AGRICULTURE IN A TURBULENT WORLD ECONOMY

PROCEEDINGS
OF THE
NINETEENTH
INTERNATIONAL CONFERENCE
OF AGRICULTURAL ECONOMISTS

Held at Málaga, Spain
26 August–4 September 1985

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INTERNATIONAL ASSOCIATION OF
AGRICULTURAL ECONOMISTS

INSTITUTE OF AGRICULTURAL ECONOMICS
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1986

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Natural Resource and Environmental Dimensions of Agricultural Development

INTRODUCTION

The productive capacity of world agriculture has grown impressively during the last half century. Although erratic over time and uneven among countries and regions, that growth, coupled with increased international trade, has afforded a modest improvement in food availability per caput in most parts of the world. Yet the global capacity to feed a population projected to increase to about 6.0 billion in 2000 and perhaps 10–11 billion before levelling off in the second half of the twenty-first century remains the subject of widespread discussion and debate. In part, the concern continues to be defined by the notion of 'limits to growth' – the mathematical imperatives of compound population growth rates pressing upon a finite supply of natural resources. This theme, so central to the projections and conclusions of the Club of Rome school prominent in the 1970s, dates back to Malthus nearly 200 years ago.

The environmental movement has added new dimensions to the Malthusian thesis. The very goals of economic efficiency and present patterns of productivity growth in agriculture are coming under increasingly intense scrutiny. Agriculture is viewed as an inseparable part of the larger ecosystem and as an increasingly important source of environmental pollution. A plethora of 'command-and-control' regulations to limit the use of environmentally-damaging technologies and production practices in agriculture is evolving in the United States and other industrial countries, with possible consequences for future agricultural productivity growth. This, the future productive capacity of agriculture may be constrained not only by the quantity of natural resources available but also by the quality of those resources and by market and non-market measures to assign to agriculture the environmental costs of externalities created by the sector.

It is not our purpose to develop still another assessment of potential future states of agriculture, natural resources and the environment. Most such assessments are subject to very large 'errors of estimate' because so many of the critical relationships between agricultural development and environmental quality indicators are themselves unknown or poorly measured. Nevertheless, we are convinced that the growing public concern in many parts of the world concerning agriculture and its relationship to natural resources and quality of the natural environment is neither ephemeral nor transitory. We suggest that these increasingly complex issues will pose formidable challenges to agricultural institutions for decades to come.

Our remarks are in three principal parts. We begin with a review of agricultural development in the United States and the nature of relevant current and emerging resource and environmental issues. Although institutions, resource endowments and public policies shaping US agricultural development are to some degree unique and the results therefore cannot be generalised, the US experience may nonetheless be instructive in considering agricultural development issues in other countries, particularly industrialised market economies. We turn then to a brief exposition of analytical approaches to assessing development and environmental tradeoffs in agriculture. Finally, we develop implications of the issues for agricultural economists and agricultural economic research.

DEVELOPMENT, NATURAL RESOURCES, AND THE ENVIRONMENT: THE U.S. EXPERIENCE

By conventional measures, productivity and output of US agriculture have increased dramatically since the Second World War. Based on our recent research, total factor productivity grew at an average annual rate of 2.2 per cent in the 15 years immediately after the Second World War, 1.0 per cent in the 1960s, and 1.7 per cent in the 1970s (Capalbo, Vo and Wade 1985).

A large part of the growth stemmed from development and application of land and labour saving technologies – new and improved mechanical power, improved seeds and animal genetic stock, hydro-electric and fossil fuel based energy, fossil fuel based fertilizers, pesticides, herbicides and fungicides, and other chemicals to aid livestock and crop production. Pesticide and fertilizer use, for example, increased annually at more than 6 per cent between 1948 and 1978. Several major publicly-financed water development projects became operational in the 1950s and 1960s. Irrigation, in response to low water and energy prices and new water application technologies, expanded rapidly from both surface and underground sources to 50 million acres in 1980 – almost double that of 1950.

Productivity of land, as measured by yield per acre, grew nearly 50 per cent between 1948 and 1978. Although the harvested cropland area was variable, acreage in 1982 was virtually identical to that in 1950; but crop production nearly doubled in that period. Labour inputs declined by nearly 70 per cent; labour productivity grew at an annual average rate of 4.8 per cent during 1948–78.

The regional effects of these patterns of agricultural development on the natural resource base have been uneven, as they depend on the physical properties of land, climate (and weather related variables), water and agricultural production systems and management. Evidence of effects on environmental quality is partial and incomplete, sometimes circumstantial and anecdotal. Yet the presumptive evidence continues to mount that 'high-tech' agriculture is a major source of environmental pollution and a source of significant risk for human and animal health and wildlife habitats.

A comprehensive recent assessment of the resource and environmental effects of agriculture in the United States suggests that the major environmental threat emanating from agriculture is that of soil erosion and associated effects on water quality (Crosson and Brubaker 1982). Sheet and rill erosion now exceeds the level that permits crop yields to be maintained economically and indefinitely on some 27 per cent of US cropland. Sediment delivered to the nation's waterways is projected to nearly double by 2010 under economic and technological assumptions of the study. These estimates derive in large part from a 60–70 million-acre increase in cropland to meet projected domestic and foreign demand for US agricultural products. Crosson and Brubaker conclude that such an expansion in cropland would further induce agricultural production on erosion-prone land and thus cause a significant decline in marginal agricultural productivity growth rates. A more recent RFF assessment of global food prospects suggests a lesser but still substantial increase in cropland by 2010 given no major breakthroughs in technology (Farrell, Sanderson and Vo 1984). In either case the pressure could be high on natural resources and environmental quality.

For most of the last half-century, US agriculture had access to low-cost energy and publicly subsidised low-cost water for irrigation. As a result, farmers have made profligate use of both. Current irrigation levels with average precipitation result in the 'mining' of over 22 million acre-feet of water from aquifers in the western United States. Nationally, nearly a quarter of the groundwater used by agriculture is not replenished. Falling groundwater levels coupled with higher energy costs are forcing major adjustments in agricultural production in a multimillion acre area in the central and southern Plains states.

Beyond these physical and economic dimensions of water resources are major problems of water quality. Groundwater contamination from agricultural as well as non-agricultural sources has become serious in many parts of the country. Western irrigation practices have raised groundwater salinity. 'Perhaps one-quarter of the lands currently under irrigation in the West are heavily dependent on non-renewable water supplies, and the productivity of several million additional acres is threatened by rising salt levels' (Frederick 1982).

Other water quality problems – dissolved oxygen; suspended solids carrying bacteria, nutrients, and pesticides; excessive phosphoric and nitrogenic nutrients – derive in part, occasionally in major part, from agricultural production practices and runoff into streams and lakes. Growing public pressure to control non-point pollution could significantly increase agriculture's future production costs.

About 1,000 new chemicals are introduced each year in the United States. Some 55,000 to 60,000 chemicals are marketed annually. Comparatively little is known about the potential toxicity of many of these chemicals, about precisely how they are used, whether and how they enter the food chain and other ecosystems, and their ultimate effects on human health and other species. Controls on use of pesticides in agriculture and forestry have become more stringent, and progress has been made in developing less toxic but effective pesticides and integrated pest management systems that reduce application rates. Nonetheless, pesticide use remains pervasive in the production of major field crops.

The presumptive evidence seems compelling that high agricultural productivity growth rates are linked with some types of undesirable consequences for natural resources and the natural environment. But presumptive evidence must be carefully interpreted: cause and effect are not easily specified among complex relationships of the type under discussion. Many technologies now in use appear quite compatible with public goals of long-term resource conservation and retention of environmental quality hospitable to complex ecosystems, e.g. plant genetic improvements, control of endemic diseases, production technologies to control erosion. Further, the effects of technology depend not only on the inherent technical properties of the technology but also on the economic and managerial environments that govern its use. Improper management of the technology may create or exacerbate environmental externalities; economic incentives, sometimes reinforced by public policies, may induce private, short-term profit-seeking entrepreneurs to use technology in ways that generate longer-run resource and environmental costs. Thus, attribution of the resource and environmental costs of technology cannot be disassociated clearly from the institutional and economic environment that conditions its use.

Population and economic growth also generate pressures on the natural resource base and environmental quality. The demand for land for urbanisation, industrialisation and transportation resulted in an average annual conversion of about one million acres of agricultural land from 1967 to 1982. Competition for water, particularly in the centres of population growth in the West, may yet bring about major changes in water pricing and allocation schemes to the economic disadvantage of agriculture. Demand continues to grow for resources for recreation. Although rising competition for natural resources is unlikely to seriously impair the US agricultural productive capacity as a whole, dislocations may be substantial in some regions.

Some of the most flagrant damages to environmental quality are the direct products of population growth and industrialisation – disposal of human and industrial wastes that contaminate water supplies, for example. Air pollution from industrial activity and high consumption of fossil-fuel energy pose potentially serious threats to atmospheric quality and as yet largely undetermined effects on agricultural productivity in the form of acid rain and the 'greenhouse effect'.

The long-term implications of these changes in agriculture's relationships to larger environmental and ecological systems may not be fully understood but it is clear that agriculture must be viewed in the context of interdependence in those systems as well as economic systems. The production of food and fibre affects and is in turn affected by the quality of the natural environment. The goals of enhancing agricultural productivity and output *per se* without due regard for the costs of externalities on natural resources and quality of the environment are becoming less acceptable to society as a whole.

Ultimately, trade-offs between high rates of productivity growth as currently derived in favour of greater protection of the resource base and reduced levels of environmental pollution could mean higher real costs of food and fibre. However, as Barnett and Morse remind us, the nature of future trade-offs among goals related to agricultural development, natural resources and environmental quality can best be viewed as a dynamic process:

> as one of continual adjustment to an ever-changing economic resource quality spectrum. The physical properties of the natural resource base (and quality of the natural environment) impose a series of initial constraints on the growth and progress of mankind; but the resource (and environmental) spectrum undergoes kaleidoscopic change through time. Continual enlargement of the scope of substitutability – the result of man's technological ingenuity and organisational wisdom – offers those who are nimble a multitude of opportunities for escape (Barnett and Morse 1963).

Therein lies a major challenge to science, agricultural research and economists.

TOWARD ASSESSING DEVELOPMENT AND ENVIRONMENTAL TRADE-OFFS IN AGRICULTURE

In this section we sketch possible approaches to modify current economic analysis better to reflect the environmental and resource trade-offs in agricultural development. We examine selective models and measures to reflect these economic trade-offs as well as the economic health or performance of the agricultural sector.

The methods we examine fall within the realms of resource and agricultural economics. This area is important because some of the natural resources of concern are not exchanged through markets as are other agricultural resources, have common property aspects, and/or cause externalities to other users and non-users. Yet by the same token, these resources are extremely important to the continued efficiency and productivity of the agricultural sector. Furthermore, while the non-market and common-property characteristics of these resources provide a solid rationale for government intervention, this rationale is often quite removed from the current objectives and effects of agricultural policies. These policies may have little to do with the economic efficiency criteria for using natural resources.

Zilberman notes that the depletion patterns for water from a non-replenishable aquifer depend highly on technical change and agricultural price policies. Technical improvements in irrigation practices and some types of agricultural price support policies may operate in opposite directions on the output price. The former tends to depress the output price because of a shift in the producer's marginal cost curves; the effect of the latter may be to increase output price in the early periods. With respect to the depletion of the resource, technological improvements operate to reduce water use , while the price support policy tends to indirectly increase water use by increasing the quantities of output producers are willing to provide.[1] Over the long run the more rapid depletion of the aquifer will increase water prices and reduce output levels. While the extent that Zilberman's results can be generalised to other resources and policy scenarios is an open research area, the evidence illustrates the importance of addressing both agricultural policies and technological change in systematic analysis of agricultural development and environmental trade-offs.

The pesticide controversy offers a second illustration of the need to incorporate both technological change and agricultural policy options in a dynamic manner. The public policy solution to this externality problem in the past has been to restrict or prohibit the use of many chemicals. Restricting or eliminating the use of a particular pesticide of course reduces or eliminates its beneficial as well as its detrimental effects. Understanding the economic incentives that induce farmers to use chemical-intensive technologies is important in addressing the policy implications of pesticide bans. To assess properly the environmental trade-offs, one needs to know how using a pesticide in period *t* may affect the future ability to control target pests. For example, pesticides are likely to be temporarily beneficial but have declining marginal products. Thus, it is important to understand and incorporate the marginal benefit relation into a dynamic model.

The results of pesticide productivity studies are consistent with the high adoption rates of chemical-intensive technologies in post-Second World War agriculture. Headley found a high marginal productivity for pesticides and chemicals based on aggregate (state-level) production function analysis for the mid-1960s. Evidence at the micro level confirms the highly productive nature of chemical pesticides through the 1970s (Archibald 1982). This expansion in the use of chemical inputs has been encouraged by price and income policies for agriculture that restricted land inputs, increased crop land prices and provided output price supports. Since the market price of pesticides to farmers has not reflected both the private and social costs due to externalities, the current combination of land, pesticides and other inputs may not be the socially least-cost option for producing a given output.

The above concerns underscore the types of dynamic and inter-disciplinary analyses needed to explore the economic growth and environmental trade-off problems in agriculture. The short-run static nature of many models, combined with the limited information concerning the effects of continued use patterns for environmentally damaging inputs or the assimilative capacity of the environment, severely restrict the empirical analysis to provide anything more than an estimate of the current benefits and costs. These limitations have been well documented and attempts are being made to relax the static assumption and replace the analysis with a dynamic framework.[2]

One distinguishing feature of this new generation of models is that they should be based explicitly on dynamic economic optimisation incorporating costs of adjustments for the adoption of new technologies as well as biological relations that link intertemporal uses of environmental resources. That is, the speed with which firms adjust to new technologies should be endogenous and time varying, rather than exogenous and fixed. Also, the quality and quantity of the resource stock in period t should be explicitly related to the utilisation and conditions of the stocks in period $t-1$. This last component of the dynamic framework takes on a variety of forms and complexities. For a water resource problem, a single equation of motion describing the stock of water as a function of previous use levels may suffice. If the production involves agricultural runoff, the dynamic component is likely to involve complex interactions among many subsystems.

While integrating research on agricultural policy and resource management is paramount in evaluating the private and social cost of the growth/environmental trade-offs, the models developed for this purpose tend to be both commodity and policy specific. This is partly dictated by data requirements and limitations on model specifications, but there is a parallel need to provide some means of comparing the trade-offs at a more aggregate level. In our introductory comments we employed the familiar yardstick of the economic health of a sector – total factor productivity (TFP). The evidence suggests that the largest gains in TFP in US agriculture occurred during the decade and a half immediately following the Second World War, with slower growth rates observed during the 1960s and 1970s. In the most narrow sense one might suggest that there has been a relative decline in the economic performance of the sector. This conclusion needs to be qualified by examining the components of the productivity index.

The broad productivity criteria concentrate on *measurable* outputs of goods and services and neglect environmental quality. Some attempts are being made to adjust the conventional inputs to reflect quality change, but explicit recognition of the role of non-market inputs is lacking. A sector is productively efficient if it is producing as much as possible of every good and service given the amount of resources used. The neglect of the environmental quality components from these measures is a serious misstatement of the economic performance of the sector and, thus, TFP is inadequate for assessing economic efficiency and the trade-offs between environmental quality and economic growth.

To incorporate these trade-offs, one might utilize a more inclusive concept – augmented TFP[3] – which includes measurable agricultural output as well as the value of improvements to the resource base and environmental quality. This measure would reflect the social output as well as the private output from using a given bundle of inputs. Inputs devoted to restoring the quality of the environment or slowing resource depletion would have a beneficial value on the output side. Likewise, if the production of marketable output involved a decrease in the environmental quality, then this would show up as a diminution to the augmented output index, relative to the traditionally measured output index.

To illustrate the implications of this modification to TFP, one might correlate the growth rates of the potentially damaging inputs such as fertilizer and pesticides with the growth rates of the conventionally measured output. The 1948–60 period in US agriculture saw a large displacement of labour by agricultural chemicals; TFP also grew at a phenomenal rate of over 2 per cent per year. By contrast, the 1970s showed a slowdown in the rate of growth of chemicals and a slowdown in the exodus of labour from the agricultural sector. Given the changes in the input composition that occurred, one might hypothesise that an augmented TFP measure would be less than the observed TFP in the 1948–60 period and possibly greater in the 1970–8 period. In the absence of any statistical analyses our point regarding the TFP measure can only be suggestive: using the conventionally measured TFP index is likely to be misleading if one is concerned with environmental trade-offs. A decline in this TFP index may be a Pareto improvement and the high growth rates of the 1948–60 period for US agriculture may be less attractive using the augmented TFP measure.

Alternatively, the process can be viewed as an adjustment on the input side. Define the production function of a sector as:

$$Y = F\,(v, x, x, t)$$

which represents efficient combinations of the conventional inputs v, and the environmental inputs x that can be used to produce output Y at time t. If the level of quality of the environmental inputs declines ($\dot{x} \neq 0$), output produced with any given amount of the conventional inputs would decline because of the necessity to utilise inputs to increase the stock of x rather than produce output. This diminution in output constitutes an internal cost of adjustment to the agricultural sector.

The apparent inverse relationship between environmental quality and increasing productivity leads to several implications concerning public policies to raise agricultural productivity. Obviously, it is not enough that such policies should simply encourage individual farmers to become more efficient. Equally important is ensuring a high rate of gross investment in both the capital stock and the environmental stock. The relation described above in principle is the basis for an intertemporal model in which the accumulation of capital and environmental resources link the production processes through time.

CONCLUSIONS AND IMPLICATIONS

We view trade-offs between agricultural development and natural resource and environmental quality as a dynamic, ever-changing process in responding to changing technological, institutional and economic criteria and the goals of society. There is need to define and measure the trade-offs more fully and accurately so that more informed choices can be made. And new or improved institutional designs are needed to facilitate effective expression of those choices. Nevertheless, the environmental risks associated with agricultural production cannot be reduced to zero.

Clearly, science and technology must play a major role in enlarging the future scope of substitutability between environmental resources and other resources in meeting future world needs for food and fibre. For some, the *sine qua non* of future agricultural technologies is that of biotechnology and the promises of dramatic productivity-enhancing breakthroughs in both plant and animal science. But before 'the genie is unleashed from the bottle' we should inquire rigorously of the potential effects of such technology on variables other than agricultural productivity as conventionally defined. In the thesis of this paper those variables include natural resources and quality of the natural environment.

If our perceptions and conclusions are valid, major implications ensue for agriculture and related institutions and for public policies. In concluding we single out four such implications of particular significance to agricultural economists and offer recommendations for addressing each.

(1) Agricultural research and extension programmes need to be re-examined – possibly reoriented – to more fully reflect that 'natural resources are an integral part of the ecosystem, and they have values transcending that of production for today's harvest' (Batie). Agricultural research and extension programmes in the United States and, we suspect, in other countries, have been heavily influenced by 'technological determinism' – a tendency to develop and extend agricultural productivity and output-enhancing technology sometimes without due reference to potential natural resource and environmental effects of the technology. If joint objectives of maintaining agricultural productivity, protecting natural resources and quality of the environment are to be achieved, more purposeful research and extension programmes reflective of those objectives are called for.

(2) Much of the research required to better identify the terms of trade-off between agricultural productivity and natural resource and environmental quality will be perforce interdisciplinary. Research

administrators should seek ways to provide incentives to induce more extensive and effective participation of scientists in cross-disciplinary research. We suggest that agricultural economists should play a larger role in such research. Current micro and macro analyses need to be modified to reflect dynamic forces in the use of natural resources.

(3) Data and information systems concerning the physical and economic attributes of natural resources should be strengthened and made more consistent within and across countries. Measures for monitoring environmental quality should be improved; monitoring should occur more frequently and rigorously; data should be systematised and made readily available for research and policy purposes.

(4) Agricultural, natural resource and environmental policies and programmes should be brought into closer harmony. The public goals underlying many current agricultural policies should be re-examined in the light of evidence of conflict with other public goals concerning natural resources and the environment. The rationale for such policies has often been tied closely to enhancement of agricultural production. We may now be seeing, all too clearly, the true social costs of these policies.

Perhaps the most basic implication of our perceptions and conclusions is the need for agricultural economists to perceive themselves and to define their agenda in a context that recognises and reflects the interdependence of agriculture in larger and more complex environmental and ecological systems as well as economic systems. If that is done, agricultural economists have much to offer in identifying the trade-offs between agricultural productivity, natural resource use and protection and environmental quality, and in the design of institutions to facilitate implementation of those trade-offs.

NOTES

[1] This latter result assumes that the demand for water is fairly responsive to output price.

[2] The studies by Zilberman and Archibald are two such examples.

[3] Augmented GNP was originally proposed by Dorfman and Dorfman.

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