage as a percentage of net sown area, to indicate the relative importance of rice cultivation in the different countries, and per hectare rice yields. The importance of rice varies considerably among the countries, ranging from 10 per cent of net sown area in Pakistan to more than 100 per cent (by virtue of multiple cropping) in Bangladesh, but in most cases it is clearly the pre-eminent crop. Rice yields per crop in 1983 ranged from less than 15 quintals per hectare (qu/ha) in Bangladesh, India, Kampuchea, Laos, Nepal, and Thailand, to more than 45 qu/ha in Japan and Korea. There is an evident relationship between yields and irrigation, as readily seen from the scattergram in Figure 1. The correlation coefficient between the two variables is 0.68; when Pakistan, in which rice is a relatively minor crop, is dropped from the set, it rises to 0.80.

Irrigation development is also uneven within countries. In India, for example, the share of net sown area irrigated in 1978-79 ranged from 10 per cent in Kerala and Maharashtra to 78 per cent in the Punjab (see Table 2). Again, there is a clear correlation between irrigation and rice yields, with Punjab and Haryana leading in both respects.[11]

The unevenness of irrigation development between and within Asian rice-producing countries may in part be attributable to differences in ultimate irrigation potentials. Climate, topography, and water availability clearly are more favourable to irrigation in some settings than in others. To judge the relative success of irrigation development in different locations, it would be useful to have some measure of ultimate potential against which actual achievements could be weighed. Unfortunately, such data are not readily available. Estimates of water supplies for

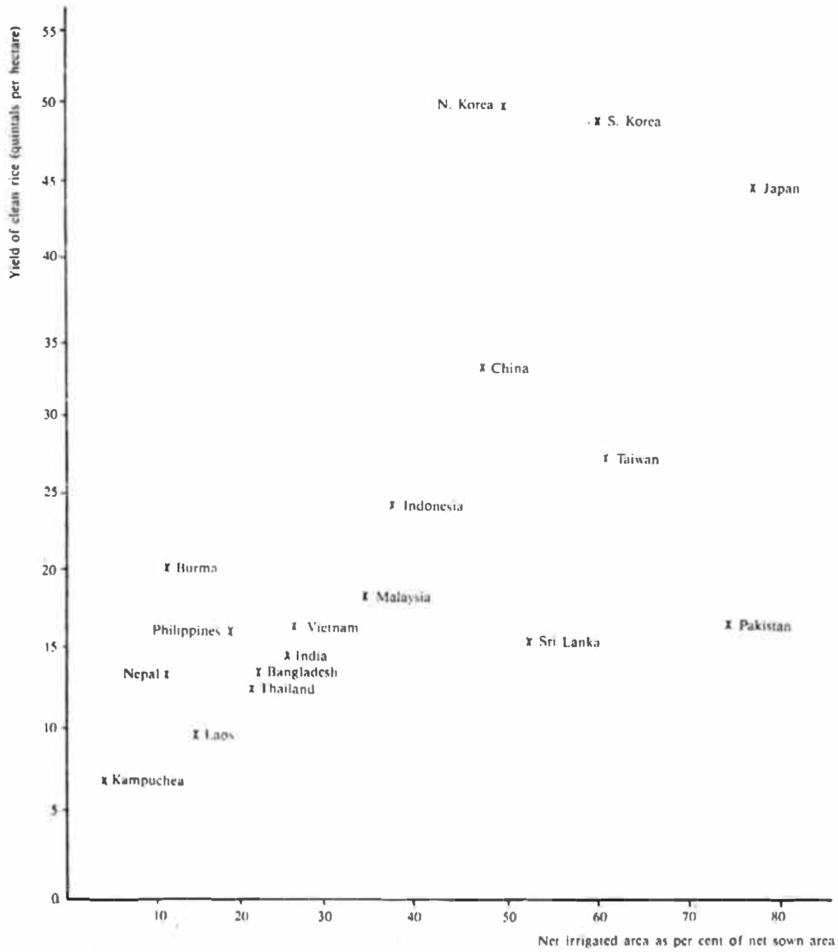
TABLE 1: IRRIGATION AND RICE PRODUCTION IN ASIA, 1983

Country	Net Irrigated Area[1] (Per cent net sown area)	Rice Acreage[2] (Per cent net sown area)	Rice Yields[3] (quintals/hectare)
Bangladesh	20.7	118.9	13.7
Burma	10.5	48.9	20.7
China	46.3	34.9	33.9
India	24.0	24.9	14.7
Indonesia	36.1	60.7	25.3
Japan	76.5	53.6	45.6
Kampuchea	3.1	60.5	6.5
Korea (N)	48.2	37.3	50.7
Korea (S)	58.6	60.4	49.5
Laos	13.6	77.0	10.0
Malaysia	32.7	68.6	19.1
Nepal	9.9	55.7	14.3
Pakistan	73.1	10.0	17.3
Philippines	17.8	42.0	16.5
Sri Lanka	50.6	87.0	15.9
Taiwan	60.0	52.1	27.7
Thailand	20.0	54.0	13.2
Vietnam	24.7	84.3	16.5

Notes: (1) Excluding permanent tree crops.
(2) Percentage may exceed 100 owing to multiple cropping.
(3) Clean rice; converted from paddy yield data by FAO conversion ratios of 0.8 for Japanese brown rice and 0.67 for white rices.

Sources: *FAO Production Yearbook 1983* and *FAO Production Yearbook 1984* (all data except for Taiwan).
Taiwan estimates are from Framji and Mahajan (1969) and Colombo, Johnson and Shishido (1978).

FIGURE 1: SCATTERGRAM OF RICE YIELDS AGAINST PERCENTAGE NET SOWN AREA IRRIGATED, 18 ASIAN COUNTRIES, 1983



Data Source: Table 1.

individual countries remain a matter of controversy among hydrologists. For example, a joint study by the government of Bangladesh, the FAO and the United Nations Development Programme concluded in 1977 that groundwater supplies in that country were "sufficient to support full development of irrigated agriculture for the entire area [excluding the coastal zones and hill areas] to which surface water supplies are not readily available".[12] But a 1982 study by a British consulting firm arrived at far more conservative estimates; in north-western Bangladesh, in the absence of inter-catchment water transfers, the ultimate irrigation potential was estimated to be only 38 per cent of new sown area.[13]

The assessment of ultimate irrigation potentials is further complicated by uncertainties about ecological constraints. For example, canal irrigation can in some instances result in waterlogging and soil salinity, reducing agricultural productivity and ultimately making land uncultivable. In India it is estimated that at least 15 million acres of once productive land have been lost in this way.[14] Similarly, the 'mining' of ground water—extraction in excess of the rate of natural recharge—leads to falling water tables and cannot be sustained indefinitely. Irrigation experience around the world demonstrates that these long-run ecological constraints are often not well understood or taken into account in initial plans.

Aside from the technical difficulties involved in assessing ultimate irrigation potential, there are economic ones. Irrigation development is costly, and at some point the marginal cost of bringing additional acreage under irrigation can be expected to rise. Any definition of 'ultimate irrigation potential' must incorporate, implicitly if not explicitly, some judgment as to the point at which the marginal benefits of further irrigation development are no longer worth the marginal costs. In the absence of any such benefit-cost criterion, the utlimate irrigation potential would always be 100 per cent: the Chinese could desalinate seawater and transport it inland to the deserts of inner Mongolia, and so on. In a world of pervasive distributional inequities and market imperfections, however, the measurement of costs and benefits is not a straightforward task. Moreover, both costs and benefits can be expected to change over time as a result of technological change and shifts in factor and output prices.

State-level estimates of the percentage of ultimate irrigation potential attained in India are reported in the last column of Table 2. Bearing in mind the preceding cautionary remarks, these estimates cannot be regarded as definitive, but they do permit three tentative conclusions. First, there remains substantial potential for the expansion of irrigation in India. Second, the extent to which irrigation potential has been developed varies widely among states, ranging from less than 20 per cent in Assam to more than 80 per cent in Punjab and Tamil Nadu. Third, there is a clear correlation between the percentage of the net sown area irrigated and the percentage of irrigation potential realised. In other words, the variations in the share of crop land irrigated cannot be attributed solely to environmental differences in irrigation potential. The same is probably true of the inter-country differences reported in Table 1.

IV

Alternative Irrigation Strategies: Some Characteristics

Irrigation in Asian rice agriculture varies not only in its pace of development, but also in terms of various characteristics including water source, power source, capital-labour ratio, scale, institutional arrangements, and the degree of farmer control. These are discussed in turn below.

(a) WATER SOURCE AND POWER SOURCE

Irrigation systems are most commonly classified in terms of the hydrological and engineering criteria of water source and power source. The two basic sources of water for irrigation are surface water and underground aquifers. Surface water can be lifted manually, for example by *dhones* and swing buckets, or by animal-drawn devices, or by diesel or electric-powered pumps. (A *dhone* is a pivoted canoe used in the Indian subcontinent to lift water 1-2 metres.) In some cases, water distribution can be accomplished through gravity flow from rivers or reservoirs, and no lifting is necessary. A single surface water irrigation system may combine several power sources; for example, water may be drawn from gravity-fed canals to field channels by means of a diesel pump, and then manually lifted by cultivators to irrigate fields lying above the channels.

In the case of groundwater, there is some scope for manual lifting of water from open dug wells, and for animal-powered techniques. In addition, a variety of manually-operated pumps have been developed for use with tubewells, which penetrate that aquifer by means of a pipe sunk in a bored hole. In most cases, however, groundwater irrigation today relies on diesel or electric-powered tubewells. These are frequently classifed as 'deep' or 'shallow', according to not only their depth, which depends upon aquifer conditions, but also their capacity, which depends upon their diameter and pump size.

(b) CAPITAL-LABOUR RATIO

Irrigation techniques can also be classified in terms of their relative factor intensity, that is, the ratio of labour to capital used in their construction, operation, and maintenance. These ratios vary within as well as between the various techniques mentioned above. There is a clear difference, for example, not only between the operational labour requirements of hand tubewells and diesel-powered deep tubewells, but also between labour-intensive and capital-intensive techniques for deep tubewell construction. Similarly, in the case of canal irrigation projects the labour-capital ratio in the construction phase can vary greatly, depending above all upon the earth-moving techniques chosen. The share of labour can never reach 100 per cent, but there is a tremendous range of variation between the shovel-and-head basket method and the use of bullodozers.[15]

When economists speak of the 'direction' of technological change, they are usually referring to this dimension. A technological change is defined as labour-saving if it decreases the average labour-capital ratio, capital-saving if it increases the ratio, and neutral if it leaves the ratio unchanged.[16] Non-neutral technological change is sometimes described as being 'biased' in a labour-saving or capital-saving direction. This is a rather curious use of the term 'bias', in that non-biasedness is defined in terms of the *status quo* at any given moment, despite the fact that this *status quo* incroporates the effects of any previous biases. An alternative definition would start from an explicitly normative specification of the optimal labour-capital ratio, and define bias as a departure from it. Such a norm need not coincide with the prevailing capital-labour ratio, either in the economy as a whole or in the agricultural sector. Rather, it would express judgments as to the appropriate shadow prices of labour and capital which would depend, among other things, upon the priority given to employment generation as a social goal. For present purposes, however, it need only be observed that the labour-capital ratio of irrigation techniques has important implications for their economic viability, for the distribution of the benefits of irrigation development among owners of labour and capital, and for the extent to which irrigation development can be accomplished by relying upon local resources.

(c) SCALE

Irrigation techniques can also be classified according to their scale, the range of which is enormous. At one extreme are individual techniques irrigating a fraction of an acre: manually-operated tubewells, or traditional lift irrigation from dug wells or surface water bodies. At the other are large-scale canal irrigation systems serving tens of thousands of acres. In between are small and medium-size reservoirs ('tanks' in south Asian parlance) and river diversion works, and low-lift pumps and tubewells capable of irrigating 10 to 200 acres, depending upon soil characteristics, conveyance losses, evapotranspiration rates and the crops grown, as well as upon the volume of water produced.

The scale of an irrigation technique, coupled with the operational structure of landholdings, determines how many cultivators must jointly use the water for the unit to operate at its full capacity. The agrarian structure of Asian rice-producing countries is typically characterised by fairly small and fragmented landholdings. In Bangladesh, for example, the average farm size is approximately two acres, and consists of half a dozen non-contiguous plots. As a result, the efficient use of a deep tubewell with a capacity to irrigate 80 acres typically would involve more than one hundred cultivators. Hence Asian rice irrigation very often requires an institutional framework within which co-operation among individuals is achieved, and conflicts among them resolved, in both the construction of irrigation facilities and their day-to-day operation and maintenance. The social difficulties of achieving joint water use among many irrigators may exceed the technical difficulties of constructing large-scale systems, a fact which has become increasingly recognised in recent years in large canal irrigation schems. For some purposes, therefore, the number of cultivators involved may be a more meaningful measure of scale than the number of acres irrigated.

(d) INSTITUTIONAL ARRANGEMENTS

A classification of irrigation systems in terms of institutional characteristics has been advanced by Chambers (1980), who distinguishes five types of irrigation organisations based upon different processes for the allocation of water. The first is *direct appropriation*, in which the user acquires the water directly from its source. The second is *acquisition through contract*, in which the user acquires water through an exchange relationship with a supplier. The third is *community allocation*, in which a communal source of water is allocated among a community of users. The fourth is *bureaucratic allocation*, in which water is allocated by a bureaucratic agency (governmental or parastatal) directly to individual users. The fifth is *bureaucratic-communal allocation* a hybrid type in which water is first allocated by a bureaucratic agency to communities of users, and then by the communities to their individual members.

Chambers notes that in practice the lines between these types are often fuzzy, but the possibility of boundary disputes does not detract from the importance of the distinctions upon which his classification is based. There are, of course, further distinctions to be drawn within each of these organisational forms. For example, in the case of 'acquisition through contract', there are a variety of possible payment systems, including sales of water on a volumetric or time basis, fixed-rate payments on an acreage basis, or 'sharecropping' with water in which the water supplier receives a share of the crop.[17] Similarly, community water allocation systems include the physical division of waterflows, rotational distribution of water,

TABLE 2: IRRIGATION AND RICE PRODUCTION IN INDIA, 1978-79

State	Net Irrigated Area (Per cent net sown area)	Rice Acreage (Per cent net sown area)	Rice Yield (qu/ha)	Per Cent of 'Ultimate Irrigation Potential' Realised, 1982-83
India	26.6	28.1	13.4	55.8
Andhra Pradesh	32.2	34.6	18.6	57.6
Assam	21.4	83.7	9.7	18.5
Bihar	34.7	65.5	9.9	44.4
Gujarat	18.0	4.8	11.6	54.2
Haryana	52.5	12.7	26.8	69.6
Himachal Pradesh	15.9	17.7	12.5	33.3
Jammu and Kashmir	42.1	36.9	20.4	62.5
Karnataka	13.7	11.1	20.1	50.0
Kerala	10.3	36.6	15.4	42.9
Madhya Pradesh	12.3	25.1	7.4	34.3
Maharashtra	10.4	8.2	14.7	45.2
Orissa	18.8	71.7	10.1	40.7
Punjab	78.1	25.2	29.2	83.3
Rajasthan	18.7	1.4	11.1	69.2
Tamil Nadu	44.1	41.6	22.5	82.1
Uttar Pradesh	50.9	29.2	11.6	68.9
West Bengal	26.9	83.6	13.6	50.8

Sources: Government of India, Ministry of Planning, Central Statistical Organisation, *Statistical Abstract India 1979* and *Statistical Abstract India 1982*.
Estimates of percentage of ultimate irrigation potential realised are calculated from data in Tata Services, *Statistical Outline of India, 1984*, Table 51.

with or without acreage restrictions upon individuals, and less formal methods in which water is 'not so much allocated as appropriated' by those who have the political or physical strength to do so.[18]

Closely related to these water allocation methods are different institutional arrangements governing the construction and maintenance of irrigation facilities. In the case of direct appropriation, the irrigation asset is typically owned and maintained by the individual user. In the case of contractual acquisition, the water supplier typically would have installed the irrigation facility and would bear the responsibility for its maintenance, although some water supply contracts include provisions whereby the buyer pays certain maintenance costs. Community systems employ a variety of procedures, many of which are designed to ensure that individual contributions to construction and maintenance costs are roughly proportional to expected benefits. For example, Chambers describes several surface-water irrigation systems in south India which rely on communal labour for their maintenance. In one muti-village system, each village agreed to provide labour at the rate of one man for every ten acres irrigated; in another system, every family's labour obligation was proportional to its acreage; and in a third, each cultivator was obligated to clear three feet per day of the water supply channel for every acre of land irrigated.[19] In the case of bureaucratic systems, construction and maintenance are typically financed by the government and labour is hired on a wage basis, although China's labour accumulation' projects provide an example of non-wage labour mobilisation.[20] In the former case, the construction and maintenance arrangements may differ little from those which would be employed by a private owner, while in the latter case the arrangements may be closer to those of a community irrigation system.

(e) CONTROL

Chambers' five-fold organisational classification points to a further dimension in which irrigation methods vary, which can be termed 'farmer-controlledness'.[21] The economic significance of this dimension for the cultivator is evident, since greater personal control implies fewer constraints upon crop choice and upon the timing of agricultural operations, and greater certainty that water will be available in the desired amount at the desired time. This dimension also has far-reaching social and political ramifications, for control over water is inextricably linked to control over people. It is this linkage which formed the basis of Wittfogel's (1957) famous theory of 'Oriental despotism', according to which the managerial requirements of irrigation development led to the emergence of despotic, 'agro-bureaucratic' states in ancient China, India, Egypt, and Mesopotamia. Similarly, Worster (1985) has recently characterised the western United States in the present century as a 'hydraulic society' in which water development has given rise to "a coercive, monolithic, and hierarchical system, ruled by a power elite based upon the ownership of capital and expertise".[22]

Although the degree of farmer control is mediated by the institutional arrangements distinguished by Chambers, one cannot assume that control necessarily decreases, step by step, as one moves through the categories from direct appropriation to bureaucratic-communal allocation. Acquistion through contract, for example, does not always impart greater control to the water user than a community or bureaucratic system. The cultivator remains dependent upon the supplier, who in turn may depend upon others for fuel, spare parts, or maintenance. The contracts linking these individuals are often incomplete, and their enforcement is costly. This is illustrated by a case in Bangladesh, in which the private controllers of a deep tubewell unilaterally altered the terms of their agreement to sell water to other cultivators, at the crucial flowering stage of the rice crop, by reneging upon their commitment to provide the diesel fuel. Fuel could be obtained only with great difficulty on the black market, and only timely rains saved the water purchasers from serious losses.[23] Even direct appropriation need not imply maximum farmer control given the possibility of externalities. Thus a cultivator relying upon his or her own hand tubewell or dug well could be left without water if the use of shallow or deep tubewells by neighbouring cultivators causes the water table to fall.[24]

The degree of farmer control is also distinct from the scale of an irrigation system, although the two are often inversely related. There is a tendency for increases in scale (in the number-of-cultivators sense) to be accompanied by a loss of farmer control for two reasons. First, larger systems typically require sophisticated technical expertise for their planning, execution, and operation, and those who possess such expertise are likely to demand, and secure, a substantial measure of control. Second, the allocation of water among individuals and communities is a source of conflict, particularly in times of water scarcity, and adjudication of these conflicts by a higher authority again entails a loss of control.[25]

The degree to which this tendency can be counteracted by the development of democratic irrigators' institutions is an open question, but it is clear that even large-scale systems can involve substantial local control over water allocation and infrastructure maintenance. Critics of Wittfogel have questioned the degree to which traditional Asian irrigation systems were administered by a centralised bureaucracy, arguing that community participation at the local level was in fact crucial to their success.[26] In this connection, some authors have drawn a distinction between 'bottom-up' and 'top-down' approaches in large river diversion schemes. The starting point for the former is the small, local irrigation system; the larger inter-connecting network emerges only in response to the demand of local irrigators for further water supply and better water control. In this model the water users and local terminal systems are viewed as the *main* systems, while the interconnecting works, "in spite of all their technological complexities, gigantic sizes, and involvement of central authorities, are still no more than sub-systems".[27] The top-down approach inverts this outlook: irrigation plans are based solely upon engineering and financial criteria, not upon the demands of local irrigators. Terminal-level systems are seen as sub-systems, and any concern with them often arises as an afterthought. In the first approach, the cultivators are the initiators of irrigation development; in the second, they are treated as its instruments.

V

Determinants of Pace and Direction of Irrigation Development

Why is irrigation more developed in some places than in others, and why do techniques with particular characteristics predominate in certain settings? These two questions are addressed jointly in this section, for their answers may be interrelated. A hypothetical example will illustrate the connection. Let us suppose that a country's topographical conditions, landholding pattern, and factor endowments imply that the direction of its irrigation development should be large-scale (in the multi-user sense) and highly labour-intensive, and that at the same time other social, political, or economic factors block this type of development. The result could be a stalemate in which irrigation development is impeded either until the obstacles to multi-user, labour-intensive techniques are removed, or until different techniques emerge as a viable alternative. In other words, the forces shaping the direction of irrigation development could also help to explain its pace. Five sets of determinants—population pressure, geography, the agrarian structure, cultural factors, and the role of the state—will be considered below. This list of possible determinants, although by no means exhaustive, draws together a number of recurrent strands in the Asian rice irrigation literature.

(a) POPULATION PRESSURE

The intensification of agricultural production, of which irrigation development is one means, has often been attributed to the need to support growing numbers of people on a limited land area. Indeed, some anthropologists maintain that the advent of agriculture itself, via the domestication of plants and animals some 10,000 years ago, was a response to demographic pressure.

Thus Cohen (1977) writes that the growth of hunting and gathering populations made a new mode of subsistence necessary: 'the development of agriculture was an adjustment which human populations were forced to make in response to their own increasing numbers'.[28] Similarly, Ester Boserup (1965) has argued that population pressure led to shifts from slash-and-burn agriculture to settled cultivation, and led to the intensification of cultivation even in fairly densely populated settings such as Japan and Java.[29] In the same vein, Colin Clark has termed population growth "the principal motive force' behind the events which 'historians tend to describe as 'agricultural revolutions' ", including the clearing of uncultivated land, the drainage of swamps, and the introduction of improved crops and manures.[30]

Simon (1975) applied this logic directly to irrigation systems. His cross-sectional analysis of 48 third world countries, and of a subset of 18 Asian countries, revealed strong positive correlations between irrigation and population density, a finding he interprets as indicating that population pressure leads to higher levels of non-monetised capital formation in the form of irrigation systems. This correlation could also arise, at least in part, from the reverse line of causality: irrigation development could lead to higher population densities by raising life expectancies, inducing in-migration, and so on. Simon dismisses this possibility with the statement that although irrigation may affect intra-country population distribution, it would not affect population densities at the national level, 'given the reasonable assumption that the irrigation project does not affect national fertility or international migration'.[31] An even stronger assumption would be needed, to sustain Simon's unilinear interpretation of the correlation, namely that inter-country differences in population density are not attributable to other factors, such as differences in water endowments, which also help to explain the variations in irrigation.

The view that demographic pressure can induce agricultural intensification stands in marked contrast to the bleak Malthusian proposition that population growth follows upon, and ultimately swallows up, any gains in agricultural productivity. The former holds out the possibility of rising per capita incomes; the latter predicts that the mass of humanity will inevitably subsist in abject poverty, with their numbers held in check only by disease, war, or starvation. The history of the West amply demonstrates the twin fallacies of the Malthusian logic—the underestimation of the potential for technological change, and the neglect of the possibility of a 'demographic transition' to low fertility rates. Yet Malthusianism remains a major theme in contemporary discussions of the third world, and many writers have questioned the applicability of the Boserup thesis in the latter context. Indeed, Boserup herself remarked that the necessary investments for agricultural growth might not be forthcoming in 'densely peopled communities if rates of population growth are high'.[32] Some scholars have gone further, and argued that in such a setting, population growth could in fact *adversely* affect agricultural growth, in absolute as well as per capita terms, by leading to lower savings rates, environmental degradation, and inefficient agrarian structures.

There is no reason to expect that the direction or magnitude of the effects of population pressure upon agricultural growth will be everywhere the same. Empirical studies can shed light, however, upon the relative strength of the predicted positive and negative effects in specific historical and environmental settings. A district-level analysis of Bangladesh and West Bengal reveals that in world's most densely populated agricultural region—the Bengal delta—positive inducement effects from population growth are not entirely absent. Districts which experienced more rapid rural population growth in the first half of the present century subsequently have experienced more rapid agricultural growth.[33] Nevertheless, per capita agricultural output in Bangladesh and West Bengal has declined since 1950, and in this sense, the positive effects of population pressure were inadequate. Population pressure may well have played an important role in the development of irrigation in many Asian settings, but the low level of irrigation in Bangladesh today, where demographic pressures are exceptionally intense, makes it clear that population pressure alone is not sufficient to ensure irrigation development.

The theory of induced innovation predicts that population growth will affect the direction as well as the pace of irrigation development: a rise in the ratio of labour to land and capital will lead to labour-using technological change. In the first major empirical application of this theory, Hayami and Ruttan (1971) found that in the 19th century, Japan, with relatively abundant labour and scarce land, experienced land-saving, labour-using technological change, whereas the US, with relatively scarce labour and abundant land, experienced labour-saving technological change. The Japanese innovations were largely bio-chemical, involving new varieties, fertilisers, line planting of paddy, and so on, while in the United States the innovations were primarily mechanical.

Prices play a key role in induced innovation theory, for it is shifts in the relative prices of labour and other inputs which stimulate a search for "new methods of production which will use more of the now cheaper factor and less of the expensive one".[34] The theory runs into difficulties, however, when different producers face different sets of factor prices. In much of rural Asia, larger landowners face lower prices for land and capital relative to labour than do smaller landowners. This reflects differential access to capital markets and to government subsidies, differences between hired and family labour, and differences in the costs of supervising hired labourers. As a result, agricultural techniques are often found to vary systematically across farm size classes, with smaller farms using relatively more labour and less capital per acre.[35] For this reason, Griffin (1974) distinguishes between 'landlord-biased' and 'peasant-biased' technical change; the former refers to techniques which can be profitably adopted only by cultivators who face relatively low prices for capital and material inputs, while the latter refers to techniques which are profitable only for those who face a relatively low price of labour. In such a situation the direction of technological change, rather than being dictated by the relative factor endowments of the economy as a whole, will be subject to different demands from different classes. The balance of power among rural classes can thus be expected to influence the degree to which irrigation development proceeds along a labour-intensive or capital-intensive path.

Population pressure may also influence the institutional arrangements, scale, and farmer-controlledness of irrigation development. Two opposing influences can be hypothesised. On the one hand, larger populations increase the difficulty of collective action. As Olson (1965) noted, the larger the number of people who benefit from a public good, the smaller the share of the gains that accrues to any one individual, and the higher the transactions costs involved in its provision. This makes the 'free rider' problem—whereby individuals seek to reap the benefits of a collective good without sharing in its costs—more severe, and implies that as the number of individuals increases, the supply of collective action decreases. A small-scale river diversion project, for example, will be easier to organise if 50 households are involved than if 500 are involved. On the other hand, a growing population increases the demand for food and hence for irrigation, and this in turn increases the need for institutional arrangements to achieve joint use of water resources. The net effect of population pressure upon the extent of collective action in irrigation will depend upon the relative strength of these opposing 'supply' and 'demand' effects, and upon the ease with which irrigation can be supplied by alternative private or bureaucratic means.

(b) Geography

Geographical factors—topography, hydrology, rainfall, and temperature—constitute a second set of determinants of the pace and direction of irrigation development. These factors affect both the need and the possibilities for irrigation, that is, both demand and supply. On the demand side, however, one must be wary of the mechanistic assumption that areas with higher rainfall and lower evapotranspiration losses always have less need for irrigation. Once variations in population density are taken into account this simple inverse relationship breaks down. The Pearl River delta in China and the Bengal delta in south Asia, for example, receive far more rainfall than the deserts of Xinjiang or Rajasthan, yet when their very different population densities are taken into account, it is by no means clear that the demand for irrigation is greater in the more arid settings.

Certain geographical effects upon the possibilities for irrigation development are quite obvious. Differences in the volume of river flows, for example, clearly affect the potential for surface water irrigation. Gentle slopes are more conducive to river diversion irrigation than either very flat or very steep terrain.[36] Where river flows are highly seasonal, the construction of ponds, tanks, and reservoirs to impound water for dry season use will assume greater importance, and this will increase irrigation costs.[37] Similarly, water table depths and recharge rates directly affect the possibilities for groundwater irrigation.

In discussing the effect of topography upon irrigation development, Hsieh and Ruttan (1967) draw a basic distinction between mountainous and deltaic regions. They argue that the short river valleys and narrow coastal plains of Japan and Taiwan "lent themselves to locally organised, small-scale, labour-intensive irrigation and drainage works", whereas the broad river valleys and plains of southeast Asia require large national systems, the construction of which "lends itself to much more capital-intensive patterns of investment".[38] Since the latter impose greater organisational and investment requirements, these topographical differences could help to explain variations in the pace as well as the direction of irrigation development. A similar argument is advanced by Hayami (1981), who contrasts the possibilities for local collective action in the hilly terrain of Japan and Java to the impracticability of such action in the Chao Phraya River delta of central Thailand.

The links between topography and the pace and direction of irrigation development may be less straightforward than these authors suggest. First, there is no necessary connection between scale and capital intensity. Asian rice irrigation provides examples both of large-scale, labour-intensive irrigation projects and of small-scale, capital-intensive ones. Second, even in flat deltaic regions there is considerable potential for small-scale irrigation works, notably in the construction of ponds and the use of groundwater. Finally, the large ancient irrigation systems of China and Indus demonstrate that scale alone does not pose an insuperable obstacle to water development.

While geographical factors undoubtedly play a major role in shaping the hydrological and engineering features of irrigation systems, their role in determining the pace and direction of irrigation development thus cannot be regarded as decisive. Japan and Java are both mountainous, yet local institutions for water control have developed more successfully in the former. China's Pearl River delta and the Ganges-Brahmaputra delta of Bangladesh share of similar topography and climate, yet irrigation is more extensively developed in the former. Clearly, there are other factors at work which affect the ability of a society to modify its physical environments.

(c) Agrarian Structure

Asian rice agriculture provides little support for the belief, grounded in some interpretations of European and North American experience, that large-scale farming is inherently more efficient and dynamic than small-scale agriculture. As Bray (1983) observes, the historical trend in Asian rice agriculture has been towards smaller and smaller production units. In some cases, such as late nineteenth-century China and contemporary Java, this trend has been associated with a stagnant agriculture and deepening rural impoverishment, but in others, such as medieval China and Tokugawa Japan, holding size reductions were accompanied by 'spectacular increases in agricultural productivity'.[39]

Much of the literature concerning the impact of agrarian structure upon agricultural productivity in Asian rice-producing countries has focused upon inter-farm differences. In many cases, researchers have found an inverse relationship between farm size and land productivity; that is, smaller farms often have higher output per acre than large ones.[40] Differences in irrigation sometimes contribute to the size-productivity relationship. For example, Rao (1966) found an inverse relationship between farm size and irrigation in India in the 1950s. Given the high labour requirements of wet-rice agriculture and traditional irrigation techniques, these findings can be attributed, at least in part, to lower labour and supervision costs on smaller farms—a powerful argument in their favour.[41]

More recently, however, the spread of capital-intensive 'modern' irrigation technologies, such as shallow and deep tubewells and low-lift pumps, has led in some places to the erosion or reversal of the inverse relations between farm size on the one hand and irrigation and land productivity on the other.[42] Larger cultivators frequently obtain greater access to these new technologies for three reasons. First, if the allocation is left to the market, the larger cultivators are better able to afford the substantial outlays required. Second, if irrigation equipment (or credit to buy it) is rationed or subsidised by the government, the larger cultivators often receive preferential treatment owing to their political leverage. Finally, larger cultivators are better able to utilise such irrigation techniques to capacity on their own holdings. The last factor is significant only insofar as institutional mechanisms for joint water use are imperfect, entailing greater costs or risks than individual use. Both a priori reasoning and practical experience suggest that this is so.

Inter-regional differences in the degree of sub-division (the splitting of an agricultural holding into a number of smaller holdings) and fragmentation (the existence of a number of non-contiguous plots within a single holding) may thus affect the spred of private irrigation techniques. Dhawan (1977, 1982) has calculated that the minimum farm size at which a shallow tubewell becomes profitable on an individual holding in northern India increases steadily as one moves eastwards across the Gangetic plain, primarily owing to differences in fragmentation and interest rates. At the same time, the average holding size declines from west to east. The combined effect is a far greater need for institutional mechanisms for co-operative tubewell use in the east than in the west, and Dhawan suggests that this helps to explain why tubewell irrigation in West Bengal and Bihar is lagging far behind that in Punjab and Haryana.

Despite the fact that Asian rice irrigation very often involves joint water use by a number of cultivators, relatively little attention has been devoted to the impact of agrarian structure upon collective action in irrigation. Both sub-division and fragmentation increase the number of individuals involved in the irrigation of a given acreage, and as noted above, this will, *ceteris paribus,* increase the difficulty to collective action. But aside from this simple effect upon the number of individuals involved, the agrarian structure will also, and perhaps more importantly, affect the relationships among these individuals. In particular, it can be hypothesised that the *degree of equality* of the agrarian structure, as measured, for example, by the Gini coefficient of land ownership distribution,[43] will affect the likelihood of collective action. Plausible arguments could be advanced in either direction, for both co-operation and dictatorship provide possible solutions to public good problems. It could be argued that greater equality facilitates collective action, since it reduces the scope for malfeasance by a powerful minority who might otherwise be able to pursue their self-interest at the expense of the community as a whole. Or it could be argued that inequality is conducive to collective action, in that if fosters the emergence of strong leaders whose authority helps to initiate group action and prevent free riding. Both points of view have been expressed in the Asian irrigation literature.

A number of authors have maintained that relatively egalitarian agrarian structures help to foster social cohesion in general and collective irrigation activities in particular. The basic idea is that people are more willing to collaborate in a joint endeavour when they are assured of a fair share of the benefits. Thus Colombo et al (1978) note, "It has often been reported that community work programmes are difficult to organise for irrigation projects that primarily benefit larger farmers and landlords". As an example, they cite research carried out in the Philippines by the International Rice Research Institute, which indicates that "participation of community members in communal irrigation projects is greater and more uniform in a village where farmers are more homogeneous in terms of tenure and farm size".[44]

Several researchers in India have drawn similar conclusions. For example, a recent analysis of ten irrigation tanks in Tamil Nadu concluded:

> One of the most important factors besides water scarcity which encouraged farmer co-operation in acquisition and distribution of the water was the homogeneity of farms. The smaller the variation in farm size, the better the co-operation among the farmers on tank management issues.[45]

Studies of river diversion-based tank irrigation in south Bihar and canal irrigation in Gujarat have likewise indentified equitable property relations as one determinant of successful group action.[46]

Many economists are uncomfortable with such conclusions. They note that an equal distribution of benefits is necessary only if we assume that costs are borne equally. If costs were distributed in proportion to benefits, then inequality would not pose a barrier to collective action. The only conflict between individual rationality and collective rationality is then the free rider problem, which arises when individuals believe they can obtain in the benefits without bearing any costs. But this arises regardless of the degree of inequality.

To understand how inequality could make the resolution of public good problems more difficult, we must probe more deeply into the conflicts between individual and collective rationality. One such conflict, frequently observed in irrigation systems, is that excessive water use by those with first access often deprives 'tail-enders' of their share. Cultivators with unrestricted access to water frequently find it more profitable to grow highly water-intensive crops, such as rice, than less water-intensive ones such as wheat or oilseeds. Similarly, treating the marginal cost of water as near-zero (since volumetric pricing is seldom practicable), they may use water to save labour by drowning weeds.[47] Furthermore, if the future reliability of the water supply is uncertain, they will seek to store as much water as possible in their own rice fields or ponds. Such water use is rational for the individual cultivator, yet less water-intensive cropping patterns and practices would often be more profitable from a social standpoint, expanding total irrigation coverage and maximising returns per unit water.[48] This dilemma is most frequently ascribed to location-based disparities: the lands of some cultivators lie closer to the head of the system than those of others, and in the absence of countervailing pressures the former take advantage of this fact. An analogous situation can arise within any given locality, however, in the relationship between large landowners and small landowners. In Indonesia, for example, it has been reported that the "wealth and power of some rich landowners have enabled them to gain control of irrigation water to benefit themselves; as a result, they enjoy a surplus of water while others have to endure water shortages and consequent low productivity".[49] In such, cases, the smaller landowners might be termed 'political tail-enders'.[50]

Location-based disparities would be reduced if individual landholdings were fragmented such that each cultivator has plots at the head, middle, and tail of the distribution system. Precisely this arrangement of landholdings has been reported in studies of traditional community irrigation systems in Sri Lanka, the Philippines, and India.[51] When applied to the analogous problem posed by size-based disparities, this suggests that a more equal distribution of holding sizes would increase irrigation efficiency.

An analysis of public canal irrigation in India's Punjab reports a variant of this problem, arising when tubewell irrigation was introduced as an alternative water source. In both districts studied, maintenance of water-courses was the joint responsibility of all cultivators who shared a given outlet. This worked well in one district, "where canals were the only feasible source of irrigation and all the shareholders, therefore, had a vested interest in the efficient operation of the same". In the second district, however, those farmers who had been able to install tubewells subsequently neglected water-course maintenance, "thereby depriving even the others of water since it was not practical for them to clear the entire length".[52] It was typically the poorer cultivators who lost access to irrigation, since they could not afford tubewells.

Elsewhere (Boyce, 1987) I have presented evidence that an inegalitarian agrarian structure poses a serious impediment to water control development in Bangladesh, where ten per cent of rural households own more than half the cultivable land. The argument can be briefly summarised here. The mobilisation of seasonally underemployed labour for water control projects in the slack winter season is impeded, in the first instance, by the fact that the landless and near-landless families who have the surplus labour do not own the land which would be improved. Therefore, they must be paid and supervised. In theory, local landlowners could pool their financial and managerial resources for this purpose, but in practice they seldom do so owing to (a) problems of co-operation among themselves; (b) the availability of capital-intensive irrigation alternatives, which are often subsidised; (c) the presence of more profitable avenues of investment often outside the agricultural sector; and (d) the landowners' perception, which finds some basis in the history of government rural works projects, that agricultural labourers might organise if brought together to work in one place for an extended period of time, with potentially explosive consequences.

Efforts to circumvent these obstacles via government initiation and funding of rural works projects run into a further set of difficulties. The motivation of the participants in such projects shifts from the mobilisation of internal resources for long-term land improvements to the capture of external resources for immediate gain. The local committees which implement the projects are dominated by politically well-connected large landowners. This has three negative effects upon the productive impact of the projects: (1) a substantial fraction of the allocated resources are lost through 'leakages', which constitute a direct form of political patronage; (2) projects are selected so as to maximise returns to the dominant individuals, through enhanced land values, rather than to maximise social returns; and (3) maintenance is neglected in the absence of continued external financing.

Similar problems afflict deep tubewell development in Bangladesh. Although nominally provided to 'irrigation groups' comprising a hundred or more cultivators, government installed deep tubewells are frequently controlled by a small clique of powerful individuals. Again, efficiency as well as equity suffers, as these individuals set out to maximise their own self-interest. First, the tubewells tend to be sited at locations which are optimal not from a technical standpoint, but rather from the standpoint of the controlling individuals.[53] Second, monopoly pricing of irrigation water, favouritism in water allocation, and the possibility that the terms of water supply agreements will be unilaterally altered in mid-season by the 'waterlord' combine to discourage other cultivators whose lands lie within the command area from purchasing water. Third, the tubewell controllers may deliberately withhold water from other cultivators, with a view to ultimately gaining control of their land, the potential value of which is greatly enhanced by access to irrigation. Finally, the resentment of those excluded from the tubewell's benefits, for whom the waterlord's enhanced wealth and power is not only a source of envy but also a potential threat, manifests itself in the sabotage of irrigation equipment. These social factors, rooted in the country's inegalitarian agrarian structure, help to explain why a large percentage of Bangladesh's deep tubewells are non-operational, and why those which are operational tend to be chronically underutilised.[54]

A remarkable institutional innovation in Bangladesh, in which irrigation assets are provided to landless co-operatives, hints at the potential production gains of a more egalitarian framework. In the early 1980s a number of landless groups, which had been previously organised by non-governmental organisations, were provided with tubewells and low-lift pumps by the ministry of agriculture. The landless groups operate the irrigation equipment and sell the water, sometimes on a cash basis and sometimes for a share of the crop, to landowners within their command areas. Ownership of water is thus divorced from ownership of land—a separation facilitated, as Wood (1984) observes, by the country's fragmented land-holding pattern—and control of the water resides in the hands of people from the poorest stratum of the rural society. The distributional implications of such a strategy are of course far-reaching, but for present purposes it is the efficiency implications which are of interest. Wood reports that "small farmers get better access to water through not being political tail-enders". In a 1985 survey of 92 tubewell and low-lift pump schemes, Palmer-Jones found that those pumps managed by landless groups performed as well or better than private pumps or traditional state-sponsored projects. He concluded that "the belief that the landless will not put irrigation of their own lands first or use control of water to obtain control over others' land" contributed to larger command areas and possibly higher yields on the irrigation schemes managed by the landless.[55]

The experience of China has also been cited in support of the proposition that a more egalitarian agrarian structure facilitates collective action. The percentage of acreage irrigated in China expanded greatly after the 1949 revolution and the accompanying land reforms, and while not problem-free, water management in China appears to have surmounted a number of the difficulties encountered elsewhere in Asia. Reporting on canal irrigation in the arid Xinjiang region, Griffin observes:

> Certainly there is no problem, common in other countries, of farmers located conveniently at the head of the system getting more than their share of water or of richer farmers obtaining extra supplies of water through bribery. The high degree of economic and social equality in the rural areas obviously helps to overcome problems such as these, as does the existence of well-organised communal institutions.[56]

It will be instructive to see how the recent shift of Chinese agricultural policy towards greater reliance upon individual incentives, and greater tolerance of inequalities, will affect water allocation and irrigation system maintenance.[57]

An opposing strand in the literature sees inequality as playing a positive role by facilitating hierarchical, top-down control of irrigation systems. It has been argued, for example, that community irrigation in India has historically been "predicated on the existence of inequality", since "inequality in landholdings allows for sufficient private gains to the dominant caste/lineage/ethnic group to invest in organising local irrigation".[58] This line of reasoning casts doubt upon any presumption that greater equality invariably increases the likelihood of collective action. The essential problem, it will be recalled, is the gap between what is rational for the individual and what is rational for the society as a whole. The inequality-as-*advantage* argument rightly observes that one solution to this problem is for a cohesive subset of individuals to achieve sufficient economic and political dominance to capture the lion's share of the benefits and to compel others to contribute as necessary to this end.

The inequality-as-*disadvantage* argument sketched above reminds us, however, that economic and political domination is seldom absolute, or absolutely secure. The weak employ myriad 'everyday forms of resistance' to combat the power of the strong.[59] This resistance constrains both the willingness and the ability of the strong to ensure the efficient utilisation of productive resources. Property rights to land and water are neither immutable nor indisputable, but rather are an object of incessant struggle, and irrigation develops in this contested terrain. Powerful (though not omnipotent) individuals shape irrigation development in their own interest, but this need not coincide with the public interest, even if the latter is very narrowly defined in terms of efficiency. Asian rice irrigation thus illustrates the tension between the potentials for co-operation and conflict inherent in all economic intercourse. A more egalitarian agrarian structure does not eliminate conflicts over water but at least it avoids those social tensions inherent in the subordination of the many to a few.

The success with which co-operative solutions are achieved and conflicts resolved in a given demographic and environmental setting cannot, in any event, be mechanically reduced to a simple function of the agrarian structure. It also depends crucially upon how that structure and its attendant social relations are perceived by the people who constitute it. This brings us to fourth influence upon the pace and direction of irrigation development: culture.

(d) Cultural Factors

Remarking upon differences in irrigation development in settings with similar population pressure and topography, Hayami (1981) has maintained that local irrigation institutions emerge more readily in the cohesive, 'tightly-structured' communities of Japan than in the more individualistic, 'loosely-structured' communities of southeast Asia. The validity of this 'tight-loose' distinction, first advanced by Embree (1950) in his work on Thailand, remains a matter of debate among anthropologists.[60] Nevertheless, culture often plays a vital role in facilitating collective action, and regardless of the terms in which cross-cultural differences are defined, there can be little doubt that societies vary in this respect. These variations affect the institutional arrangements governing rice irrigation; and insofar as irrigation can be achieved *only* through collective action, they also affect its extent.

As noted above, Asian rice irrigation often faces a disjuncture between individual and social rationality, that is, between the self-interest of atomistic individuals, each of whom takes the behaviour of others as given, and the interest of these same individuals when taken as a group. If, in the construction or maintenance of community irrigation facilities, each individual assumes that others will (or will not) contribute labour to the task, regardless of the individual's own contribution, then it will always be rational for the individual to withhold his or her own labour. This is an instance of the well known prisoners' dilemma: if each individual acts 'rationally', then all are in the end worse off than if they had reached a co-operative solution.[61] In other cases, as illustrated by the head-tail dilemma in canal irrigation, certain individuals (the head enders) will in fact be better off if they pursue their own self-interest than if they defer to the public interest in the efficiency of the irrigation system as a whole. In both cases, a society can achieve a collective rational outcome only by assigning rights and responsibilities by means of a set of values internalised by individuals, or a set of rules enforced by an external authority. Even the latter must be internalised to some extent via individual acceptance of the authority's legitimacy, since enforcement through coercion alone would generally entail prohibitive costs. As Lipton remarks, a society's "assignments of liability [and, one might add, its assignments of assets] depend upon the general moral consensus for their acceptability, and thus for low enforcement costs and reliability".[62] Culture can be viewed as a medium in which such consensus is, to a greater or lesser extent, achieved and maintained.

The Balinese *subak*, described by Geertz (1980), provides an example of a local irrigation institution embedded within a larger cultural framework. A *subak* is an irrigation group comprising a number of households, usually from several different villages, who irrigate their rice terraces from a single dam or canal. The *subak* regulates water supply to the individual plots, but Geertz observes that it "is in fact very much more: an agricultural planning unit, an autonomous legal corporation, and a religious community". Each *subak* has two temples, one dedicated to the goddess of fertility, the other to the god of water. The temples are the foci for a complex set of rituals, synchronised with the flow of agricultural activity, which serve as "one of the major regulating mechanisms in the whole, marvelously intricate ecological system the *subak* represents".[63]

Similarly, Duewel (1984) observes that the *dharma tirta* water users' associations in central Java "have blossomed in *Kejawen* cultural zones, where there is a congruence between peasant values and social norms and the socio-organisational requirements of irrigated rice cultivation and water management".[64] He argues that official efforts to promote the *dharma tirta* model in other regions in Java have failed, in part owing to their less 'culturally fertile' settings for irrigation development.

A culturally fertile setting for collective action need not be an egalitarian one (although Duewel's evidence suggests that the two attributes tend to coincide in rural Java), for what is at issue is not the extent to which interpersonal relations occur among equals, but rather whether they are cemented by bonds of trust. Each individual must trust the others will bear their fair share of the costs of collective action, and will not seek to appropriate more than their fair share of the benefits. Fairness, of course, lies in the eye of the beholder. A very unequal distribution of wealth and power may be perceived as fair by rich and poor alike; indeed, the rich can be expected to expend considerable resources to persuade the poor that this is so. At most, what can be hypothesised is that maintenance of trust and moral consensus will prove more difficult in a highly inegalitarian social order—in other words, that liberty, equality, and fraternity are complements rather than substitutes.

If cultural factors do help to explain variations in the pace and direction of irrigation development, the question arises as to how the relevant cultural differences are themselves to be explained. Hayami hypothesises that demographic pressure plays a crucial role: "the basic force underlying tightness in community structure", he asserts, "is relative resource scarcity—the scarcity of non-labour resources relative to labour".[65] If this were so, one might expect to find extremely 'tight' village structures in a country such as Bangladesh, where the rural population density is very high and capital is in relatively short supply. Yet Bangladeshi village society is far from being 'tight' in Embree's sense.[66] As noted above, Hayami also stresses the importance of topography. If local collective action for water control is indeed easier in mountainous regions than in river deltas, this might help to explain why villages in deltaic areas remain 'loose' despite intense demographic pressure. In a similar vein, Hayami speculates that climatic differences may explain why Japan has a tighter village structure than Java, even though both share a similar topography and similar population densities: in Japan the growing season for rice is more limited, owing to the cold winters, and this compels cultivators to schedule their agricultural operations more tightly, implying a greater need for co-ordination in water use.

Few would argue that the cultural differences relevant to irrigation development can be fully explained in terms of population pressure or geography. Yet the broader issue remains of the degree to which culture can be viewed as an autonomous determinant of the pace and direction of irrigation development. Insofar as cultures vary in the degree to which they facilitate collective action, is culture to be regarded as the exogenous variable? Or is it rather the necessity for, and possibility of, collective action which impels cultural evolution in a particular direction? The question is a deep one, and no axiomatic answer will be asserted here. Clifford Geertz cautions that "arguments from functional potency to functional necessity are both empirically dangerous and logically suspect," but he concludes that "it is nonetheless difficult to see how a social system of the Balinese sort could possibly operate without something very much like the temple system to give it form and outline".[67] Whatever the strands in the web of causality, it is clear that irrigation organisations cannot be abstracted from their cultural context. The implications for the transferability of irrigation institutions are evident.

As a culture confronts changing economic and political circumstances, the bonds of trust which once facilitated collective action can weaken and break. Customary notions of fairness may be violated by individuals who aggressively pursue new avenues for the advancement of their self-interest, apart from or in opposition to the interests of others in the community. At the same time the legitimacy of traditional hierarchies may be undermined by new ideas of economic and social justice. Such pressures upon the cultural norms and internal cohesion of rural communities often follow upon interventions by external forces. Sengupta (1985) argues that in India, for example, British colonial rule and the reforms undertaken by the post-colonial state have gradually eliminated the 'congenial social and civil systems' which were essential for the maintenance and operation of traditional community irrigation works, resulting in their physical decay.[68]

Another example can be found in Sri Lanka, where the government has sought since the mid-1950s to replace long-standing local irrigation officers, known as *vel vidane*, with participatory institutions in traditionally irrigated villages and with centralised bureaucratic management in the new canal systems. Neither institutional innovation has proven terribly successful. As Lipton (1984) reports:

> Many an individual farmer lacked trust in the capacity of the new authorities—whether participatory or bureaucratic-centralised—either to control overuse by other individual farmers, or to deliver water and maintain systems well enough to render his own overuse untempting. If land reform had been implemented, so that big landlords could not subvert new participatory authorities in traditional systems; or if maintenance and water-management had received more priority in modern systems; then a 'core' of farmers, sufficient to uphold the new means of water control, might have become effective.

Instead, the outcome was "an island-wide spate of gross water overuse", irrational from a social standpoint, and yet "perfectly rational for each farmer, mistrustful of both his neighbours and the control and delivery capacity of the new water managers". The result, according to Lipton, is that irrigation in Sri Lanka is today "a war of each against all".[69]

In discussing cultural influences upon irrigation organisation, Chambers maintains that the 'more egalitarian and more anarchic' character of rural Sri Lankan society gives rise to a greater need for bureaucratic controls than in south India, where "the controls already exist in the hierarchical strucutre of society".[70] The cultural contrast between Sri Lanka and south India may turn, however, not upon which society is more egalitarian, but upon the extent to which traditional bonds of trust between individuals have been corroded by what is sometimes termed 'modernisation'.[71] If so, the prescription for more bureaucratic control in the Sri Lankan case loses some of its appeal, for state intervention can be seen as one source of the problem, and not only, nor perhaps even necessarily, as an essential part of the solution. Ultimately rural Sri Lanka may experience what Lipton terms a 'transition of trust', whereby local rules and traditional values are effectively supplanted by the moral suasion and coercive power of the modernising state. Or perhaps new local institutions, embedded within an evolving rural culture, will emerge to restore the capacity for co-operation among water users. In any event it is clear that cultural factors interact not only with demographic pressure, geography, and the agrarian structure, but also with the state. To this final determinant of the pace and direction of Asian rice irrigation we now turn.

(e) Role of State

The single most influential work on the relationship between irrigation and the state in Asia has undoubtedly been Karl Wittfogel's *Oriental Despotism* (1957), which asserted a causal historical relationship between the development of irrigation in arid and semi-arid settings and the emergence of despotic state bureaucracies exercising absolute control over the agrarian population.[72] The geographical scope of Wittfogel's thesis did not extend to the major rice-growing tracts of Asia, where he believed that the more hospitable environmental circumstances permitted a more decentralised political economy. Yet similar imperatives for social control of water arise in multi-user rice irrigation systems, at the local level and, in the case of the large-scale systems, at the regional or national level. As noted above, self-interested, atomistically 'rational' individuals will underinvest in the construction and maintenance of water control facilities, hoping to free ride on the investment of others; similarly, treating water as a free good, they will attempt to appropriate excessive amounts so as to maximise returns on their own land, rather than maximising the efficiency of water use in the irrigation system as a whole. Wittfogel's thesis points to one theoretical solution to these conflicts between individual and social rationality: dictatorship. In effect, the state becomes a supra-individual economic agent, internalising externalities and 'privatising' public goods within its domain.[73] Here the inequality-as-advantage argument, discussed above with respect to agrarian structure, assumes its most extreme form. The hypotheticial dictator may be a local leader in the case of a small-scale irrigation system, or a despotic emperor as in Wittfogel's vision of the ancient hydraulic civilisations; in either case, the obstacles to irrigation efficiency posed by competing individual interests are swept away by the dictator's absolute power.

In practice, despotisms are rarely as absolute as those envisioned by Wittfogel. Rather than an impersonal authority which internalises all externalities and maximises efficiency in its own self-interest, the more typical agromanagerial bureaucracy is caught up in a social matrix of competing interests. It is powerful, but not ominipotent. It serves and in turn receives essential political and material support from specific private interests, in a mutually beneficial relationship which rests upon the exclusion of other, competing private interests. In the case of bureaucratic water allocation, we can thus distinguish three groups: the *bureaucracy* itself; the *privileged* users, who receive a disproportionate share of the water and can grow more water-intensive crops, reduce weeding costs through flooding, and so on, maximising their self-interest at the expense of the efficiency of the irrigation system as a whole; and the *excluded losers*, who receive inadequate water or none at all. The latter lose not only relative to the bureaucracy and privileged users, but also absolutely insofar as (a) they bear, directly or indirectly, part of the costs of financing government irrigation investment, and (b) irrigation by privileged users results in lower output prices, or in higher prices for mobile inputs. There are conflicts between the bureaucracy and the privileged users, notably over the partitioning between them of the income streams generated by irrigation, but these are conflcits between allies. Each remains dependent upon the other, and both present a united front against the excluded losers.

Such a situation is depicted by Robert Wade (1982a, 1984) in his penetrating studies of the 'system of administrative and political corruption' governing a canal irrigation system in south India. Kickbacks from maintenance contracts, and illicit payments for privileged access to irrigation water, are collected by local irrigation officials and then are 'aggregated and channelled up the bureaucratic hierarchy, each level taking a share.' Officials who do not satisfactorily fulfill this informal responsibility, or who display an inconvenient devotion to their more formal duties, are reassigned to undesirable posts. After recounting the failure of one modest policy effort to increase irrigation efficiency by reducing head-tail disparities, and portraying the powerlessness of a reform-minded official who tried to implement it, Wade concludes that the institutions of governance do not serve the social goals of productive efficiency, but rather "have themselves become a means by which resources are illicitly and coercively channelled out of the hands of the public and out of the state treasury, into the hands of senior officials and politicians".[74]

Such practices are not uncommon. Carruthers (1983) writes that his own extensive field experience "tends to confirm that the process Wade describes is, with variants, found elsewhere". He reports that an appraisal of "any irrigation scheme is likely to reveal that there is an unofficial system of illicit payments", including "bribes for additional water or ignoring illegal crops", and "extortion for delivery of allocated water—a kind of insurance or protection racket". Citing nineteenth century accounts from northern India, Carruthers notes that "such transactions have long been established practice". He underscores some of the efficiency implications:

> Given that this process creates uncertainty and unreliability it must affect farming investment. Indeed, as Wade points out, to maximise bribes, engineers have to persist with *ad hoc* unannounced cut-offs, water rotations and *create* uncertainty. He points out that operating engineers may blunt reform if it weakens their financial interests. Running the complex water financial market must detract from their professional activity and tapping the O&M [operation and maintenance] budget must produce substandard work. . . [I]n very few of the official donor evaluation reports is the subject mentioned and in none is it given any prominence. But it probably does constitute a major impediment to efficiency. Bribery is not a lubrlcant to the operating system, it is corrosive.[75]

The efficiency costs cited by Carruthers—the deliberate creation of uncertainty and the opportunity costs of the time devoted to rent collection—are enforcement and transactions costs incurred to assert and protect the *de facto* property rights of the irrigation bureaucracy, and to capture the resultant income streams. To some extent, such costs are inevitable: property rights must be tended to, and this tending requires the expenditure of resources. Carruthers' argument can thus be rephrased as the claim that enforcement and transactions costs are *too high* under a 'system of administrative and political corruption'. This is probably true—such costs could be reduced, though not eliminated, under a less 'corrupt' system—but the efficiency implications of politicised bureaucratic water allocation go further.

Consider the counterfactual situation in which the water bureaucracy enjoys absolute control over water allocation. Its *de facto* property rights in irrigation water, established and protected at whatever cost, are exclusive. The privileged users have no *de facto* rights of their own in respect of this water; they are customers, not allies. If this bureaucracy proceeded to maximise its net income from the 'bribes' paid for the water, one would expect an efficient outcome in the specific sense that the marginal value product of the water would be equalised across farms. Discrimination against locational or political 'tail-enders' would disappear, for such discrimination would reduce the total volume of rent available for appropriation by the bureaucracy. In other words, privileged users and excluded losers would no longer exist; we are left only with the bureaucracy and the users. There will still be enforcement costs and transactions costs, but the system will otherwise be efficient.

If, in the real world, we find privileged users and excluded losers, this suggests that the irrigation bureaucracy does not in fact exercise absolute power or have exclusive property rights in irrigation water. Rather, the privileged users constitute a separate power bloc with *de facto* water rights of their own. The bureaucracy dispenses irrigation water not as a simple commodity, but also as patronage; the state appears to sell water, but at the same time it buys political support. In Wade's example of the failed irrigation reform, opposition came not only from the irrigation bureaucracy but also, quite strongly and effectively, from the privileged users. The latter instituted legal proceedings to delay the reform, physically threatened the lone official who tried to implement it, and ultimately, after 'lobbying hard and expensively' in the state capital, secured his transfer out of the area. The political power of the privileged users thus conditions and circumscribes the power of their allies in the irrigation bureaucracy.

This duality of power, in which the state is not omnipotent but rather operates in partnership with powerful private interests, gives rise to the free rider and externality problems which, in addition to enforcement and transactions costs, undermine efficiency on canal irrigation systems in south India and elsewhere. Indeed, the two sources of inefficiency often go hand in hand. Privileged users deny water to excluded losers not only to maximise profit on their own lands, but also to protect their *de facto* water rights. Again, Wade provides telling evidence:

> Any water sent into the distributory which was surplus to the requirements of the upstream paddy was sent into the drains—deliberately wasted by the upstream villages rather than let to flow down to the lower villages, in case the latter were able to plant an irrigated crop; for once farmers have an irrigated crop in the ground, they are in a stronger position to insist on water than when they are able to insist merely that abstract zoning rights be respected.[76]

In this light, Carruthers' recommendation that irrigation users associations be promoted as a 'countervailing voice' to the bureaucracy can be seen to go only halfway. To act as an effective force for improved efficiency, such associations would have to be formed above all by the excluded losers, the cultivators who now receive inadequate irrigation or no water at all.

In south India, then, we find not the absolute despotism of Wittfogel's ancient empires, but the petty despotism of the modern bureaucratic state. Political and economic inequality is not an instrument of productive efficiency, but an impediment to it. The vested interests of those who profit from the irrigation *status quo*—favourably situated cultivators, irrigation officials, and ruling politicians—effectively thwart the public interest; the conflict between individual and social rationality is resolved in favour of the former. In theory, it is possible, in Wade's (1980) phrase, to 'substitute management for water' by improving the efficiency of canal irrigation schemes, but in practice this proves difficult or impossible in the absence of self-regulating local irrigation organisations. The state is a poor substitute for such organisations; as A Sundar remarks, "In a socio-political situation where what is legitimate is what one can get away with, can there be any concern about public system performance?" He cites a proverb which eloquently sums up the frustrations of the would-be water manager: "In the land of nudists, what can a washerman do?"[77]

Wade characterises this state of affairs as 'a condition of populist anarchy', yet the system he depicts is carefully managed by and for an administrative and political machine: it is elitist rather than populist, well-ordered rather than anarchic. Wittfogel's emperor may have no clothes, but the state is by no means absent. Instead of an impartial arbiter of disputes and maximiser of efficiency, the state appears as a creator and dispenser of economic rents, enmeshed in the conflicts between competing private interests. For the failures and imperfections of the market, it substitutes failures and imperfections of its own.

Attempts by the state to increase its control do not necessarily improve efficiency or equity. In particular, as noted above, state intervention in pre-existing community irrigation systems is often reported to undermine the independence and efficacy of institutions. A number of observers have noted such corrosive effects. Vaidyanathan writes that the advent of British rule in India 'invariably weakened' local water conservancy institutions and 'increased the role of the government bureaucracy', and that this trend "was if anything intensified in the post-independence period".[78] Similarly, Sengupta has argued that during colonial rule in India community irrigation organisations survived mainly in those areas where local governments were relatively autonomous.[79] In a review of irrigation development in Asia as a whole, Barker et al (1984) caution that "assistance to community systems, unless carefully staged, can not only encourage the demise of community investment and responsibility, but also attach the local system to the unpredictable future actions of the technical bureaucracy".[80]

At least three reasons can be advanced to explain this phenomenon. First, as Barker *et al* note, government interventions tend to focus upon narrow, technical issues, to the neglect of the social intricacies of community irrigation institutions. Second, as Hart (1978) and Wade (1982b) have observed, government interventions frequently entail a paternalistic mode of interaction, in which cultivators become dependent on resources from 'higher' authorities. This paternalism "will more likely undermine than promote a subsequent capacity for more autonomous initiatives".[81] At the same time, government "assistance to community systems is often couched in disrespectful terms", reinforcing the devaluation of local institutions.[82] Finally, the use of public spending on irrigation development as a vehicle for political patronage creates new profit opportunities for local leaders, and this may shift their individual cost-benefit calculus against the maintenance of traditional norms and institutions.[83]

There are counter-examples in which state intervention appears to have strengthened community institutions. Barker *et al* mention government technical assistance to community irrigation systems in north Sumatra, Indonesia, as an instance of an approach supportive of local institutions. Planck and Sutawan (1983) maintain that the intervention of government agencies "does not seem to result in great strain and stress" in Balinese *subaks*; instead, the construction of dams and canals by state authorities "has eased the burden in maintenance and repairs of irrigation structures for the subak members". And Sengupta concludes that the 'melons-on-a-vine' approach to irrigation in Japan and China, whereby large-scale works are designed to serve relatively independent local sub-systems, has preserved local autonomy.[84] In contemplating government interventions, however, the common if not inevitable experience of adverse effects upon prior community systems contains salutory lessons.

The autonomy of the state is circumscribed not only by the power of private interests within the country, but also by external forces. This was most evident in the colonial era, when many Asian states were directly and formally subordinated to imperial powers. Yet external influence persists in independent states, in proportion, among other things, to their dependence upon financial flows from multilateral and bilateral international agencies. Such dependence is considerable in a number of Asian rice producing countries, and has helped to shape the pace and direction of their irrigation development.

Direct foreign involvement in Asian irrigation dates from the mid-19th century, when canal systems were constructed in the Punjab and Uttar Pradesh under British rule. The Dutch in Indonesia and the Japanese in Taiwan also initiated major surface water irrigation projects in the colonial period. Yet the major foreign involvement in irrigation development in the region as a whole began after World War II, when international agencies provided financial and technical assistance for a number of large-scale irrigation and multi-purpose water development projects. Examples include the Mekong River Plan, the groundwork for which was laid by a survey conducted by the United Nations Economic Commission for Asia and the Far East in 1951; the Damodar Valley Project in eastern India, which received financial support from the United States Agency for International Development (USAID) in 1953; the Andong Dam on the Nam River in South Korea, constructed in 1960 with financing from the Asian Development Bank; and the Mangla and Tarbela Dams in Pakistan built in the late 1960s with financing from the Indus Basin Development Fund created by the World Bank.[85]

From the 1960s, international agencies extended their involvement to smaller-scale irrigation development, including groundwater exploitation. For example, the first government-sponsored groundwater irrigation scheme in what is now Bangladesh, the Thakurgaon deep tubewell project, was designed and financed by West German bilateral aid in the mid-1960s. The World Bank subseqently sponsored the installation of 3,000 deep tubewells in the Northwest Tubewells Project, with co-financing from the Canadian and Swedish official aid agencies, and the UK government financed an even larger deep tubewell project in north central Bangladesh. In the late 1970s, the World Bank, UNICEF, USAID, and other donor agencies began to finance shallow tubewell and hand tubewell irrigation projects in Bangladesh as well.

Nevertheless, as Levine (1980) observes, "generally it has been easier to obtain external financing for large projects than for small ones". He cites a variety of reasons for this:

> [M] any international loans cover the foreign exchange component of the project and since large projects tend to have a relatively larger foreign exchange component they are favoured for funding; the accounting and oversight requirements associated with the international loans are more easily accommodated within a large concentrated project than within a set of dispersed smaller projects; the documentation for adequate consideration of the project (basic hydrology, technical details, economic projections, etc) are more easily developed for large relatively compact projects than for small projects.[86]

Reliance upon external funding can hence be expected to influence the scale of irrigation development.

Table 3 presents summary date on foreign investment in irrigation in Asian rice-producing countries from 1969 through 1981. Total investment during this period exceeded US $ 8 billion, with more than $ 2 billion in India and nearly that amount in Indonesia. In per capita terms, the highest levels of foreign investment in irrigation were in Malaysia, South Korea, and the Philippines. External financing accounted for roughly half of the total capital costs incurred for irrigation in south and southeast Asia as a whole in the mid-1970s.[87] The central role of irrigation in Asian agricultural growth is now widely recognised by international agencies, with the result that external financing for irrigation development can be expected to continue and possibly increase in real terms in the next decade, even if total development assistance budgets shrink. In 1978 the Trilateral Commission proposed an ambitious plan to double rice production in Asia by 1993 via massive irrigation investments. Thirty million hectares in south and southeast Asia were to be brought under irrigation, and pre-existing irrigation facilities on an additional 17.5 million hectares were to be improved, for a total capital outlay of $ 52.6 billion (at 1975 prices). It was envisaged that approximately 61 per cent of this expense would be borne by the OECD countries, and an additional 12 per cent by OPEC countries, with the remainder coming from the south and southeast Asian countries themselves.[88] Although resources on this scale have not been forthcoming, the proposal illustrates the potential scope of continuing external involvement in the region's irrigation development.

Reliance upon external resources often not only increases the scale of irrigation projects, but also entails reliance upon foreign technology and foreign institutional models. One frequent result is an increase in the capital intensity of irrigation development. This springs in part from the export-promotion motive in foreign assistance, in part from the fact that the technologies being transferred were generally developed under conditions of relatively greater labour scarcity, and in part from a preference among foreign and foreign-trained engineers and

TABLE 3: FOREIGN INVESTMENT IN IRRIGATION IN ASIA, 1969-81

Country	Foreign Investment	
	Total ($ m)	Per Capita ($)
Total	8,418	5.4
Bangladesh	657	7.5
Burma	169	5.1
India	2,042	3.1
Indonesia	1,896	13.6
Kampuchea	—	—
Korea (S)	781	20.7
Laos	60	16.7
Malaysia	373	27.3
Nepal	183	13.3
Pakistan	485	6.1
Philippines	952	20.1
Sri Lanka	237	16.4
Thailand	473	10.4
Vietnam	110	2.1

Source: Takase (1984), p 189.

planners for 'modern' techniques. This bias is illustrated by the World Bank's Northwest Tubewells Project in Bangladesh. The technology chosen for this project was sophisticated and expensive, akin to that used in the midwestern United States. Submersible turbine pumps were imported from West Germany, engines were imported from Britain, fibreglass screens and casings were imported from Canada (the Canadian government's contribution to the project), the drilling of the tubewells was contracted to foreign firms who used imported power rigs, and overall technical supervision was provided by a British consulting firm. The total cost was approximately, $ 12,000 per tubewell, more than a hundred times the average annual per capita income in Bangladesh.

The technology chosen for the World Bank's project was inappropriate in four respects. From a technical standpoint, the pumps were ill-suited to the less than ideal operating conditions of rural Bangladesh, and hence vulnerable to breakdowns which were often prolonged by the absence of specially trained mechanics and imported spare parts. From an economic standpoint, the high capital-intensity of the project was inconsistent with the country's labour abundance and capital scarcity. From a social standpoint, the tubewells' 60-acre-plus potential command areas would require a level of co-operation in water allocation which is unlikely to be achieved given the country's disarticulated and inegalitarian agrarian structure. Finally, from a political standpoint the technology can be characterised as inappropriate in that the ostensible beneficiaries had no opportunity for personal participation in the installation of the tubewells; they were treated as objects, rather than subjects, of the development process.[89]

An alternative deep tubewell technology, developed in Bangladesh itself, was available at the time. Its installation required 20 times more labour; its drilling equipment was highly mobile and easily transported by hand; its screens and casings were manufactured locally; its pumping equipment was easier to maintain; and it cost ony half as much. The foreign engineers who selected the technology for the Bank's project in 1970 observed this alternative in operation during their three-week visit to Bangladesh. Researcher John Thomas, who accompanied them, describes their reactions. While watching the low-cost wells being installed "in a sea of mud by a large group of villagers", one of the Bank's engineers remarked, "You can't install reliable tubewells this way." Yet Thomas notes that tests showed the low-cost wells to be of equal quality to the high-cost ones. In fact, they were *more* reliable under village operating conditions, since they were easier to maintain and repair. Thomas argues that the decisive factors behind the Bank's choice of the more capital-intensive technology were a desire for "risk avoidance, appearance of modernity, established procedures, familiar techniques, and, by no means least, control". The government agency involved in implementing the project shared many of these preferences; as Thomas notes, agencies and their staffs derive "power, prestige, and sometimes an opportunity for profit by attracting foreign aid and implementing large programmes".[90]

There are, of course, cases in which foreign-assisted irrigation projects have employed small-scale, labour-intensive, 'appropriate' technologies. Assistance to manually-operated shallow tubewell development in Bangladesh is one example. Few generalisations about the disbursement of billions of dollars by dozens of different agencies in more than a dozen countries can be universally true. Yet one can hypothesise that, in general, official foreign assistance tends to bias irrigation development towards larger scale, greater capital intensity, greater reliance on imported goods and services, and more centralised, top-down methods of control.

The experience of irrigation development in the People's Republic of China provides an interesting contrast, although the facts of the situation remain somewhat unclear. What is not disputed is that after the 1949 revolution, China vastly increased its irrigated acreage with very little foreign assistance.[91] Highly labour-intensive earth-moving projects are widely credited with much of this increase. For example, a World Bank study reports:

> The enormous effort implied by the development of [irrigation on] over 29 million hectares since 1949 would not have been possible without the massive involvement of the local populace organised by the collective institutions... Except for large dams built on major rivers or extensive dredging, almost all water conservancy work in China is done by hand, using wheelbarrows, small carts, and often shoulder poles and baskets for transportation. Projects with tens of thousands of workers are common. On average, as many as 50-80 million participants are engaged in winter/spring construction campaigns.[92]

Yet some observers, skeptical as to the productive impact of these projects, maintain that irrigation expansion has been primarily attributable to tubewell development on the north China Plain.[93] The extent of centralised control in Chinese irrigation has also been a matter of debate.[94]

Thus while the state has played a major role in shaping the pace and character of Asian rice irrigation, it cannot be regarded as an autonomous, let alone omnipotent, agency able to maximise efficiency and subordinate private interests to the public interest. Rather, state power is circumscribed by the influence of the vested interests on which it depends for political support, by the resistance of those who are subordinated, and by the leverage of external agencies with their own agendas to pursue. Once again, the issue of exogeneity arises: why, for example, does a more powerful or interventionist state emerge in one setting, and a weaker or less interventionist one in another? To some extent, the answer may lie in the other factors we have considered—population pressure, geography, agrarian structure, and cultural factors. For example, Ruttan (1978) characterises the Chinese revolution as an institutional change, induced by the "long period of secular economic stagnation" in China in the preceding 100 years, which "gave both the local community and the broader society more effective control over local and national resources".[95] Yet few social scientists (and fewer historians) would advance an entirely deterministic account of state formation.

VI

Conclusions

This paper has surveyed the technological and institutional alternatives in Asian rice irrigation, with a view to explaining the wide variations in the pace and character of irrigation development in the region. In much of Asian rice agriculture, irrigation acts as the 'leading input', or binding technological constraint upon increases in land productivity. Yet the pace of irrigation development in the region has been very uneven, with the percentage of net sown area irrigated ranging from only three per cent in Kampuchea to 76 per cent in Japan. At the same time, the character of irrigation development varies in a number of dimensions, including scale, relative factor intensity, institutional arrangements, and the degree of 'farmer controlledness', in addition to the usual hydrological and engineering criteria.

No attempt will be made here to summarise in detail the various factors which may help to explain these variations. Rather, a few concluding observations will be advanced. First, much of Asian rice irrigation requires action above the level of the individual farm, and thus lies in the large intermediate terrain between the extremes of pure private goods and pure public goods. This intermediate terrain is inhospitable to the elegant but fragile axioms of conventional economic theory. The pursuit of individual self-interest cannot be assumed to promote the public interest; the invisible hand loses its grip. Conflicts between individual and collective rationality are a common feature of irrigation development, and Asian societies differ considerably in the success with which they have resolved them.

Second, the determinants of irrigation development considered above—population pressure, geography, agrarian structure, cultural factors, and the role of the state—are not independent variables, much less mutually exclusive ones. It is not the case that there are simply several causal factors at work, the relative strength of which could be assessed, if all variables were quantifiable, and measurable via a multiple regression procedure. Rather, the various determinants are themselves interrelated: population pressure affects the agrarian structure, cultural factors affect the role of the state and vice versa, and so on. Moreover, the relationship between these 'determinants' and irrigation is not unilinear, since irrigation in turn may profoundly influence each of them. Any attempt to explain variations in the pace and character of irrigation development must hence find a passageway between the pitfalls of reductionism and of particularism, between the impulse to identify an ultimate prime mover which explains all, and the urge to abandon any comparative framework and instead treat each case as *sui generis*.

Finally, the process of technological change is not always smooth or elastic with respect to population pressure, as evidenced by the underdevelopment of irrigation in much of contemporary south and southeast Asia. The foregoing analysis suggests that such underdevelopment is not accidental, but rather is the outcome of a particular constellation of factors. In such a situation, it may be tempting to search for a magic wand of government policy which can, at a stroke, surmount conflicts of individual interests and ensure efficient outcomes. Thus Wittfogel's vision of the oriental despotism of ancient times is reborn in the modern, technocratic vision of irrigation development, in which rights and responsibilities are clearly demarcated by an impartial, efficiency-maximising state. The relative importance of bureaucratic versus market allocative mechanisms is here a secondary issue; what defines the technocratic approach is not its choice of instruments for social engineering, but rather its assumptions as to who will make such choices and direct the development process. A comparative analysis of Asian rice irrigation underscores the limitations of this vision, and points to the potential merits of alternative strategies based upon the democratisation of control over water resources.

Notes

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1 Masefield (1977), pp 21-22.
2 Food and Agriculture Organisation (1985), p 59. Of course, not all this acreage is sown to rice; for an indication of the importance or rice in their cropping patterns, see Table 1, below.
3 Calculated from data presented by Todaro (1985), pp 33, 40.
4 Much of the existing literature on Asian rice irrigation is highly fragmented, along both locational and disciplinary lines. Among the few works which adopt a comparative perspective are Coward (1980), Vaidyanathan (1983), and Barker *et al* (1984).
5 Ishikawa (1967), p 94. Ishikawa's figure for the yields of paddy (unhusked rice) is here converted to clean rice using the FAO conversion factor of 0.8 for Japanese brown rice.
6 The environmental differences between Japan and southern Asia are reflected in the characteristics of the *japonica* and *indica* races of rice native to them. The *japonica* varieties require the long day-lengths of summer in the high latitudes, and they need a longer growing season than the *indica* varieties, a point which should be borne in mind when comparing their yields.
7 See, for example, David and Barker (1978).
8 Boyce (1978), Chapter 6.
9 For example, Alamgir (1980) reports visiting the Ganges-Kobadak project, the main canal irrigation scheme in the country, as a member of a Planning Commission evaluation team in 1974, and finding less than 10,000 acres of actual dry season irrigation, in contrast to the published official figures of 61,292 acres. The 1977 Agricultural Census (Government of Bangladesh, 1981) found net irrigated area to be 11.3 per cent of net sown area; official data for the same year reported net irrigated acreage to be approximately one-third higher, at 14.7 per cent (Government of Bangladesh, 1985, pp 690, 825).
10 Gopinath (1976).
11 The relationship is somewhat clouded by intra-state variations; in Uttar Pradesh and Bihar, for example, irrigation is concentrated in wheat-growing areas.
12 Government of Bangladesh and FAO/UNDP Mission (1977), p 4.
13 Calculated from data in MacDonald and Partners (1982), Vol 3, Report V, Tables 2.2 and 7.10.
14 Agarwal *et al* (1982), p 6.
15 Biswas (1980); Carruthers and Clark (1981), pp 129-131.
16 This concept of neutrality is generally attributed to Hicks, although it can be traced to Pigou. See Boyce (1987), p 50, n 2.
17 Palmer-Jones (1986) reports variants of these three payment systems encountered in a survey of deep tubewells and low-lift pumps in Bangladesh, and analyses their equity and efficiency implications.
18 Chambers (1980), p 36. To illustrate the latter, Chambers quotes John Harriss on a system in Sri Lanka where 'in time of scarcity water supplies depend on the strength of a man's right arm'.
19 Chambers (1980), pp 40-41.
20 See Nickum (1978).
21 I am indebted to Michael Lipton for suggesting this term.
22 Worster (1985), p 7.
23 Howes (1984), pp 22-23.
24 Dhawan (1982), p 154, reports that falling water tables due to the installation of tubewells may help to account for 'the disappearance of traditional wells from the Punjab agriculture'. Howes (1982) and Gill (1983) report similar conflicts between deep and shallow tubewells in parts of Bangladesh.
25 See Worster (1985), pp 141-2.
26 Sengupta (1985), pp 1930-1.
27 Sengupta (1985), p 1927; see also Tamaki (1977), p 24.

28 Cohen (1977), p 14.
29 Boserup (1965), pp 59-61.
30 Clark (1967), pp 137-138.
31 Simon (1975), p 76.
32 Boserup (1965), p 118. See also the comments of Coale and Sovani regarding Sri Lanka, India, and Japan, in Coale, ed (1976), p 296.
33 Boyce (1987), Chapter 5.
34 Hicks (1932), p 120.
35 For a summary of evidence from India, see Sen (1975), Appendix C.
36 In India, for example, as Sengupta (1985, p 1920) observes, "The steeper slopes of the Himalayas or the Western ghats do not provide as much slope [for gravity flow irrigation] as the gentle slopes of the Eastern ghats".
37 Vaidyanathan (1983) explains the prevalence of tanks in south India in this way.
38 Hsieh and Ruttan (1967), pp 337-9.
39 Bray (1983), p 26.
40 For an international review of the evidence, see Berry and Cline (1979). Much of the Indian evidence is summarised by Sen (1975), Appendix C. Rudra (1982), pp 150-189, stresses the non-universality of the inverse relationship, however.
41 For discussion, and a consideration of the related issue of land quality differences, see Boyce (1987), pp 38-41, 201-213.
42 For discussion, see Ghose (1979).
43 Ideally, such a distributional measure should be adjusted for variations in household size, and for variations in the proportion of income derived from non-agricultural sources.
44 Colombo *et al* (1978), p 29. More generally, Uphoff and Esman (1974, p 64) write: "The first condition for developing effective local initiative seems to be the relatively equitable distribution of assets, which in the Asian rural context means primarily land".
45 Palanisami and Easter (1984), p 223.
46 Ramamurthy (1984), Part 1, pp 6, 22, citing conference papers presented by Nirmal Sengupta and T K Jayaraman.
47 Lipton (1984), p 44.
48 For example, in the Mayurakshi canal irrigation project of West Bengal, it was originally envisaged by planners that half of the acreage irrigated in the dry winter season would be sown to wheat, and the remainder to mustard, pulses, vegetables and sugarcane. In practice, however, the principal crop irrigated is rice. This helps to explain why winter season irrigation in the mid-1970s covered only 31 per cent of the projected command area. See Boyce (1987), pp 232-3.
49 Horst (1984), p 212.
50 The phrase is used by Wood (1984), p 79.
51 See Leach (1961), pp 158-9; Coward (1979), pp 30-31; Siy (1982), pp 54-55; and Sengupta (1985), p 1931. In these cases, it will be noted that fragmentation of landholdings promotes efficient water use. Sengupta observes that in such a context government-enforced land consolidation programmes are likely to be counter-productive.
52 Jairath (1985), p A-6.
53 A divergence between technical and individual optima can arise for two reasons. First, water does not flow uphill. Maximisation of the tubewell's command area hence requires siting it on high ground, whereas maximisation of individual control requires that it be sited on the waterlord's land; the two criteria often dictate different sites. Second, individual neglect of externalities arising from falling water tables will result in tubewells being sited too close to each other.
54 For further discussion see Boyce (1987), Chapter 7.
55 Palmer-Jones (1986), p 14.
56 Griffin (1985), p 19.
57 For some preliminary observations, see Hinton (1983).
58 Ramamurthy (1984), Part II, pp 7, 12.
59 Scott (1985) provides an exceptionally close observation of such resistance in rural Malaysia.
60 For references, see Hayami (1981), p 14.
61 See Rapoport and Chammah (1965); Sen (1977); Lipton (1984); and Axelrod (1984).
62 Lipton (1984), p 30.
63 Geertz (1980), pp 79-82.
64 The very name, *dharma tirta*, has social and religious connotations. '*Dharma* suggests social interdependency, and community, while *tirta* signifies sacred, pure water with life-giving fertility'. Duewel also notes that the land ownership pattern in the central Javanese villages he studied was quite egalitarian: absentee landlordism was 'practically non-existent', and very few households owned more than one hectare of land. He suggests land tenure systems elsewhere might be another impediment to *dharma tirta* development. Duewel (1984), pp 265, 269, 284-5.
65 Hayami (1981), p 14.
66 As evidence of the greater 'looseness' of Thai village structure, Embree cited the 'less clearly defined and less strictly enforced' rights and duties of villagers; the mobility of the population; and the lack of emphasis on long-term obligations, as exemplified by the absence of long-term village financial credit associations. For evidence of comparable 'looseness' in rural Bangladesh, see Van Schendel (1981) and Hartmann and Boyce (1983).
67 Geertz (1980), p 87. In speaking of 'social system of the Balinese sort', Geertz is here refering to more than simply irrigation, but the underlying issue is the same.
68 Sengupta (1985), pp 1930-5.
69 Lipton (1984), pp 45-46.
70 Chambers (1980), p 48.
71 Both factors could, of course, be jointly at work, and it may be that in some circumstances an inegalitarian, hierarchical culture is more resilient in the face of external pressures.
72 The causality need not be unilinear; that is, the need for irrigation could help to induce the emergence of authoritarian states, and, at the same time, the emergence of such states could increase the possibilities for irrigation development. See Mitchell (1973).
73 Dictatorship plays an analogous role in social choice theory; see Arrow (1951).
74 Wade (1984), pp 288, 298-9.
75 Carruthers (1983), pp 64-66.
76 Wade (1984), p 290.
77 Sundar (1984), p 22.
78 Vaidyanathan (1983), pp 37-38.
79 Ramamurthy (1984), p 5, citing Sengupta's work on *aharpine* irrigation in southern Bihar.
80 Barker et al (1984), p 30.
81 Wade (1982b), p A-103.
82 Barker et al (1984), p 29.
83 The use of irrigation development funds for patronage is stressed by Vaidyanathan (1983), pp 38-39. For an illuminating account of the corrosive effects of the introduction of external resources upon traditional social organisation, see Van Schendel (1981), pp 215-8, 247-8.
84 Sengupta (1985), pp 1927, 1935. On irrigation development in Tokugawa Japan, see Kelley (1982). On China, see Nickum (1979, 1982), and Vaidyanathan (1984).
85 Cruz, Briones and Hufschmidt (1984), pp 3-4.
86 Levine (1980), p 9.
87 Colombo, Johnson and Shishido (1978), p 36.
88 Ibid, pp 31-36.
89 Hartmann and Boyce (1983), pp 259-260.
90 Thomas (1975), pp 53, 56-57.
91 According to the World Bank (1981), p 62, irrigated acreage rose from 16 million hectares in 1949 to 45 million hectares in 1981.
92 World Bank (1981), p 9.
93 Perkins and Yusef (1984), pp 50-51.
94 Vaidyanathan (1984), pp 80-81, states that the organisational structure for the construction, operation, and maintenance of irrigation systems in China 'has been and remains considerably less centralised than is generally supposed', and that the role of the state bureaucracy is much more limited than in India. Nickum (1982), p 65, on the other hand, observes that "the actual role of the present democratic management bodies is unclear", and that evidence from some places indicates that they "have little say over the choice of their *ex officio* leadership" and "are 'top-heavy' with higher-level officials".

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