

# Impacts of Climatic Variability in Australian Agriculture: A Review

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A framework is sketched for exploring the pervasive impacts of variations in climate on the uncertainties and instabilities of the Australian rural sector. Low rainfall is identified as the dominating climatic variable. Effects of climatic variation are investigated and measured at farm, regional, industrial, sectoral and national levels. Where possible, sensitivities to climate are measured by elasticities of production with respect to rainfall indexes. Some consequences of possible climatic change are discussed.

## 1 Introduction

Climatic variability is an important fact of life of Australian agriculture. The topic has already been the subject of reviews from various points of view (see, *e.g.*, Williams, 1946; Rutherford, 1950; Everest and Moule, 1952; Anon., 1966; Campbell, 1966; Anon., 1967; Anon., 1968; Lovett, 1973; McQuigg, 1975; Chapman, 1976; Butler and Doessell, 1979; Heathcote and Thom, 1979; Young and Wilson, 1979). However, the observation of Campbell (1958, p. 3) that "one cannot but be impressed by the extremely limited progress which we, as a people, have made . . . in coming to terms with the most insidious and pervasive characteristic of our climate—its variability" is still cogent. The objective in this paper is to complement the previous reviews with one that spans agriculture from farm to the macro-economy and spans climate generally rather than one that focuses particularly on drought.

However, within this broad charter, the present review is selective in scope and is confined to economic (as opposed to the important ecological, environmental, meteorological, physiological and sociological) aspects. First, a framework is developed to provide a structure in which particular studies including future work might be considered. This features behavioural motivations and probability distributions of financial performance, physical performance and prices. Second, investigations of the impacts of climatic variability on domestic agriculture are reviewed against this framework. These studies are categorized first by level (farm, industry, region and sector) and within level variously by region, industry or type of impact. In the final section, conclusions are reached about the desirability of further work, particularly concerned with interventions by governments in the impacts of climatic variability.

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## 2 A General Framework for Reviewing the Impacts of Climatic Variability on Agriculture

The complexity of the relationships between climatic variations and the people in, and dependent on, the agricultural sector can be tackled by a simplified disaggregation of the major effects. By an approach of “divide and conquer”, it is intended to address the pervasive effects of instability and uncertainty that emanate from climate.

### 2.1 Behavioural Assumptions

A starting point is the basic behavioural assumption about what motivates the key economic agents in farming—the farmers who make the economic decisions. This objective or utility function can be stated as—

*Function 2.1: Satisfaction in farming depends<sup>1</sup> on—*

- (a) personal characteristics; and
- (b) the probability distribution of financial performance.

Although the utility function is a basic element of economic models, it is inadequately understood and deserves refinement. Too much of conventional economics has been predicated on the assumption that producers simply maximize expected profits. One personal aspect that is being recognized more widely is that producers have individual and non-neutral attitudes to risk (Anderson, Dillon and Hardaker, 1977).

There is mounting evidence (Francisco and Anderson, 1972; Bond and Wonder, 1980) that these attitudes are typically ones of aversion to risk so that, in Function 2.1 (b), features of the probability distribution other than the expected value (*e.g.*, variance, semivariance, lower range, skewness *etc.*) are also relevant to decision making.

An important personal characteristic, which influences attitudes to risk and is itself determined by bequest, previous financial performance and luck, is the wealth or asset base of the farmer. This changes over time, partly as a result of climatic fortunes.

### 2.2 Probability Distributions of Financial Performance

The second general relationship is a mix of behavioural and environmental effects which enter into Function 2.1 (b)—

*Function 2.2: The probability distribution of financial performance depends on—*

- (a) allocative decisions;
- (b) the probability distribution of yields (productivities);
- (c) the probability distribution of prices (unit returns); and
- (d) institutions, and governmental interventions.

<sup>1</sup> In this and the three following relationships, the arguments are listed in the believed order of importance.

Allocative decisions subsume all the decisions made by the farmer such as improvements, intensities of operation, combinations of activities *etc.* The probability distributions noted in Function 2.2 (b and c) may not, in fact, be independent, *e.g.*, drought-reduced cuts of wool may be associated with reduced strength and quality (see Chislett, 1973) and price, in which case the joint distributions must be accounted for (Anderson, 1976). Interventions by government other than through prices may be passive (*e.g.*, the progressive income taxation structure) or active (*e.g.*, various forms of assistance for relief from natural disasters such as drought, flood and tempest).

Functions 2.1 and 2.2. can be combined and rearranged so that only measures of allocative decisions appear on the left-hand side. Such supply analysis has been extensive in agriculture (see, *e.g.*, a recent review by Askari and Cummings, 1977) but only recently has attention been focused on estimating the considerable effects of variability *per se* (*e.g.*, Just, 1974; and references reviewed in Griffiths and Anderson, 1978). It is broached here in Section 4.2.

### 2.3 Probability Distributions of Yields

The third general relationship summarizes the main direct effects of climate at the farm level—

*Function 2.3:* The probability distribution of yields depends on—

- (a) climate; and
- (b) allocative decisions.

The influence of climate on yields is obvious even if not precisely understood. The following generalization for the growing of plants in Australia is based on the discussion of Fitzpatrick and Nix (1970). Solar radiation is rarely an important constraining factor, the thermal regime sets the major seasonal growth patterns and constrains growth in most of the country during winter, and the dominating climatic factor in growth is the moisture regime. This is determined by evaporation, and precipitation (mainly as rainfall) which is typically meagre, strongly seasonal and inevitably variable. The validity of these generalizations is supported by the empirical work of Easter (1975) who related several measures of pastoral production to rainfall and/or to estimated soil moisture levels over different periods. The relationships of Function 2.3 are exemplified here in Sections 3, 4.2 and 4.4 and the consequent aggregative impacts are explored in Sections 5.1 and 6.1.

Many of the allocative decisions of farmers are influenced by climate and are, in turn, often intended to mitigate the effects of climatic variation—consider, *e.g.*, drought feeding of livestock (Hill, 1973), irrigation scheduling, trapping soil moisture by fallowing (Caro, 1975), choice between wheat and barley, *etc.* Moreover, there is typically a strong “interaction” between controlled decision variables and uncontrolled climatic factors in production, *e.g.*, between rainfall and other climatic factors, and crop variety (Anderson, 1974), stocking rate (Chisholm, 1965; Byrne, 1968; McArthur and Dillon, 1971) or fertilizer (Anderson, 1973; Watson and Anderson, 1977).

## 2.4 Probability Distributions of Prices

The fourth and final general relationship is concerned with what are normally thought of as economic considerations but which surely also have a climatic component—

*Function 2.4:* The probability distribution of prices depends on—

- (a) consumer demand (*i.e.*, incomes, tastes, habits, fashions, *etc.*);
- (b) institutions, and governmental interventions; and
- (c) supply and thus also climate.

Climate may also directly impinge on consumer demand (as noted by Kefford, 1979) and may also act directly on price (*e.g.*, rain on wine grapes in the pre-harvest week). However, the major effects in mind under Function 2.4 (c) are the aggregate shifts in supply caused by variations in climate, *i.e.*, aggregations of the effects noted in Function 2.3 (a) and here explored further in Section 6.1. Some of these variations will, of course, be experienced by Australia's trading partners and may be experienced in Australia as shifts in export demand (*e.g.*, USSR crop failures—see Section 4.3).

The prices in mind in Function 2.4 are mainly prices for agricultural products. However, prices for farm inputs also can be influenced through general equilibrium effects of widespread climatic events (*e.g.*, price increases for farm materials through increased demand in a good season following a drought). Following Campbell (1958), it has been widely held that most farm investment derives from "residual funds" available for such purposes after income-unresponsive consumption outlays have been made. If this generalization is true, climatic variability, through its effect on disposable incomes, must have a direct impact on variability of investment in the agricultural sector (see Section 5.1). There is some evidence (BAE, 1976a, pp. 20–2) that instability is associated with differences in the amount and type of investment undertaken. However, the significance of this evidence is difficult to assess, given the cross-sectional interactions among instabilities of income, enterprise orientations and investment decisions.

Taken together, Functions 2.1 to 2.4 depict an agricultural sector directly dependent on climate, and hence farmers are subject to the vagaries of climatic variability. In short, this sector of the economy (like others) is risky and, when the impact of climatic uncertainty is exacerbated by market uncertainties, agriculture could well be described as "turbulent".

Agricultural performance certainly varies with climate. One of the evident roles of man the farmer is to buffer crop and animal production against natural climatic variations. This role of "stabilizer" can be frustrated further by variations arising from the non-physical environment of agriculture—especially from consumers' changing tastes, reflected in varying prices. For example, at meteorological stations in the eastern Pastoral Zone, coefficients of variation (*i.e.*, standard deviation/mean) of annual rainfall<sup>2</sup> are about 0.5 whilst for annual wool production on individual farms they are about 0.3. However, after allowance for variable costs and product prices, coefficients of variation of net farm incomes (and rates of return) of individual wool producers in this zone are about 0.8 (Anderson, 1972).

<sup>2</sup> Variability within years is also considerable (Verhagen and Hirst, 1961).

Each of Functions 2.1 to 2.4 has a dual interpretation depending on whether it is being construed as a planning (*ex ante*) device or as an observational recording (*ex post*) device. Broadly speaking (see Quiggin and Anderson, 1979), the *ex ante* relationships can be characterized as risk (or uncertainty) and the *ex post* relationships as instability. Of course, these interpretations are connected (by the extent of predictability) and improvements in forecasting mean reductions in some of the costs associated with risk towards the lower costs associated with instability. However, the prospects for long-term forecasting of rainfall are so bleak that it appears that Australian farming will continue to be both unstable *and* risky. Unfortunately for the student of climatic variability, only the effects of instability can be studied with relative ease because most available data are *ex post* observations. Study of *ex ante* effects requires either elicitation of subjective probability distribution or inference about such distributions through econometric methods and is accordingly shirked in this review.

### 3 Farm-Level Impacts

Most of the pertinent farm-level economic research has involved interview surveys in drought-affected and drought-prone regions. It is usually difficult to pin down particular changes in the financial performance of farms as being due entirely to climate. Recalling Function 2.4, most droughts have been associated with price movements not entirely dependent on the drought itself.

#### 3.1 The 1965–6 Drought

Several studies followed the drought of the mid-1960s (*e.g.*, Cumming, 1966) and these serve to exemplify Functions 2.2 and 2.3 as *ex post* descriptors. In a study centred on the sheep and cattle industries of south-west Queensland, Haug and Hoy (1970) concluded that substantial negative net farm incomes occurred in drought years. These arose partly from reduced productivity and partly from falls in the size and value of livestock inventories. In this region since the late 1800s, cattle numbers have ranged erratically between an early peak of 1.3 million and 0.2 million, while sheep numbers have fluctuated between 5.5 million and 2.7 million.

Herd and flock performance and size are also highly variable in this region (Rutherford, 1948; Anderson and Bruyn, 1978; and the review by Young and Wilson, 1979). For example, over the six-year period 1962–3 to 1967–8, annual herd branding rates (branding to breeders) ranged from 28 to 60 per cent and herd mortality from 5 to 39 per cent. The impacts of drought on livestock farms can be very persistent and, as Rickards and Anderson (1967) have argued, planning (especially financial planning) for recovery must take explicit account of the dynamics of breeding programmes. In the sheep areas of the region over the same period, the ranges of flock performances were: lamb marking, 26 to 60 per cent; mortality, 5 to 37 per cent; and wool cut, 3.7 to 4.1 kg per sheep. Sheep turned off ranged from about 24 per cent in times of drought to 7 per cent in the subsequent flock build-up period. Net farm incomes in the beef area ranged from –\$26 to \$11 per cattle equivalent and in the sheep areas from –\$2 to \$2 per sheep equivalent. Generally because of falling herd and flock numbers, property asset values fell while borrowings rose to meet drought expenditures and post-drought restocking needs.

A similar picture has emerged from other surveys. A survey (BAE, 1969) of drought-affected properties in northern New South Wales and southern Queensland established that the net financial effects of the drought were considerable reductions in net farm incomes in 1964-5 and negative net farm incomes in the following year. In summary, net farm incomes in the period 1964-5 to 1966-7 relative to those prevailing in the preceding three years fell by about 30 per cent in the Wheat-Sheep and High Rainfall Zones of New South Wales and by about 80 per cent in the Pastoral Zone of both States.

An estimated 40 per cent of properties in the affected regions had borrowed during the drought and at the time sample farms were visited a slightly smaller proportion were intending to borrow for recovery. Amounts borrowed and intended to be borrowed totalled an estimated \$91m, about 60 per cent of financial requirements. It appears that very few properties were financially affected by the drought so seriously that the owners were forced to leave the industry. This contrasts with the rather more drastic consequences of severe drought in the semi-arid areas of some other countries, for example, India (Jodha, 1978).

The BAE authors endeavoured to cost the measures and strategies adopted by pastoralists in drought (BAE, 1969, pp. 20-6). These measures, recalling Function 2.2 (a), included (often in combined strategies) supplementary feeding, disposal, agistment, adjustment of breeding programmes and "no action" (see also Waring, 1960; Butler, 1975). A strategy of "no action" with regard to initiating reserves of stored fodder for drought use has been found in several studies to be sensible (Dillon and Lloyd, 1962; Officer and Dillon, 1965). Indeed, this strategy is one used most widely in the Pastoral Zone and typically in the High Rainfall Zone (Candler, 1958). Excepting the southern areas with a Mediterranean climate, it seems that financial reserves may be more important and useful in livestock drought management than are fodder reserves (Waring, 1976). Observations (BAE, 1969) were made on the extent to which pastoralists were able to draw on off-farm reserves. On many properties, expenditures of reserves were of the order of \$8,000 to \$20,000. Various budgetary techniques were applied to the management patterns adopted by the drought-affected producers in this survey.

Officers of the Reserve Bank (Anon., 1968) made a detailed sample survey of drought-affected properties in northern New South Wales. Farms were visited after the drought conditions of 1965 and, in view of the persistent adverse seasons, again in 1967. The impacts of drought on farm operations were found to include not only the usually accepted moves to reduce stock numbers and improve feed supplies but also a variety of other measures including reductions of development and living expenditures, increased crop-growing under reduced stocking pressures and increased borrowing and asset run-down. It was revealed that some producers had substantial off-farm reserves available for use in times of low farm income.

Drought relief measures are set on an individual State basis. They include concessions on road and rail freight on livestock to and from agistment; restocking movements; forced sales of livestock; fodder; water and grains. Loans to primary producers are also available at concessional rates and conditions for carry-on finance and restocking. Other measures are stock slaughter compensation, provision of centralized water points, and various forms of unemployment relief. Such measures are clearly of importance to affected individuals but in aggregate the cost is usually not very high. In 1966-7,

drought relief amounted to only 0.6 per cent of all government expenditure (Heathcote, 1967). However, in 1977–8, payments amounted to 1.2 per cent of expenditure for drought and 2.1 per cent for all natural disaster relief.

For overview purposes, some summary measure of sensitivity to climate seems required. Reid and Thomas (1973) and Easter (1975) explored the influence of rainfall and soil moisture on the performance of sheep in terms of effects on mating rates, reproductive rates and wool cut. Waring (1976) had similar statistical success in relating milk output for dairy cows in central New South Wales to autumn and spring rainfalls. The quantitative impact of such effects can be summarized roughly by means of elasticities with respect to annual rainfall.<sup>3</sup> Some such partial elasticities can be derived from Kingma and Kerridge (1977, p. 101) for the southern New South Wales Wheat–Sheep Zone: wool cut, 0.14; lambing rate, 0.12; sheep mortality, –0.33; and cattle mortality, –0.59.

### 3.2 In the Centre

The Alice Springs district is a semi-arid one which has been the focus of several BAE farm-level studies (BAE, 1968; Reeves and Crellin, 1972; Wonder and Howlett, 1977). Cattle numbers in the Centre rose to a peak of 353 000 in 1958 under the influence of a run of relatively good seasons, improved communications, improving prospects for beef, and property investments supplementing the existing waterholes and opening up new country. Severe drought over nine years caused numbers to be reduced to 134 000 by June, 1966. Numbers by 1971 had increased to 200 000 but the combination of poor markets and the run of subsequent good to excellent seasons created conditions where the Alice Springs herd approached half a million head in 1978. With the infrastructural constraints on the rate at which cattle can be moved out of the Centre, grazing pressures have thus recently approached alarmingly high levels.

One impact of the early 1960s drought was the stimulation of the Territory Administration to ask the Soil Conservation Service of New South Wales to mount a detailed study (Condon, Newman and Cunningham, 1969) of consequent erosion problems and to suggest restorative measures—many of which have been implemented as policies. Despite the apparently simple, single commodity system of production in central Australia, the complexity of the decision environment, involving interactions of property characteristics, managerial skills of the pastoralists, climate and cattle prices, is considerable (Campbell, 1966).

Wonder and Howlett (1977) found in a modelling study that properties generated widely different levels of income over sequences of 20 years with variations not necessarily related to income-generating capacity. Probabilities of financial failure were computed on the basis of simulated probability distributions of net cash incomes. A few favoured properties in the district have characteristics whereby, on average, they have (under the price regime imposed) a less than 0.01 probability of rendering their operators bankrupt. However, for some climatic sequences there was up to a 0.24 probability of failure for the same property types. Typically, district properties were shown to have a range of chances of failure due to climatic influences of from 0.10 to 0.75. The necessity for operators to build up financial reserves to buffer the impact of adverse seasons in such a business environment is apparent.

<sup>3</sup> The concept of an elasticity is elaborated at the end of Section 4.1.

Pastoral companies, of course, have embodied climatic risk-spreading in their management since the early days of pastoral settlement by gaining ownership of strings of properties in areas unlikely to be influenced by highly correlated climatic events (Anderson, 1970 *a, b*), as well as branching out into investment in other sectors of the economy. Some of the costs and benefits of spatial diversification of grazing properties have been reviewed by Anderson (1971).

### 3.3 Planning

Farm business management, involving decision making under price and climatic uncertainty, lags in production, and institutional and legal restraints, is never easy to do well. Management must constantly make adjustments to resource use to cope. Kingma and Kerridge (1977), in order to handle adequately the physical and financial interactions in a farm model for analysis of resource-adjustment options, incorporated stochastically the influence of climate (through rainfall and/or temperature) on nine other important variables, such as crop yields and pasture and livestock performance. Such developments (essentially the estimation of Functions 2.1 to 2.3) are important if farm modelling is to provide output useful for planning future resource-allocation under risk as well as guidance for policy on such aspects as the provision of credit facilities and improved adjustment options to farmers.

During and after droughts there are inevitably recriminations about the virtue of various strategies and tactics that have been adopted by different farmers. For instance, with the reduced agricultural maintenance and investment rates in the past decade (BAE, 1976*b*, 1977*b*), the pastoral resource base has been run down. This may predispose increased sensitivity to future drought. Whatever is done, there is clearly an element of luck in the success of any planning. Moreover, given the individuality of Function 2.1, it is not prudent to offer general guidelines for drought management on farms—before, during or after a drought (Campbell, 1966; Anderson and Hardaker, 1973). Useful analysis must incorporate the individual nuances of environment and farmer.

## 4 Industry-Level Impacts

The impact of climate at the industry level can be gauged approximately by the extent of variation in the volume of production. A measure of variation in volume, which facilitates comparison across industries of diverse size and nature, is the conditional coefficient of variation. Motha, Sheales and Saad (1975) have estimated such coefficients for the period 1949–50 to 1972–3 and these range from low values of about 0.05 for the wool and wholemilk industries to high values of around 0.37 for the sorghum, cotton and oilseeds industries. The wheat industry experienced an “intermediate” conditional coefficient of variation of 0.23 and is the industry selected for most attention in this section.

As for other Australian agricultural industries, the history of the wheat industry has been punctuated by climatic extremes—particularly droughts. Callaghan (1973) has documented aspects of eleven major droughts that have afflicted this industry in the past nine decades. He has argued that the impact of drought, while still serious, has become less dramatic because of productivity improvements (especially through mechanization and better varieties), expansion of the industry into more meteorologically dispersed regions and investment in bulk storages.



#### 4.1 Some Impacts on the Wheat Industry

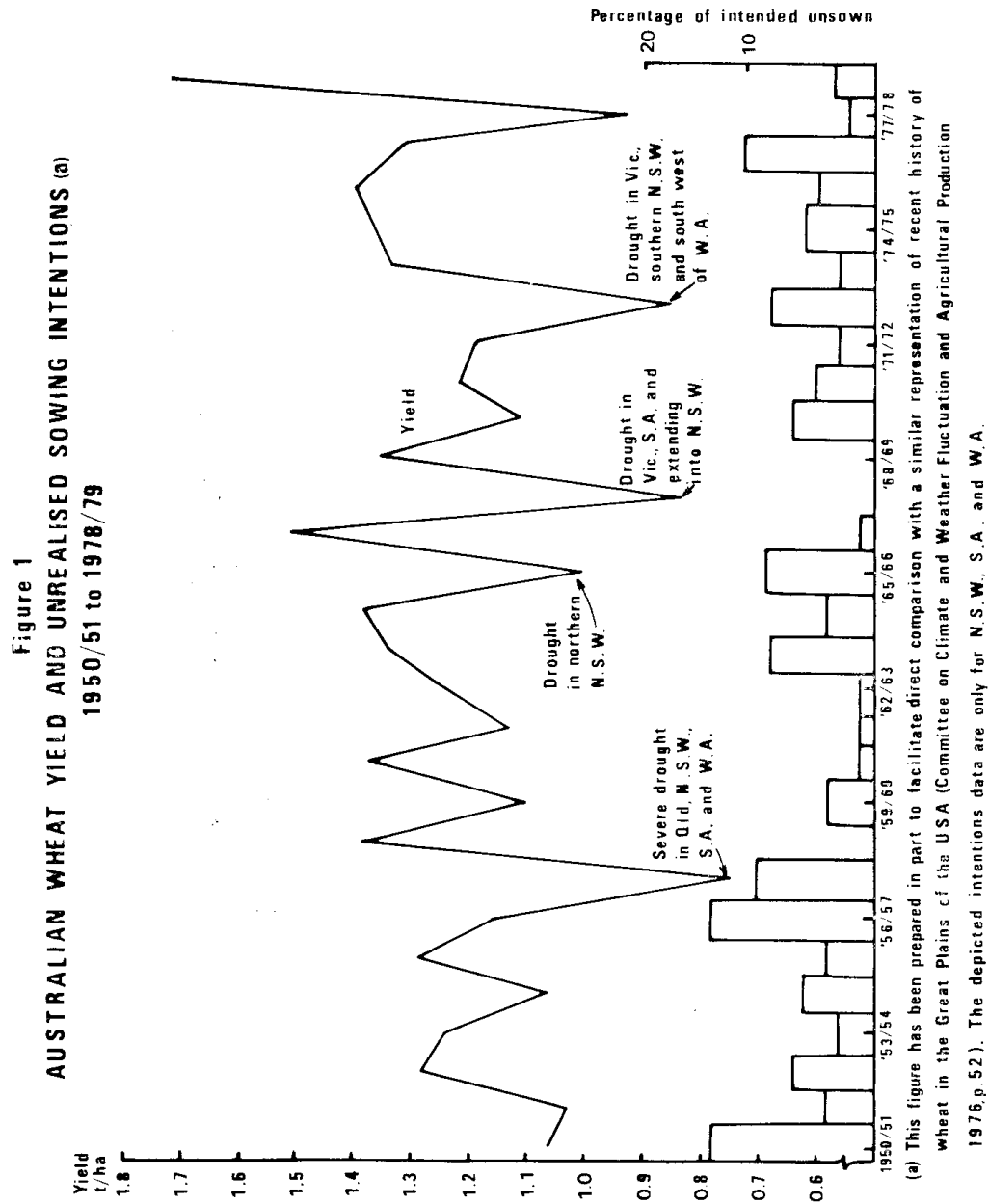
The effect of the 1965-6 drought on the wheat industry at the national level was not drastic. However, at the State, regional and local levels, the effects of the drought were severe. In New South Wales the actual area sown to wheat was about 80 per cent of the intended area of 2.3 million ha. The pre-sowing rainfall (averaged cross-sectionally) was only 17 mm a month from March through to May compared with the mean of 49 mm a month (standard deviation 21 mm) for the 26 years 1951-76. All other States received below average pre-sowing rainfall in 1965-6 although conditions were considered "dry" rather than "drought".

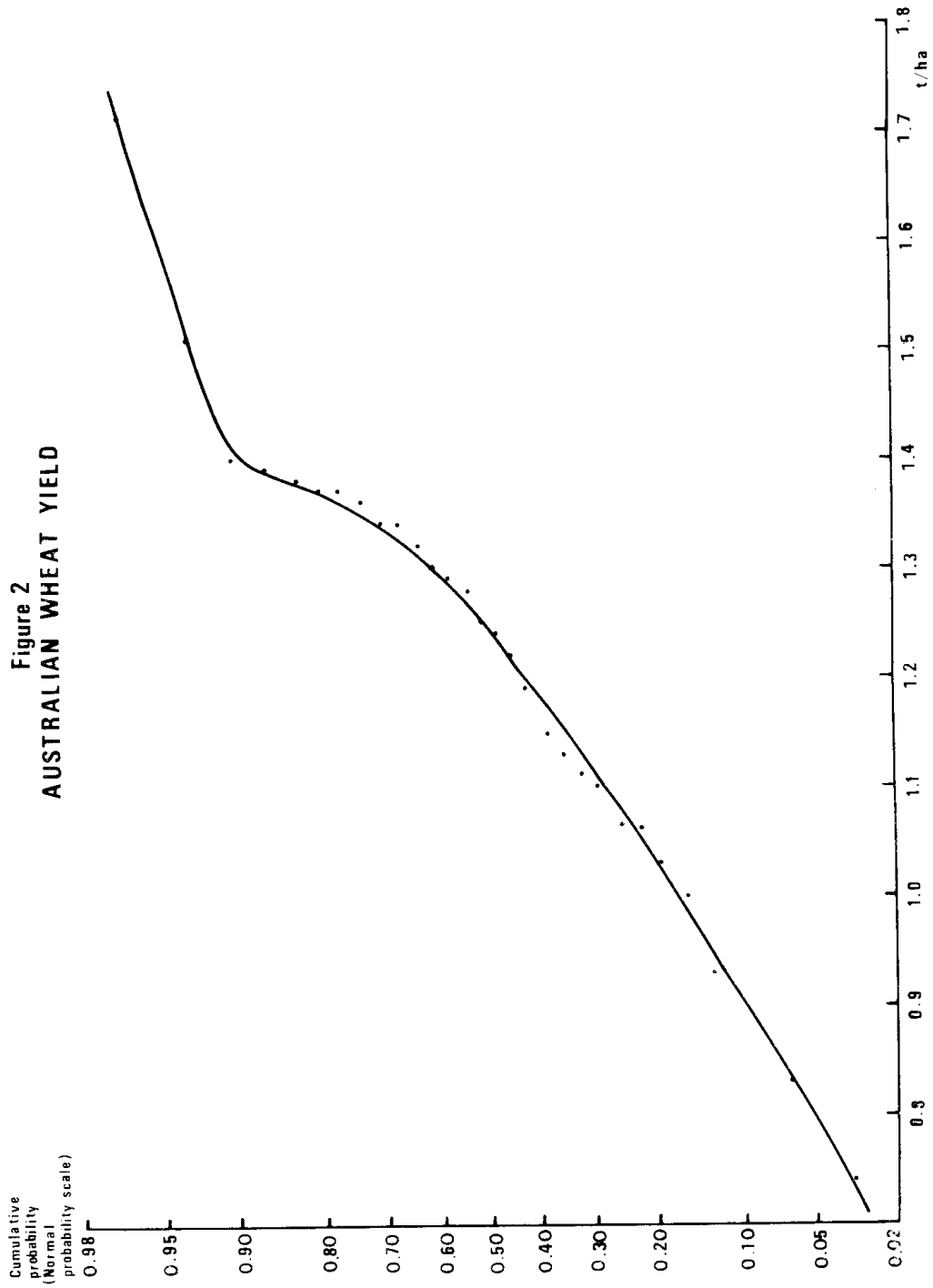
Yield is importantly dependent on weather. In New South Wales the 1965-6 yield of 0.57 t/ha was the second lowest for that State for the 28-year period to 1977-8 (mean 1.23 t/ha, standard deviation 0.37 t/ha). Yields in other eastern States were only marginally affected in 1965-6. As shown in Figure 1, Australian yield was not drastically affected by this drought and actual sowings fell short of intended sowings by only 9 per cent. The national yield series has been virtually trendless since the 1950s (Figure 1) and is characterized (over the 30-year period to 1978-9) by a mean of 1.21 t/ha and a coefficient of variation of 0.16. Even at this level of aggregation (for Victorian districts see Ryan, 1974), yields (with median 1.25 t/ha and first decile 0.90 t/ha) are not especially normal, as indicated by the nonlinearity of the empirical distribution function plotted on normal probability paper in Figure 2.

Rainfall is, as has been noted in discussing Function 2.3, but one of several climatic factors influencing yields. Hail, wind and temperature, especially frost (Single, 1975), can be even more crucial on occasions. However, rainfall variability does account for much of the overall impact of the many effects of climatic variability. Probably the single most important summary measure of climatic influence on yields is rainfall during the growing season (see, e.g., Cornish, 1950; Byerlee and Anderson, 1969; Guise, 1969; Francisco, 1979) although pre-sowing rainfall is also important and can substitute to some extent for early growing season rainfall. At aggregations beyond particular plots, the precision of the relationship between a rainfall index and yield necessarily suffers although Fisher (1978, pp. 30-3) found some relationships of acceptable precision using wheat yields for local government areas in several States. Low precision is evident in the State and national regressions reported in Table 1.

Table 1: *Regression Results*  
 $\log(\text{yield in t/ha}) = A + B \log(\text{growing rainfall in mm})$

Region	R <sup>2</sup> (DW)	A	B (SE)
Australia .. .. .	0.57 (1.69)	-2.12	0.60 (0.10)
New South Wales.. ..	0.34 (1.70)	-2.89	0.79 (0.21)
Victoria .. .. .	0.26 (2.31)	-1.11	0.37 (0.12)
Queensland .. .. .	0.02 (1.45)	-0.73	0.26 (0.21)
South Australia .. ..	0.40 (2.50)	-2.69	0.73 (0.17)
Western Australia .. ..	0.26 (1.84)	-1.40	0.37 (0.12)





These are log-linear equations so that the slope can be interpreted directly as a (partial) elasticity of production (*i.e.*, ratio of proportional change in output to a small proportional change in the factor of production). This specification for ordinary least squares estimation is rather restrictive in imposing a constant elasticity of response to rainfall, irrespective of its level. With this qualification in mind, it is notable that, for all these equations, response is "inelastic", so that a 1 per cent increase in growing season rainfall induces a yield response ranging from 0.26 per cent in Queensland through to 0.79 per cent in New South Wales. A further implication of the constant and inelastic proportional response model is that the marginal product of rainfall diminishes with increasing rainfall. This effect can be interpreted more conversationally by noting that the gain from a given "above average" rainfall does not symmetrically compensate the loss from an equal "below average" rainfall. Implications of such elasticities in a context of resource allocation have been noted by Edwards (1978).

#### 4.2 Wheat Yield Variability in New South Wales

The random nature of major climatic variables such as rainfall makes farm planning difficult and can lead to wide variations in area sown as well. In examining the magnitude of these climatic impacts on the wheat industry, data for sixteen selected local government areas in New South Wales, representing "traditional" and "marginal" parts of the wheat belt, are employed. The extent of variability in rainfall and yield is summarized in the statistics presented in Table 2.

The eastern (traditional) side of the wheat belt generally has a longer history of wheat growing than the western (marginal) side (Macindoe, 1975). This is due in part to the earlier settlement of the eastern areas and the associated development of transport and other grain marketing facilities, and in part to climatic patterns. Rainfall, in particular, tends to be lower and more variable in the west.

Since the mid-1950s, the area sown to wheat in New South Wales has increased dramatically and in 1977-8 was 3.7 million ha compared with only 0.7 million ha in 1956-7. A feature of this expansion has been the rapid increase that has occurred in western areas (even to areas administered by the Western Lands Commissioner) which were once considered "marginal". Substantial amounts of wheat are now grown in these areas, which demonstrates that the concept of a wheat growing area is dynamic if not ephemeral (*c.f.* McLennan, 1963). Expansion of wheat growing into climatically less favourable areas can be presumed to mean lower average yields (Russell, 1973). The question of whether wheat yields are lower in "marginal" areas than in "traditional" areas has been the subject of occasional attention (Lewis and Dawson, 1948; Rutherford, 1958; Anon., 1967). Average shire wheat yields for the period 1956-7 to 1975-6 ranged from 1.60 t/ha in Waugoola to 0.90 t/ha in Walgett. Between these extremes, however, several shires have recorded similar average yields. At a test of whether the "marginal" average yields are different from "traditional" average yields was made. The result was null at the 1 per cent level of significance. Productivity developments in the form of improved technology, better varieties and improved management practices have possibly resulted in more efficient use of available moisture and this may have enabled farmers to achieve profitable yields in areas where wheat production was previously considered too risky as well as in "traditional" areas.

Table 2: Rainfall and Yield Characteristics of Selected Shires in New South Wales\*

Shire	Rainfall				Yield	
	Mean		Coefficient of variation		Mean	Detrended coefficient of variation†
	Jan.-June	July-Oct.	Jan.-June	July-Oct.		
	cm	cm			t/ha	
Marginal areas—						
Lachlan .. .. .	22	25	0.38	0.32	1.09	0.35
Bland .. .. .	22	26	0.44	0.33	1.24	0.27
Walgett .. .. .	30	20	0.50	0.45	0.90	0.60
Warren .. .. .	30	23	0.82	0.49	1.01	0.54
Boomi .. .. .	30	23	0.50	0.47	0.98	0.62
Boolooroo .. .. .	29	16	0.42	0.37	1.24	0.37
Namoi .. .. .	32	16	0.36	0.47	1.17	0.40
Average marginal .. .. .	28	18	0.48	0.41	1.09	0.45
Traditional areas—						
Mitchell .. .. .	17	21	0.41	0.33	1.51	0.22
Merriwa .. .. .	23	17	0.36	0.23	1.18	0.47
Liverpool Plains .. .. .	21	18	0.37	0.35	1.37	0.36
Gooblang .. .. .	22	21	0.45	0.31	1.22	0.38
Talbragar .. .. .	21	22	0.41	0.38	1.10	0.44
Waugoola .. .. .	21	23	0.41	0.36	1.60	0.29
Wellington .. .. .	23	23	0.48	0.35	1.26	0.40
Mudgee .. .. .	22	23	0.32	0.36	1.17	0.34
Macintyre .. .. .	24	22	0.32	0.32	1.34	0.29
Average traditional .. .. .	22	21	0.39	0.33	1.31	0.35

\* All data are for 1956-7 to 1975-6.

† Based on deviations from semi-logarithmic trends.

Previous researchers (*e.g.*, BAE, 1961; Nix, 1975) have found that Australian yields do not show a definite inverse relationship between level and variability. For the “marginal” and “traditional” areas, it was found that yield variances were also not significantly different. There has, of course, been considerable production variability. The vagaries of weather are recognized as influencing the area and yield of wheat but it is generally true that farmers have very little control over the performance of the crop once it is sown. Correlations over time between area sown and yield (actually realized and also lagged exponentially smoothed) for nearly all local government areas are less than 0.1.

The impact of climate on yields is reflected in year-to-year variability. In regression analysis with shire yield as a function of pre-sowing, sowing and growing rainfall, rainfall was found to be no more significant in explaining yield in western parts than in central and eastern parts of the wheat belt. The proportion of yield variability explained by the crude rainfall variables ranged from around 0.75 for Warren to 0.00 for Wellington (Trevor Ole, BAE, personal communication). Similarly, in regression analysis of areas sown as a function of supply-conditioning factors (including wheat price), it was found

that only in northern New South Wales (where incidence of rainfall is greater in summer than in winter and where the black soils have a relatively high capacity to store moisture) does pre-sowing and sowing rainfall have a measurable positive impact on the area sown to wheat. These results are consistent with those reported by Fisher (1978, p. 32). Any definition of the agroclimatic limit to wheat production therefore must be somewhat arbitrary. Despite seemingly stable climatic averages, the area where farmers are prepared to grow wheat has shifted through time in a generally westward direction.

### 4.3 Some Effects of Climatic Variability on Wheat Industries in Other Countries

Every country is subjected to climatic extremes and of particular relevance for the Australian wheat industry are the other large wheat producers and importers; see, e.g., McKay and Allsopp (1977) on Canada; and Committee on Climate and Weather Fluctuations and Agricultural Production (1976) and Thompson (1975) on U.S.A. Table 3 shows some yield characteristics for major wheat producers. The major effect apparent among the correlations reported is related to "hemisphere"—the average correlation between countries in the same hemisphere is 0.55 and in different hemispheres is 0.12.

Table 3: *Variability and Covariability in International Wheat Yields\**

Item	Australia	USA	Canada	EEC	USSR	Argentina	China	India
Mean .. ..	1.210	1.974	1.723	3.388	1.344	1.428	1.093	1.157
Standard deviation†	0.213	0.132	0.185	0.206	0.219	0.239	0.131	0.092
Coefficient of variation† .. ..	0.176	0.067	0.107	0.061	0.163	0.167	0.120	0.080
Correlations—								
USA .. ..	-0.18							
Canada .. ..	0.21	0.58						
EEC .. ..	0.19	0.67	0.21					
USSR .. ..	0.11	0.68	0.47	0.65				
Argentina .. ..	0.27	0.04	0.10	0.06	-0.04			
China .. ..	0.23	0.45	0.26	0.59	0.37	0.57		
India .. ..	0.16	0.88	0.63	0.83	0.69	0.03	0.53	

\* Based on 1963–78 data from International Wheat Council (1977).

† Computed from residuals about arithmetic linear trends.

In the USSR, for example, the wheat crop has suffered drastically through unfavourable climatic events. The Soviet wheat crop is particularly susceptible to prolonged cold weather conditions, winter kill, spring drought and wind and hail storms at the time of harvest. During the period from 1963 to 1976, several sharp falls in wheat production occurred in the USSR. This analysis is concentrated on two recent falls in production, in 1972 and 1975, although these were by no means the most drastic. The decline in production in 1972 was due to a reduction in the area sown and a severe drought, especially in the Ukraine. During 1972–3, wheat production in the USSR fell to 86 megatonnes (Mt), some 22 per cent below that of the record high of 110 Mt in 1973–4. The result of this decrease in production together with a change in policy

favouring the grain feeding of livestock was that, in order to meet its commitments, the USSR had to import much more than anticipated.<sup>4</sup> Imports of wheat and flour totalled 15 Mt in 1972-3 compared with a yearly average of 1 Mt from 1967-8 to 1971-2.

The effect of the change in import requirements in 1972-3 had a dramatic impact on world trade and prices, exemplifying Function 2.4 (c). The 15 Mt purchase represented over 20 per cent of world wheat trade. However, to disaggregate the effects of the drought in the USSR from changes in Soviet agricultural policy and the policies of other trading nations at that time is a challenging task. The Soviet purchase came at a time when the USA had opted for a policy of reduced stockholding, world fertilizer production had slumped, and increasing oil prices were adding to an inflationary spiral in most countries. The net result of all of these factors was that not only did Australia benefit from the direct sales of around 1 Mt to the USSR but also the total Soviet purchases contributed to raising the world price of wheat. For example, the average f.o.b. export price of ASW wheat rose from \$49/t in 1971-2 to \$70/t in 1972-3.

Due to drought conditions in 1975, Soviet wheat production slumped to 66 Mt, the lowest level for a decade. Soviet policy, however, dictated that only 10 Mt of wheat would be imported at the higher prevailing world prices. Thus, although the 1975 drought was more severe than the one in 1972, it had a lesser impact on world wheat trade. The USSR, however, did purchase much larger quantities (15 Mt) of coarse grains in 1975-6 compared with the quantities (6 Mt) in 1972-3 (International Wheat Council, 1976).

In contemplating the impact of climate on agriculture, there are thus dangers in taking a perspective that is too parochial. A severe drought may bankrupt some growers and cause many others extreme discomfort in both farm and household matters. Drought on the scale of that in 1965-6 may currently reduce industry returns by, say, \$250m. However, an analogous event in the USSR may well result in a windfall gain to the same Australian growers of, say, \$150m.

The repercussions for the Australian wheat industry of adverse seasonal conditions in North America are unlikely to be large. Yield of USA wheat is relatively stable (Table 3) and the chances of a poor national harvest are slight. Moreover, in the USA, in particular, there is capacity to hold large quantities of wheat (in excess of 30 Mt or over 50 per cent of typical production) and the effects of poor seasonal conditions can thus be mitigated. Although the USA has considerable storage capacity, the desirability of stockholding has been vigorously debated recently. In general, importing countries benefit and exporting countries lose through a stockholding policy in the major exporting countries. In providing against unfavourable seasonal conditions, conflict thus arises between gainers and losers in the distribution of benefits and costs associated with the buffering of stocks. For example, using an assumption of rather inelastic demand for wheat, Reutlinger (1976) has estimated that, in managing a reserve stock with a total of 20 Mt storage capacity, the USA, Canada and Australia together could lose about \$120m a year while the developing countries, and Japan and Europe could gain about \$90m and \$60m a year on average, respectively.

<sup>4</sup> This and the following observations on Soviet policy are based on personal communications with staff in the BAE Crop Commodity Analysis Section.

#### 4.4 The Beef Industry

Whereas many climatic impacts in the wheat industry can be treated on a season-by-season basis, the effects in extensive grazing industries, as observed above in Section 3, typically take several years to "work themselves out". An example of these dynamic effects is provided here by an examination of the impact of two types of simulated variations in "climate" on the Australian beef industry as modelled in an econometric model of this industry (Longmire and Main, 1980). The behavioural equations in the supply model, concerning slaughter rates and other changes to inventories of different categories of the herd, include a "climatic index" variable (mean = 100) which is intended to capture many aspects of climatic (especially rainfall) variability. The changes in inventories include climatic-induced mortality effects. The annual mortality rate is about 3 per cent (in a national herd of, presently, about 30 million head). In the years of a major drought, annual mortalities are likely to follow a pattern like 4.5, 7.0, 5.0 per cent, and then return to the "normal" rate of 3.0 per cent. This, of course, as a national rate is much lower than the regional mortality rates which can affect particular drought-prone regions, *e.g.*, the 39 per cent encountered by Haug and Hoy (1970) in south-west Queensland.

For this simulation, the values of exogenous variables, such as prices, and the initial values of endogenous variables and inventories are held at the means observed over the sample period 1949–50 to 1976–7. Performance in the industry is summarized here by total numbers on hand at 31st March and by slaughterings each year. These are monitored in three categories of livestock over the five-year period.

In the first simulation (recorded in the top part of Table 4), the effects of a 1 per cent increase (*i.e.*, improvement) in the climatic index for one year only are measured. For ease of interpretation and comparison with results for other industries the consequent changes are assessed as partial elasticities for the respective variables with respect to the climatic index. Since the model from which these elasticities are derived is linear, all signs can be reversed to see the effects of a corresponding reduction in the climatic index by 1 per cent and the effects can be linearly scaled up for larger climatic variations. To guide ideas on such variations, the value of the index in 1965–6 fell to 49.5, the lowest point in the series.

Freebairn and Rausser (1974) also measured a strong positive effect of (a nonlinear transformation of) rainfall on changes in the inventory of Australian beef cows. However, as can be seen in Table 4, such a "once-up" effect for cows and other categories is virtually worked out by year two and has only a small impact over the whole period. This contrasts with the situation depicted in the bottom part of Table 4 where the 1 per cent change in the climatic index is sustained over the five years. With both types of change, the effects on calves, and cows and heifers are much more pronounced than on steers and bulls. With relatively severe droughts, however, destocking often involves disposal of steers so that a more female-dominated herd permits faster post-drought breeding for restoration of the herd (Waring, 1976).



*Table 4: Partial Elasticities for Inventory and Slaughter Variables in a Model of the Australian Beef Industry for a Small Increase in Climatic Index*

Year	Total numbers			Slaughterings		
	Calves	Cows and heifers	Steers and bulls	Calves	Cows and heifers	Steers and bulls
		for variation only in year 0				
0 .. ..	0.00	0.00	0.00	-0.27	-0.29	-0.03
1 .. ..	0.17	0.05	0.02	0.29	0.35	0.07
2 .. ..	-0.08	-0.01	-0.02	-0.01	-0.01	-0.03
3 .. ..	-0.02	-0.01	-0.001	0.00	-0.01	0.001
4 .. ..	-0.01	-0.01	0.00	0.00	-0.01	0.00
		for sustained constant variation				
0 .. ..	0.00	0.00	0.00	-0.27	-0.29	-0.03
1 .. ..	0.17	0.05	0.02	0.02	0.06	0.03
2 .. ..	0.08	0.04	-0.001	0.02	0.05	-0.001
3 .. ..	0.07	0.03	0.00	0.01	0.04	0.00
4 .. ..	0.05	0.02	0.00	0.01	0.03	0.00

## 5 Regional Impacts

The importance of agriculture in many regions of Australia is such that the impacts of climatic variations on local farms and agricultural industries reverberate strongly in other parts of regional economies. A ready example of such a transmitted effect is the variable activity in farm machinery retailing as seasonal fortunes vary (Davis, Mullen and Bryant, 1979). In this section, general regional effects are first noted and then the particular case of impacts associated with floods is reviewed.

### 5.1 Regional Multiplier Effects

A simplified procedure for measuring such impacts is regional input-output analysis in which the effects are conveniently summarized by various multipliers. Only a few investigations are available at this level but they are probably good guides to the magnitudes of multipliers that will be found in more widespread subsequent studies.

Agricultural-to-regional output multipliers are of the order of 2 (Mandeville and Powell, 1976; Jensen, 1976), so that a drought-induced reduction of, say, \$10m in regional farm output will lead to a reduction of about \$20m in total regional output. These output multipliers are not as high as some others (e.g., government services, about 3) because of linkages beyond the given region, especially linkages involving imports from (and thus transfer of some instability to) outside the region (Powell and Mandeville, 1978). However, they are of particular significance because of the relative instability (through climate and export markets) of the agricultural sector.

Regional income multipliers are typically even higher (about 3) than output multipliers so it follows that climatic variations can induce substantial impacts on regional incomes and especially on employment (Phillips, 1974). Consider the illustration of Powell (1978) wherein agriculture contributes on average

30 per cent of regional output. A minor drought might cause agricultural output to fall by 10 per cent and thus direct regional output to fall by 3 per cent with an associated direct income decline of, say, 4 per cent. With an income multiplier of 3, the full effect on regional income would thus exceed 10 per cent. Doubtless it is in recognition of the extent of such impacts that governments have intervened in droughts with various regional employment schemes (usually through local government authorities).

## 5.2 Impact of Floods

Flooding is an extreme event of climatic origin which clearly has important economic consequences, particularly at the regional level (Rutherford, 1956; Forsythe, 1975) and, because it has not been mentioned specifically elsewhere in this review, the topic is taken up here. A search for a comprehensive analysis of the impact of floods on agriculture proved futile, and constraints on research resources prevented an attempt to fill this gap here, so the following discussion is regrettably anecdotal—but see reviews by Douglas in Heathcote and Thom (1979).

The impact of flooding in Australia varies with the location of the river system and land-forms of various parts of individual systems. Flooding is most destructive on the shorter rivers flowing from the Great Dividing Range to the eastern seaboard, as these rivers flow through the more densely populated eastern coastal region and floods occur here more frequently than in most other basins. Further, floods on the east coast can have a severe impact because the flood plains are more suited to and used for intensive agriculture and because concentration times are relatively short. Satisfactory decisions concerning the salvage of crops and pasture are difficult under such circumstances, especially as intense competition develops for the available stock transport and agistment when many producers are similarly affected.

In the channel country of south-west Queensland and South Australia (associated with the anabranching water courses of the Diamantina River and Coopers Creek) cattle grazing systems have developed to take advantage of the excellent pastures which are produced when flooding occurs. The flood waters originate in rainfall far to the north, and flood incidence varies considerably from year to year. In years of high flood some 38 000 km<sup>2</sup> are covered, creating, as the flood recedes, a pasture availability far in excess of the requirements of the cattle held as a regional long-term breeding nucleus. Store cattle are traditionally brought into the region, in accordance with pasture availability, for fattening and sale to east-coast markets.

The impact of floods on riparian landholders has elements of costs, which are rather obvious, and benefits which can be more subtle, such as benefits of nutrient replenishment and river freshening where salinity build-ups occur through extensive irrigation.

A comparison of costs and benefits of different types of floods has been made by Onus (1976). In a case study of a susceptible area of the Gwydir Valley of New South Wales, he found that a “watercourse” flood (occurring about one year in four) produced a positive net benefit to affected landholders. However, the less frequent major floods (like the one of early 1976), although bringing some benefits to both crop and livestock farms, cause net losses of several times the magnitude of the benefits of the watercourse floods.

In cases where regular flooding manifests itself mainly as a cost, it may be desirable to institute measures to control the flooding or to mitigate its detrimental impact. The greatest difficulty in analysing benefits and costs of various flood mitigation works stems from the limited amounts of pertinent data. The frequency of severe floods that occur rarely cannot, by its nature, be estimated very accurately.

There have been many benefit-cost analyses of flood mitigation and control works. One such study, by Ullman, Nolan and McGowan and Associates (1973) is that of the Pioneer River in Queensland. The impact of flooding along the Pioneer River is typical of that of most east-flowing rivers. The flood zone is almost exclusively the fertile lower terrace adjacent to the river. Despite the recurring flood hazard, approximately 85 per cent of this area is assigned for sugar cane. The important damage processes relevant to local rural landholders were identified in order of importance as (a) permanent loss of land, (b) deposition of debris and (c) farm structural damage. Cane farm damage attributable to these processes in the datum floods of the study (1958 and 1970) amounted to about \$40,000 with over half of this representing loss through permanent bank erosion. Direct benefits were estimated by measuring the difference between average recurring damage with and without several alternative flood protection measures. Plans were identified that had benefit—cost ratios of about 1.5.

## 6 Sectoral and National Impacts

The effects of extreme climatic regimes have been sketched as being unambiguously severe in affected regions. However, as Gibbs and Maher (1967) and Maher (1973) have indicated in their reviews of spatial patterns of annual rainfalls, it is unlikely that large proportions of Australia simultaneously experience similar extremes of climate, especially rainfall. There is considerable "cancelling out" of good and bad experiences so that impacts at high levels of geographical aggregation are not too severe. Such effects have been modelled within New South Wales by Francisco (1979) by relating regional production to spatially-correlated monthly rainfall aggregates. Naturally, when the more intensively farmed and grazed regions (e.g., south-east Australia) experience extremes, these effects are reflected more strongly in national aggregates than are extremes in the more extensively-managed regions.

### 6.1 Aggregate Impacts of Climatic Variability

Most of the work addressed to measuring the aggregate economic impact of climatic variation has been concerned with major droughts. For instance, there have been several reviews of the droughts of the 1960s. McIntyre (1973) estimated that gross rural output in the drought years 1965–6 and 1967–8 fell by 11 and 15 per cent, respectively, below the smoothed trend values. Estimation of the corresponding changes in gross value of agricultural production implies or requires assumptions about the responsiveness of prices to changed quantities produced in Australia. Bates (1976) estimated corresponding falls in gross value of 15 and 17.5 per cent, which were of the order of \$400m in 1966–7 prices. Duloy and Woodland (1967) modelled such a drought and assumed that a fall in output of 20 per cent would be associated with a 10 per cent reduction of gross value (*i.e.*, an aggregate price elasticity of demand of  $-2$ ). Bates (1976) reported that J. N. Lewis believed this assumed elasticity to be too large.

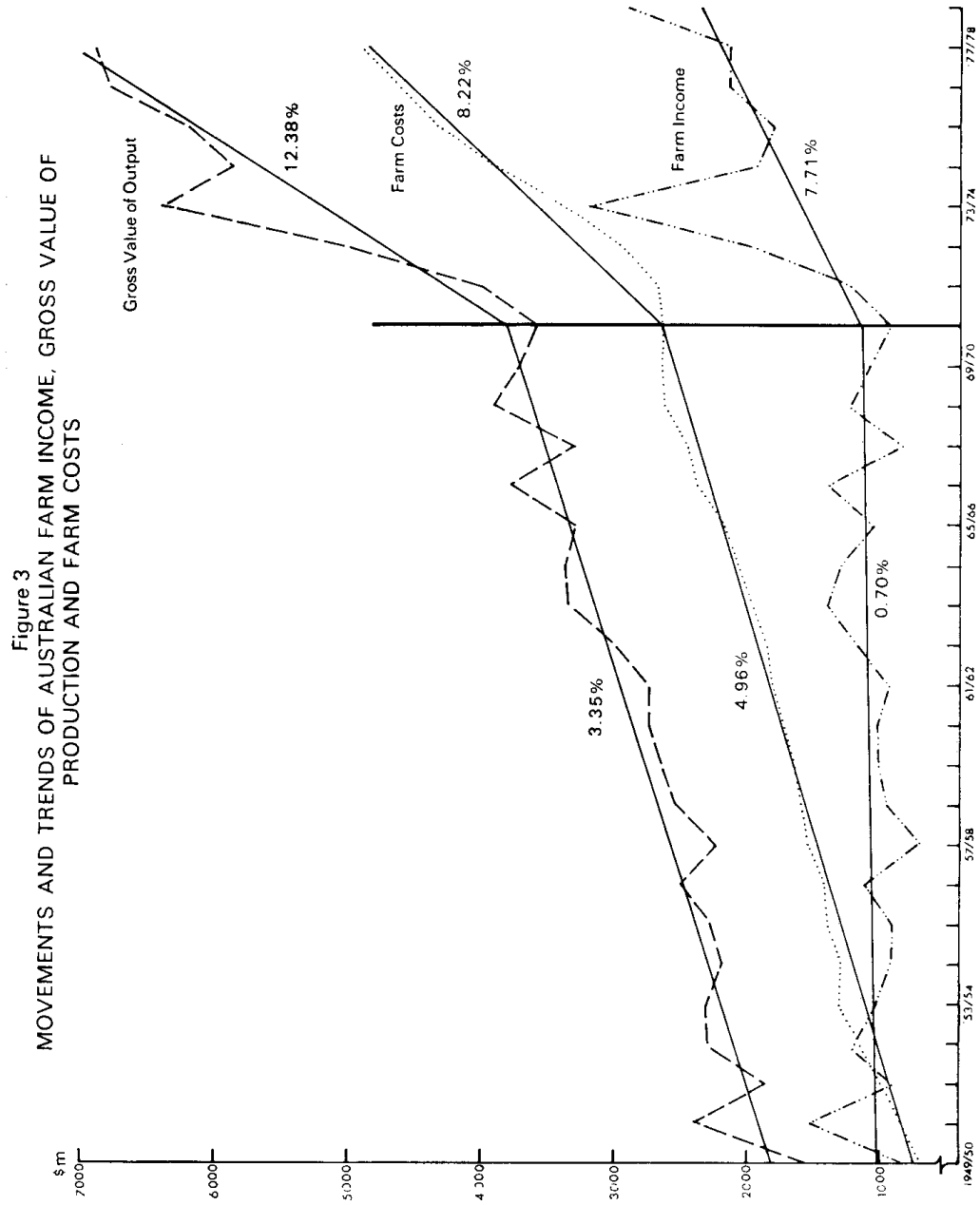
The primary purpose of Duloy and Woodland (1967) was to estimate the multiplier effects of drought on the national economy (*e.g.*, on gross national product, GNP). Using a simple econometric model of the economy, they found, in contrast to the results discussed at the regional level, that there was only a small multiplier (1.07) from gross value of agricultural production to GNP. As Bates (1976) has argued, this small effect is largely a consequence of the now small (less than 10 per cent) contribution of agriculture to GNP, although strengthening linkages of agriculture with the non-farm sector may have subsequently increased the drought multiplier. However, the effect of a major drought on GNP is still unlikely to be very much different from the 1 to 2 per cent estimated by Duloy and Woodland (1967) and Mules (1973). These authors also reviewed the consequences of drought for the balance of payments, an issue of more active interest in past decades (Campbell, 1958). The consensus view is that there is little cause for concern in this regard because of the conjunction of recent and present high levels of Australia's international reserves and the now relatively small impact of drought on the balance of trade.

To broaden attention to climatic variations other than severe droughts, the recent history of the main rural aggregates is reviewed. For the period 1949-50 to 1977-8, annual movements of farm income, value of agricultural production and farm costs, and indexes of output, input, prices received and prices paid are depicted in Figures 3 and 4, respectively. Also shown are piecewise linear trends fitted to the series. The times at which changes are imposed in the trends are arbitrary and determined merely by inspection of the patterns. All series exhibit variation and it is not too obvious what role climatic variation has played in each.

It seems reasonable to argue that most of the variation about trend in the output series is ascribable to climatic variations. Certainly the major dips in output series can be associated with recognized droughts.

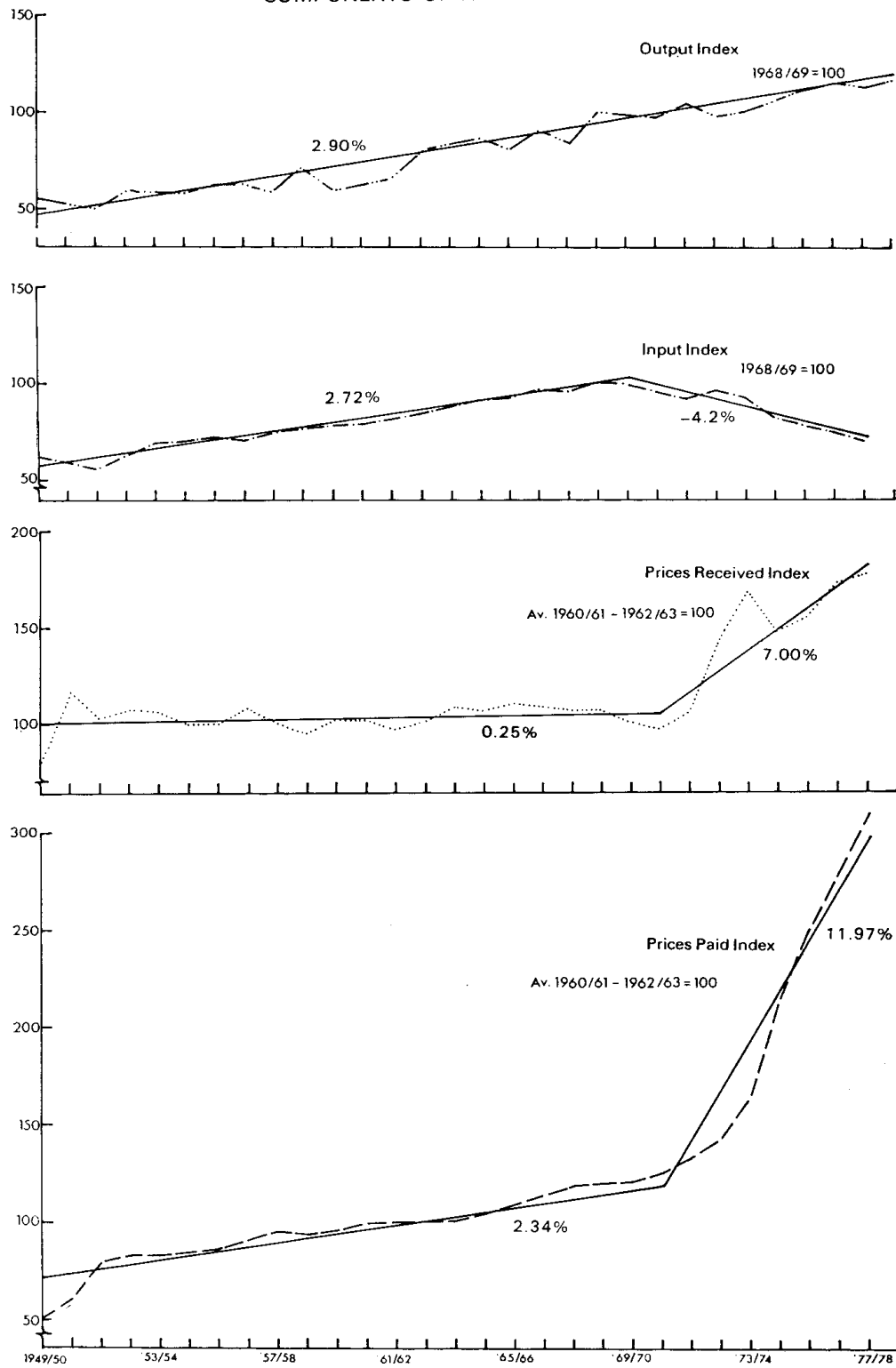
Although farmers presumably try to economize on inputs when output falls, the simple correlation between the residuals of the output and input series is only 0.14 so that, at least at this level of aggregation, it seems that climate has little direct impact on use of inputs.

Accordingly, it is assumed for simplicity that climate affects directly only aggregate output with no direct impact on input use, prices paid and costs. There is an indirect effect on prices received through the elasticity of the aggregate demand function for Australian agricultural output. The simple correlation between residuals in output and in prices received is  $-0.32$ . However, in the same spirit of simplification, and following the above-mentioned assumptions and criticisms and something of the style of related work by Powell (1960), it is assumed that the aggregate price elasticity of demand,  $e$ , is  $-1.5$  and is constant. This means that, if output in a given period is a random variable,  $Q$ , with trend mean value  $Q^*$  and coefficient of variation  $C(Q^*)$ , then gross farm product at prices that are influenced only by variation in  $Q$  can be expressed as  $G = AQ^{1 + (1/e)}$ , where  $A$  is a constant that depends on  $e$ . For  $e = -1.5$ ,  $G = AQ^{1/3}$  and  $G$  can be interpreted as a derived measure of value of agricultural production that abstracts from all other sources of variation in prices except for the aggregate impact of climate.



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Figure 4  
MOVEMENTS AND TRENDS OF INDEXES OF AGGREGATE  
COMPONENTS OF FARM INCOME



With these assumptions and the further one that  $Q$  is normally distributed, a sampling approach was adopted to measure the variation in the derived variable,  $G$ . Using the computed residuals,  $C(Q^*)$  was estimated as 0.034 and the corresponding coefficient of variation for  $G$  was found to be 0.011.<sup>5</sup>

This is an assessment of the "pure climate" component of variation in the gross value of agricultural production. It can be contrasted directly with the corresponding coefficient of variation in actual gross value of agricultural production of 0.029, denominated in the 1978–9 trend value of \$7,590m. Thus, in a rough way it can be claimed that climate is responsible for  $(0.011/0.029) 100 = 38$  per cent of the variation in gross value of agricultural production. Attempting the same rough assessment for farm income is more difficult because it is necessary to account for the effect of changing farm costs on the mean and coefficient of variation of farm income. Using a scaling factor, based on recent trends in costs and value of production, to inflate the derived coefficient of variation, the comparable ratio of climatic to total variation in farm income is  $(0.035/0.090) 100 = 39$  per cent. This analysis of the climatic component of these coefficients of variation is depicted symbolically in Figure 5.

## 6.2 Aggregate Impacts of Long-Run Change in Climate

The impacts discussed elsewhere in this review have been of a rather short-term nature. Typically, the effects of extreme climatic events have become insignificant within a few years of occurrence. In the absence of geographically detailed scenarios of potential changes in climate, it has not been possible here to chart or even to contemplate the possible detailed impact of such long-run changes on Australian agriculture. Some possibilities are explored in Pittock *et al.* (1978), including an agricultural case study by Arnold and Galbraith.

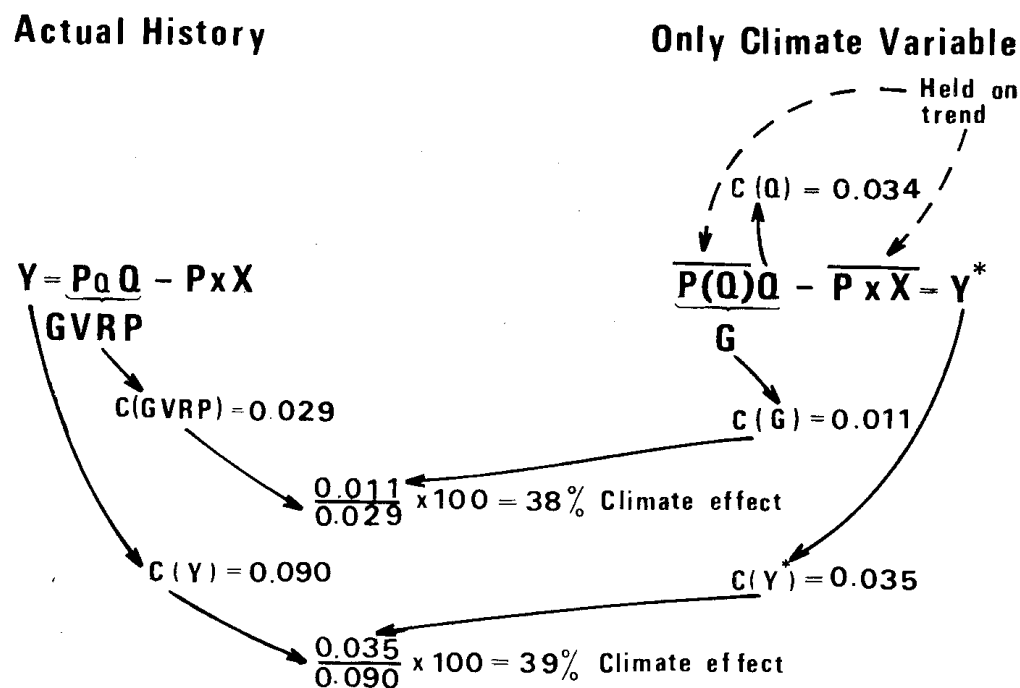
Some progress in considering such speculative changes can be made by working at a high level of aggregation and assuming a non-specific shift in aggregate output. The approach taken is to use a small general equilibrium model of the Australian economy (Stoeckel, 1978). In this way it is possible also to identify the likely balance of payments effects on the exchange rate and thus the possible gains to other sectors (*e.g.*, the import-competing sector and the mining sector).

The particular shift considered here is a 13 per cent permanent reduction in gross rural output using the 1973–4 year as a base. This is similar in magnitude to that of a serious (1960s-style) drought. The fall in output is modelled by assuming that the adverse climatic change increases average costs of production, which is equivalent to negative technical change. However, capital losses of livestock and pastures that would be associated with such a drought are ignored, as are aspects of probability distributions in Functions 2.1 to 2.4 other than means.

<sup>5</sup> This result was found to be remarkably robust with respect to the distribution sampled as several very non-normal families were used. Results for the coefficients of variation of power transformations of random variables are not covered by Anderson and Doran (1978) but the following supplementary result is tentatively offered for distributions of strictly positive random variables, such as  $X$ . Let  $Y = aX^b$ , then, if  $C(\cdot)$  denotes coefficient of variation,  $C(Y) \doteq bC(X)$ .

A selection of results is presented in Table 5. The precision of the consequent changes is indeterminate because of the non-statistical estimation and subsequent nonlinear transformation of the model and so they should be interpreted as indicating orders of magnitude and likely directions of the major effects. Although national income falls by nearly one per cent, values added by the mining sector and the import-competing sector increase by 1.2 per cent and 0.6 per cent, respectively. The reason why these sectors gain is that, with the imposed zero external balance, reduced agricultural exports lead to a devaluation of the Australian dollar. The manufacturing export sector, however, contracts since it comprises mainly food processing and relies on agricultural produce as an input. In this model, percentage changes in value added are found by adding the changes in gross output and real price.

Figure 5  
IDENTIFICATION OF CLIMATE EFFECTS ON  
AGGREGATE MEASURES OF INCOME



X - Inputs

Q - Outputs

P<sub>X</sub> - Prices paid

P<sub>Q</sub> - Prices received

Y - Farm income

GVRP - Gross value of rural production

G - Derived measure of GVRP

C( ) - Coefficient of variation



Table 5: *Percentage Change in Selected Indicators Associated with a Long-Run Reduction in Agricultural Output*

Item	Gross output	Real price	Labour use	Traded goods
Agriculture .. .. .	-13.0*	5.9	-6.3	-22.1 (exports)
Mining .. .. .	1.7	-0.5	2.1	3.6 (exports)
Manufacturing (exporting) ..	-6.1	2.9	-2.3	-17.5 (exports)
Manufacturing (import-competing) ..	1.1	-0.5	1.5	-9.4 (imports)
Services .. .. .	-0.2	-0.7	-0.1	..
Income .. .. .	-0.9			
Exchange rate .. .. .	-0.4			

\* Exogenously shifted.

Two further qualifications should be made. In imposing the slump in agricultural productivity, supposedly because of climatic change, it has been assumed that there is no related primary effect in any other sector. Second, the presumption about this unspecified climatic change is that it affects only Australia. Should such a change eventuate, it is likely to be associated with other changes throughout the world, in which case prices for rural exports would increase and tend to counter the output changes in determining Australian incomes and agricultural earnings.

## 7 Conclusion

Many of the numerous impacts of variable climate on Australian agriculture have been reviewed by addressing particular impacts at levels of aggregation ranging from the farm, through the industry and the region to the whole sector. Rainfall-related effects are generally the most important in terms of economic impact. The identified effects are always significant but the sensitivity and importance tend to wane as the level of aggregation increases.

Apart from the intrinsic interest of understanding the nature of agricultural production, the importance of perceiving the effects of climatic variability in agriculture is the potential insight into possible market failures and consequent roles for governments. Regretably, there has been very little relevant work on this topic and efforts directed to completing this part of the picture should be rewarding to analysts and relevant to policy makers.

The diversity of governmental interventions that prevail indicates that considerable progress has been made in "official recognition" of some of the impacts of climatic variability (*c.f.* Campbell, 1958 and IAC, 1978). However, not all observers of assistance-giving are convinced of the merits of temporary assistance, particularly when such assistance might distort producers' perceptions of their environment and raise problems of the "moral hazard" type (Freebairn, 1978). For instance, there is a strong tradition of governmental intervention in the rural credit market (BAE, 1977*a*) and some of the interventions have been justified on the basis of mitigating untoward climatic experiences. However, the effectiveness of such intervention is very doubtful (Standen, 1978).

It seems appropriate that policy makers have concentrated interventions by governments on the impacts experienced by producers. Measures such as income equalization deposits certainly cannot stabilize the effects of variable climate completely. However, they operate at the discretion of individuals, who hold their individual attitudes to risk (Function 2.1) and perceptions of climate (Functions 2.2 and 2.3), without distortion of the realities of their turbulent environments. These include climatically-sensitive agricultural environments and, increasingly, non-agricultural sectors of the economy. The number of rural producers and their families who derive revenue from sources other than the home farm is increasing (Reithmuller and Spillman, 1978). This compensating tendency is only partial because of the multiplier effects of drought on sectors other than agriculture. A further measure that will doubtless be important in buffering the impact of future extreme climatic events on producers is the Rural Adjustment Scheme with its provisions for carry-on finance and household support (Threlfall, 1977).

Whether governments have tended to intervene excessively or inadequately is a moot point. Some affected individuals have neither the desire nor the means to plan for and to cope with all impacts of climate on them. They will be a continuing target of relief measures but such intervention should be recognized as being part of a national welfare policy. It is politically unrealistic to expect governments not to intervene in natural disasters. However, apart from "welfare" cases, it can be hypothesized that interventions in agriculture occasioned by climatic variability have been developed and institutionalized beyond levels that are desirable on grounds of economic efficiency. Research on this hypothesis will be difficult but welcome.

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