Agricultural R&D, Technological Change, and Food Security

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1. Introduction

How is "food security" defined? The term "food security" might mean different things to different people or in different settings, but any useful concept or definition of food security concerns the balance between the supply and demand for food at some level of aggregation over people and places. The delegates at the 1996 World Food Summit suggested: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Hence, in simple terms, measures of food security, or the lack of it, quantify the extent to which some people, some of the time, do not have enough of the right kinds of food.

Agricultural science and agricultural science policy affect food security, however it is defined or measured, primarily through their effects on

- agricultural technology, productivity, and total food production
- farm incomes and the returns to factor owners
- total availability of food, food prices, and poverty

Other elements of the effects may concern the quality or nutritional characteristics of food or other characteristics of the statistical distributions of food consumption outcomes, such as the risk of widespread famine. This paper looks backwards and forwards in time at the past and potential future effects of agricultural science on elements of "food security," and the role of government policy in conditioning those effects from a national and global perspective.

It seems clear that agricultural R&D and the resulting technological change has led to several related effects:

- more abundant, cheaper food
- less poverty
- a decrease in the number of people going hungry
- a (perhaps smaller) decrease in the proportion of people going hungry

The effect on the proportion as opposed to the number of people going hungry depends on the longer-run effect on the total population, which is less clear because it combines multiple effects

- fewer people as a result of reduced fertility rates
- more people as a result of reduced mortality rates

In addition, some *possible* effects may be less clearly good effects

- more specialized and more intensive production on individual farms (and, for some, a greater risk of crop failure)
- a greater use of purchased inputs (and, for some, a greater risk of financial ruin)
- a faster rate of consumption of natural resource stocks
- less biological diversity and an increased risk of widespread famine

Some of these elements are conjectures and not really established as being the result of agricultural R&D. The pathways of the various potential effects are complicated and multifaceted. There can be no doubt, however, that in the past agricultural R&D has contributed very substantially to agricultural productivity. And it seems likely that an increase in the amount of spending on agricultural R&D would contribute to further reductions in poverty and an increase in the number of people not going hungry; by most measures, an increase in food security. Depending on the specific nature of the R&D, and other policies, it might also have some other positive or negative effects.

As in many papers about food security, for the present purpose we focus on the implications of agricultural R&D for "abundance" of food and "access" to it (i.e., poverty) as elements of food security (i.e., effects of agricultural R&D productivity, production, and price of food; and thus on real incomes of farmers and consumers). In addressing agricultural R&D policy as an element of long-term global and national productivity policy, consideration is given to research priority setting and the evaluation of agricultural science policy and outcomes.

2. Past Patterns

As pointed out by Gale Johnson (2000), since 1960, the world's population has doubled, from 3 billion to 6 billion. Over the same period, grain production more than doubled, and this increase was due almost entirely to unprecedented increases in yields. The fact that the Malthusian nightmare has not been realized is attributable in large part to improvements in agricultural productivity achieved through technological change enabled by investments in agricultural R&D.

Agricultural Productivity and Food Supply

Table 1 shows growth rates of crop, livestock, and total agricultural production over 37 years (1961-1997) around the world and for the world as a whole. In the total column, a global growth rate of 2.25 percent per year compounded over 37 years means that the index of agricultural production more than doubled, from 100 in 1961 to 228 in 1997. This global average reflects generally faster growth in the less-developed countries

(3.29 percent per year, which implies that the output index more than tripled, from 100 to 331); with especially fast growth in Asia (3.50 percent per year) and below average growth in Africa (2.16 percent per year).

[Table 1: *Growth in Crop, Livestock, and Total Agricultural Production, 1961-97*]

This growth in output reflects the combined effects of changes in input use (relatively constant or declining in some countries, especially some of the richer countries, but increasing in others) as well as changes in productivity. And the changes in productivity might come from other sources, such as improvements in input quality, infrastructure, and education, as well as from technological change resulting from agricultural R&D. But much, and perhaps most, of the growth in output is reasonably attributable to research-induced productivity growth. For instance, in the United States the rate of multifactor productivity growth in aggregate agriculture over the period 1960-1993 was about 2 percent per annum, over a period when input use was static, which might be representative of OECD countries.

Huang and Rozelle report estimates of multifactor productivity growth rates over 1976-1995 for individual commodities produced in South China, partitioned into elements attributable to research stocks and various other factors. Specifically, for **rice**, the MFP growth rate was 1.78 percent per year, of which 1.38 percent per year was attributable to the research stock; for **wheat**, the MFP growth rate was 4.54 percent per year, of which 2.82 percent per year was attributable to the research stock; for **other grain**, the MFP growth rate was 4.29 percent per year, of which 3.58 percent per year was attributable to the research stock; for **cash crops**, the MFP growth rate was 9.27 percent per year, of which 7.26 percent per year was attributable to the research stock.

It may be more relevant, when talking about food security (and poverty issues which seem inseparable) to pay more attention to the staple crops on which the world's poorest people depend for sustenance. Table 2 shows the sources of calories, by region, for 1961 and 1997. It can be seen that for much of the world, rice, wheat, sugar, and maize provide more than half of the calories; rice and wheat alone more than 40 percent.

[Table 2: *Sources of Calories Consumed, 1961 and 1997*]

Wheat and rice yields have grown enormously, especially over the past 50 years. Figure 1 provides a long-term perspective on U.S. wheat and rice yields. It can be seen that U.S. wheat yields roughly doubled in the past 50 years and rice years roughly trebled over the same period. While these figures are specific to the United States, they are broadly indicative of global movements. World wheat yields doubled over the 35-year period 1961 to 1996, and over the same period, world wheat production almost trebled (figures 2 and 3)

[Figure 1: *U.S. Wheat and Rice Yields, 1800-1996*]

[Figure 2: *World Wheat Yields, 1960-1996*]

[Figure 3: *World Wheat Production, 1960-1996*]

Figure 4 provides a picture of the long-term trends in U.S. real prices of wheat and rice. In spite of the growth in demand arising from growth in total population and income per capita, the growth of supply was such that over the period 1960 to 1996, U.S. prices of both wheat and rice fell by more than 50 percent. Similarly, figure 5 shows that an index of food commodity prices fell by 40 percent from 1959 to 1997. Johnson reports in round figures a 100 percent increase in world grain production accompanied by a 50 percent reduction in real grain prices over the period 1960 to 1995.

[Figure 4: *U.S. Real Wheat and Rice Prices, 1899-1996 (1994 U.S. dollars)*]

[Figure 5: *Real World Food Price Index, 1959 = 100*]

3. Effects of R&D and Technical Change

What do we know about the effects of agricultural R&D on these long-term paths of variables that relate to our notions of food security? To begin to think about this question, let us consider what the world market for grain would be like today if we had the current population and its distribution, but had to use 1950s agricultural technology.

Some Simple Arithmetic on Past Productivity and Prices

Suppose we assume that the medium-term elasticity of supply of grain is $\varepsilon = 1.0$ and the elasticity of demand is $\eta = -0.2$. The proportional growth of supply (g) required to achieve a proportional increase in crop output of $q = d\ln Q$, in spite of a negative proportional change in price of $p = d\ln P$, is given by $g = q - \varepsilon\, p$. Then the total growth of supply implied by a 100 percent increase in output, in spite of a 50 percent decrease in the real price of grain, is 150 percent. Now, let us suppose conservatively, for the sake of argument, that two-thirds of the past 35 years' growth in supply is attributable to research-induced productivity improvements (i.e., a proportional increase of j such that $100j = 100$ percent is two-thirds of $g = 150$ percent growth). What would the world be like today in the absence of those productivity gains? This can be analyzed by examining the price and quantity effects of a $100j/(1+j) = 50$ percent reduction in current supply against the given demand. The equations for proportional changes in price and quantity are $q = -\eta j/(\varepsilon-\eta)$ and $p = -j/(\varepsilon-\eta)$.

Then, eliminating 35 years of research-induced productivity gains would imply an increase of the current price of grain by about 42 percent (25 percent of the 1960 price) and a reduction in the current quantity produced and consumed of about 8 percent (16 percent of the 1960 quantity). It is largely a coincidence that the price change here, 42 percent, is roughly the same as the general decline in food prices over the same period, discussed earlier. These numbers refer to "with" and "without" the research-induced productivity gains. Although they are quantitatively related and of similar orders of magnitudes, they are conceptually different from the price and quantity changes over time, the "before" and "after" figures, which reflect the effects of all the variables that changed.

Distributional Considerations

When considering food security, as an issue for individuals, we have to go beyond these average or aggregate measures and think about impacts of R&D on distributions of income (or poverty), both over time (or in a probabilistic sense), and among people at a point in time. Improvements of technology for the production of staple crops give rise to benefits, B_i accruing to the ith household, approximately equal to

$$B_i = -P_i C_i \, d\ln P_i + (k_i + d\ln P_i) P_i Q_i ,$$

where P_i is the price paid by the household for its consumption, C_i (and received for its production, Q_i) of the crop, and k_i is its household-specific increase in supply (expressed as a proportional reduction in unit costs) associated with the improvements in technology giving rise to the proportional price change, $d\ln P_i < 0$. The first element of the equation represents the consumer benefit. Households that consume but do not produce the crop obtain a benefit equal to the reduction in their cost of consumption—a real income effect of the research-induced price fall. The second element represents the producer benefit. Households that produce but do not consume the crop obtain a gain equal to the difference between their proportional cost reduction and the proportional fall in price ($k_i + d\ln P_i$) times the value of their production.

More generally, households that both produce and consume the good receive a net gain equal to the sum of two gains, as shown in the following version of the above equation:

$$B_i = k_i P_i Q_i + (P_i Q_i - P_i C_i)\, d\ln P_i$$

First, is the cost saving on production (their proportional cost saving times their value of production). Second, is their gain from the reduction in their *net* costs of food purchases (the difference between their expenditure on consumption and the value of their production) resulting from the fall in price. For food deficit households, the fall in price means a benefit; for food surplus households, it means a loss. Gainers include all households who produce less of the good than they consume, regardless of whether they adopt the new technology or not. Potential losers are those surplus households (i.e., who produce more than they consume) that are not able to achieve a per unit cost reduction equal to the market-wide reduction in price associated with the technology. Among these, in this analysis, those surplus households that are unable to adopt the technology are the only sure net losers.

Longer-Term Considerations

The above analysis might be interpreted as a medium-term or partial analysis. A more general or longer-run analysis might take more explicit account of linkages with the broader economy and this might change the story. In his Presidential address at the 2000 AAEA meetings, Bruce Gardner presented evidence that over a 30-year period, 1960 to 1990, changes in U.S. farm household income were not related to changes in agricultural productivity (or any other agriculture-specific variable). The general idea is that, given enough time for adjustments of employment to take place, incomes of farm households are expected to be determined by their endowments and economy-wide prices of factors, which are equalized between agriculture and the rest of the economy. In the U.S. example, agriculture is such a small share of the total economy that the economy-wide factor prices can be taken as exogenous (with the possible exception of agricultural land). In less-developed countries, events in agriculture may change the economy-wide prices of factors as well, but the general point remains relevant: linkages with the rest of the economy through the integration of labor and capital markets (e.g., through changes in occupational choice, and migration to the cities, and remittances) mean that events in agriculture are not the sole determinants of farm household incomes.

Even if agricultural productivity has no effect on farm household incomes, it affects farm household food security or poverty through its effects on the price of food. Figure 6 shows a stylized distribution of farm household income, Y, before a research-induced gain in productivity, with an initial "poverty line" drawn at L. As a result of the productivity improvement and reduced food prices, the poverty line moves to L´, reducing the fraction of the population living in poverty. This is a big effect given a big change in the price of food (say, a 30-40 percent increase from the present price if the past 35 years of research-induced productivity gains were eliminated), and a big weight on food in the poverty line. This is so, with no changes in income.

[Figure 6: *Agricultural R&D and Household Income Distributions*]

If, as well, incomes increase and the distribution shifts to the right, say to Y´, then there is a further reduction in the fraction of the population living in poverty. The analysis above suggested that some farmers might be made worse off (if, for instance, they are surplus producers and cannot adopt the new technology). Nevertheless, the full distribution might shift to the right, as drawn. In Gardner's analysis of the United States, there were no such shifts in the distribution of incomes, but there would still be the shit of the poverty line to consider. In less-developed countries we might expect to see significant roles played by the two types of effects.

Prospects for Prices and Productivity

The analysis of past trends is suggestive of things to consider in looking forward. What will be the effect of agricultural R&D, given population projections (or allowing for interaction with population) on the future path of the measures that relate to food security: agricultural productivity, production, and food prices; rural and urban poverty; frequency and severity of famines?

What do IFPRI's 2020 projections say? Between 1995 and 2020:

- the world's population will increase by 32 percent, to 7.5 billion
- much of this population growth will occur in the cities of the developing world
- per capita incomes will increase in all major developing regions

- 85 percent of the growth in demand for food will come from developing countries
- demand for meat in the developing world will double
- demand for cereals for feeding livestock will double in developing countries
- world grain production will have to increase by 40 percent
- food prices will remain steady or fall

These price projections, in particular, are based on some technological and market assumptions, which include a continued slowdown in crop yield increases combined with strong growth in demand for meat in developing countries. They mean a continuation of serious problems of food insecurity and malnutrition into 2020 and beyond, even with a 40 percent increase in grain production. This increase in production must be achieved through gains in yields.

The specific assumptions about technological change embedded in the IMPACT analysis are based in turn on assumptions about agricultural R&D policy and investments, and the effectiveness of those investments in bringing about productivity gains. These decisions have not yet been made, and there is much discussion about what they should be—in terms of the total investment by various agencies in agricultural R&D, and the nature of those investments in terms of the commodity orientation, regional relevance, or scientific objective of the research.

Recent Patterns in Agricultural Research Institutions and Investments

It is hard to obtain up-to-date information on agricultural research spending. Alston, Pardey, and Roseboom summarize trends in total spending and agricultural research intensity ratios around the world using data for 1971 to 1991 (more detailed information is contained in Pardey, Roseboom, and Craig). The key points are:

- worldwide, investments by national governments in agricultural R&D almost doubled in real (1985 international dollar) terms from $7.3 billion in 1971 to $15 billion in 1991
- public agricultural research expenditures in developing countries grew by 5.1 percent per annum from $3 billion in 1971 to $8 billion in 1991
- corresponding expenditures in developed countries grew by 2.3 percent per annum from $4.3 billion in 1971 to $6.9 billion in 1991
- developing countries now spend more than developed countries on public agricultural research
- for all regions, spending grew much more slowly in the 1980s than the 1970s
- agricultural research intensity ratios (ARIs) in developed countries increased from $1.38 per $100 of output in 1971 to $2.39 per $100 in 1991
- agricultural research intensity ratios in developing countries increased from $0.38 per $100 of output in 1971 to just $0.50 per $100 in 1991, still much lower than for developed countries
- spending on private sector agricultural research has grown relatively rapidly, and exceeds public spending in many developed countries
- spending on international agricultural research (in the CGIAR) grew very rapidly in the 1970s and somewhat less rapidly in the 1980s, but growth stalled in the 1990s

Along with the slower growth in total funding for public agricultural research, there has been a broadening of the agenda, to include less-traditional areas such as environmental issues so that research managers are being asked to do more with less (for instance, see *Making Science Pay*, and *Paying for Agricultural Productivity*).

4. Policy Issues

Some central questions concerning agricultural R&D policy, applicable to any national or subnational government, or international joint ventures, are:

- how much R&D (what should be the total expenditure)?
- which types of R&D (how should the money be spent)?
- who should pay (how should the funds be raised)?
- who should do the R&D (should it be conducted as well as funded publicly)?
- what institutional arrangements (for allocating funds and coordinating activity)?
- what incentive mechanisms should be used in allocating research funds and rewarding effort and achievement?

Objectives for Agricultural R&D Policy

If we wished to design an "optimal" agricultural R&D policy, and determine appropriate answers to those questions, the very first step might be to define the objective or objectives for government policy related to agricultural R&D. One oft-offered argument is that the purpose for government intervention in agricultural research is to correct market failures that arise from inappropriabilty of returns to research investments, and give rise to an underinvestment from the collective viewpoint.

The essential idea can be seen in figure 7, which graphs the "supply" and "demand" for research. In the figure, MSC=MPC is the marginal social cost of research (assumed to be equal to the marginal private cost), MPB is the marginal private benefit, and R(0) (where MPC = MPB) is the quantity of research that would be produced absent government intervention. The curve MSB shows the conventionally conceived marginal social benefit, and the socially optimal quantity is R(1). The standard argument is that the government should intervene, somehow, to cause an increase in the research investment (to reduce the underinvestment equal to R(1) – R(0)). The observation that rates of return are high is used to infer that the intervention is too little, and that the rate of research investment given government intervention, say R(2) is still too small—especially in relation to developing countries or where research products are multinational collective goods.

[Figure 7: *Supply and Demand for Research, and Effects on Food Security*]

Now, suppose we recognize that, in addition to these conventionally noted benefits from research, as discussed above, agricultural research also promotes improvements in food security (in terms of abundance of food and access to it). The lower panel of figure 7 graphs a measure of food security (FS) against the quantity of agricultural research—increasing at a decreasing rate (although this shape does not matter much for what follows). It can be seen that government intervention to reduce the underinvestment in agricultural R&D would also, incidentally, give rise to an increase in food security.

Suppose agricultural R&D does, perhaps incidentally, lead to a reduction in poverty. Does it follow that poverty reduction is an appropriate objective for agricultural research? And how should the effects on poverty be considered in deciding how much to spend on research and the pattern of investment? One approach is to suppose that there are social benefits from poverty reduction, and that these ought to be included in the analysis of figure 7. Hence, MSB´ is the new curve representing the marginal social benefits from research, including the benefits from enhanced food security (or other additional social benefits as externalities from research-induced productivity improvements). Then, the new social optimum is given by the intersection of MSC and MSB´, which implies a greater optimal quantity of research, R(3) and a greater quantity of food security, FS(3) than would be implied by the conventional analysis.

The observation that R&D has positive implications for food security might be used in a political setting to induce a greater research investment (a reduction in the extent of the underinvestment). On the other hand, it might just make us aware that the underinvestment is more acute than we had previously thought, if we believe that there are positive externalities associated with increases in food security. In any event, it seems clear that regardless of any observations of implications for food security, the total investment in research will fall well short of the social optimum—even the optimum that excludes any food security benefits, R(1).

Given that there will be an underproduction of both R&D and food security, a related question is whether the research portfolio should be designed with a view to achieving food security (or other social) objectives, perhaps at the expense of other potential benefits from research. This is a tricky question. By answering this question in a general way, we hope to be able to address related notions of designing research portfolios to achieve environmental objectives, or nutritional objectives, or other social objectives.

Figure 8 graphs a trade-off between two objectives of research. The horizontal axis represents economic efficiency, E, and the vertical axis measures equity, V (E might represent total economic surplus in society, and V might represent the economic surplus of low-income families). The curve BTC represents the range of *maximum* possible combinations of economic efficiency and equity that can be achieved by varying the mix of research programs in the portfolio. Point *c* represents the result if the portfolio were chosen to maximize economic efficiency at E(max). This would correspond to R(1) in figure 7 (or R(3) if we were counting the externalities associated with food security).

[Figure 8: *A Trade-off of Equity and Efficiency using Research Policy Alone*]

Moving back along the curve, we can see how much economic surplus must be foregone in order to increase equity by shifting the portfolio away from the one that maximizes economic efficiency. The other curve on the diagram is an indifference cure, IC(0), that represents the policymaker´s willingness to substitute efficiency for equity. Thus the "optimal" research portfolio is the one that corresponds to point *b* (E*, V*). To increase equity from V(min) to V* involves an opportunity cost of economic surplus foregone of E(max) – E*.

One problem with this analysis is that it has been conducted as though there were no other policy instruments available for substituting equity for economic efficiency. Figure 9 duplicates the curves in figure 8, but adds two additional curves. BTC* is the optimal benefit transformation curve that represents the combinations of economic efficiency and equity that are possible from changing the combinations of the research portfolio and another policy instrument, or instruments (say a tax and an income transfer). This BTC is always above the one that holds when only research policy is involved. In figure 9, the higher optimal point *d* involves higher levels of both equity, V** and efficiency, E** than the optimum from research policy alone (point *b*). An extreme outcome, but not an unlikely one, is where the research portfolio is chosen without regard to the equity objective, which is pursued most effectively with other policy instruments.

[Figure 9: *Equity and Efficiency using the Least-Cost Policy Combination*]

To make matters more complicated, we should recognize that the total research budget is likely to be less than the amount required to achieve maximum economic efficiency—i.e., there is an underinvestment. This means that the observed outcome may be a point such as *e* in figure 9. Hence, by increasing the research budget, even if the objective is to maximize efficiency without regard for equity, both equity and efficiency might be increased. In the case of food security as an equity objective, for instance, this would be so. Given an underinvestment relative to the efficiency-maximizing outcome, a diversion of the portfolio towards equity might involve an even greater opportunity cost than if there were no underinvestment.

This is analogous to an idea raised by Per Pinstrup-Andersen in relation to improved nutrition through changes in dietary quality as a research objective. One approach would be to conduct research to incorporate greater quantities of particular vitamins and minerals into crops, another approach would be to conduct research to improve the productivity and lower the relative prices of foods that re already rich in these vitamins and minerals. The engineering approach might not be the most economical.

Food Security as an Objective for National and International Agricultural R&D

Food security is mostly a problem of LDCs. But R&D by more-developed countries has effects on food security through trade and world market prices. If we want to use agricultural R&D to increase food security, where should we spend the money (rich versus poor country NARSs or IARCs)? Should it be focused on technology used by poor farmers (i.e., devoted to farm-level solutions) or those farmers with the least-secure food supply, or should it be directed to where it will have the biggest effect on total availability of food or the biggest impact on food prices?

It has been proposed recently that agricultural research managers ought to give greater attention to non-efficiency objectives such as poverty, nutrition, or food security. For instance, it has been suggested that research into technologies for farmers in marginal areas ought to be given greater emphasis. Suppose that this can be done only by reducing expenditure on, say, traditional varietal improvement research. Questions that reasonably ought to be asked in this context are

- will the new research be effective?
- will it give rise to smaller total benefits than varietal improvement research?
- will it give rise to greater benefits in terms of food security or other equity objectives?
- presuming a tradeoff between total research benefits and their distribution, is this change in research priorities the least-cost way of achieving the distributional objective?

In general, to answer these types of questions well we need to have a much better understanding of both (a) the technological possibilities (will the research be effective?) among the research alternatives, and (b) the consequences for efficiency and food security if the research is effective and adopted.

Other Important Issues

Related issues that demand attention concern the division of labor among different types of private and public, national and international research institutions, for different types of research, the financing of the research, and the rights to the outcomes, taking into account issues such as knowledge spillovers and economies of size. Given that funds will be constrained and the total investment will remain too small, it will be particularly important to economize in terms of the research "output mix," and in terms of costs through the "industrial organization" to achieve economies of size, in particular. The interconnected financing, organization, and management elements are important, too. All these aspects will have implications for the total research effort, its effectiveness, and its food security implications, but cannot be dealt with here (see *Making Science Pay*, *Paying for Agricultural Productivity*, and our forthcoming Hidden Harvest and CGIAR papers).

Perhaps the biggest questions that remain unanswered concern what will happen with modern biotechnology and the implications for the global pattern of changes in agricultural technology and productivity. Per Pinstrup-Andersen has suggested that the potential of modern biotechnology to raise productivity, improve nutrition, and reduce poverty may be underutilized. One reason is the possible neglect of developing countries by private biotech firms, who might not be able to easily appropriate benefits from technology applicable in those countries. A second reason is the opposition to the use of genetically modified organisms in food products expressed by consumers in richer countries, especially Europe and Japan, which will hamper the rate of development of biotechnologies generally.

5. Conclusion

This paper has documented the important past effects of agricultural research in enabling productivity growth, which has enhanced food security first, by increasing the total availability of food, and second, by increasing access of the poor to food both by increasing incomes of producers, and by reducing the cost of food. In the past 35 years or so, food production more than doubled and food prices fell by 40 percent. Agricultural research accounted for a significant share of those changes. If we had to give up the productivity gains over the past 35 years attributable to agricultural research, simple calculations indicate that grain prices might be 42 percent higher and total grain production would be 8 percent lower. For those of the world´s poor for whom grain availability and prices matter, such changes would have significant implications for their well-being and their access to food.

Projected growth in population and incomes over the next 20 years or so translate into demands for very substantial growth in food production (i.e., 40 percent for grain), which must be achieved through productivity improvements. Some seem to take these productivity improvements for granted, but the supply of funds for agricultural research is not assured, and competing demands are being placed on those funds to be used for purposes other than enhancing the supply of food. Given the long time lags between investing in research and having an effect on productivity, any current complacency about the future food supply could be dangerous.

Among the challenges for those entrusted to allocate the limited funds for public agricultural research, is how to balance the expenditures between research intended to enhance the total food supply without regard to distributional factors (i.e., emphasizing economic efficiency), and research with a focus on a particular group of poor farmers, producing a particular commodity, in a particular agroecology (i.e., emphasizing a distributional objective).

Agricultural research policy alone might not be the best instrument for achieving certain types of food security objectives, and in many instances it will be ineffective or wasteful to divert limited research funds away from the efficiency-maximizing research portfolio. On the other hand, in some situations there might not be any other instruments available that can be used effectively to address extreme poverty. It will be important to take care in identifying such situations. At present we have very little evidence or information on the implications of different types of research investment in terms of total benefits, let alone the distribution of those benefits among producers and consumers and across various income classes, or the implications for food security, poverty, or nutrition. We ought to invest more in obtaining such information.

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Table 1: *Annual Growth in Crop, Livestock, and Total Agricultural Production, 1961-97*

	Crop	Livestock	Total
		(percentage)	
Latin America and the Caribbean (##)[a]	2.61	2.85	2.71
Asia (25)	3.01	4.93	3.50
Sub-Saharan Africa (47)	2.09	2.35	2.16
Developing Countries (158)	2.97	4.07	3.29
United States	1.98	1.23	1.61
Western Europe (20)	1.08	1.43	1.27
Developed Countries (52)	1.20	1.33	1.27
World (210)	*2.23*	*2.28*	*2.25*

Source: Pardey, Chan-Kang, and Wood (2000), Table 3, p. 53.

[a]Denotes number of countries.

Table 2: *Sources of Calories Consumed, 1961 and 1997*

Rank	1961		1997
	(percentage)		*(percentage)*
Developing Countries			
1 Rice	28.1	Rice	27.3
2 Wheat	12.0	Wheat	18.8
3 Maize	6.2	Sugar	7.3
4 Sugar	8.4	Maize	6.0
5 Sweet potatoes	0.9	Pig eat	3.6
6 Sorghum	2.0	Milk, whole	2.2
7 Millet	2.8	Cassava	2.0
8 Cassava	4.2	Sorghum	1.8
9 Milk, whole	1.7	Soyabean oil	1.6
10 Barley	0.3	Sweet potatoes	1.6
11 Beans	5.2	Palm oil	1.4
Total Calories	*1,932*		*2,650*
Developed Countries			
1 Wheat	26.7	Wheat	23.5
2 Sugar	11.7	Sugar	12.7
3 Milk, whole	7.1	Milk, whole	5.1
4 Potatoes	5.6	Soyabean oil	4.4
5 Rice	4.5	Pig meat	4.3
6 Pig meat	3.6	Potatoes	4.1
7 Rye	3.3	Rice	3.5
8 Fats, animals raw	0.4	Maize	2.8
9 Butter, ghee	3.0	Cheese	2.7
10 Bovine meat	2.8	Bovine meat	2.7
11 Maize	2.6	Sunflowerseed oil	2.5
Total Calories	*2,948*		*3,240*
World			
1 Rice	18.2	Rice	21.1
2 Wheat	18.1	Wheat	20.1
3 Sugar	8.5	Sugar	8.7
4 Maize	5.7	Maize	5.2
5 Milk, whole	4.1	Pigmeat	3.8
6 Sweet potatoes	3.1	Milk, whole	2.9
7 Potatoes	2.9	Soyabean oil	2.3
8 Sorghum	2.5	Potatoes	1.9
9 Millet	2.4	Cassava	1.5
10 Pigmeat	2.0	Bovine meat	1.4
11 Bovine meat	1.7	Poultry meat	1.4
Total Calories	*2,257*		*2,782*

Source: Pardey, Chan-Kang, and Wood (2000), Table 10, pp. 60-61.

Table 3: *Land and Labor Productivity in Agriculture, 1961-97*

	1961	1971	1981	1991	1997	Growth rate
		(1989-91 international dollars)				*(percent)*
Labor Productivity						
Asia and Pacific (28)	264.1	306.9	352.5	442.5	550.2	1.95
Sub-Saharan Africa (45)	352.5	393.6	385.0	401.8	410.8	0.24
Latin America and the Caribbean (31)	1,459.3	1,757.1	2,256.3	2,739.8	3,252.9	2.18
Developing countries (125)	351.7	410.2	470.1	561.8	664.8	1.67
North America (2)	17,297.4	28,302.1	34,282.6	40,833.2	53,419.5	2.68
Western Europe (18)	3,949.4	7,051.9	10,616.6	15,875.2	20,016.7	4.45
Developed countries (49)	3,417.8	5,724.2	7,572.2	9,718.8	11,268.3	3.17
World (174)	*703.7*	*830.8*	*899.1*	*965.1*	*1,045.7*	*0.97*
Land Productivity						
Asia and Pacific (44)	188.2	236.2	295.3	397.8	496.6	2.72
Sub-Saharan Africa (48)	34.1	44.8	52.3	63.6	71.3	1.90
Latin America and the Caribbean (42)	92.7	112.0	148.5	172.3	196.8	2.11
Developing countries (155)	101.4	129.5	167.0	216.3	264.2	2.66
North American (2)	256.4	337.4	389.2	420.6	482.8	1.55
Western Europe (20)	820.7	1,023.6	1,201.4	1,368.0	1,418.3	1.53
Developed countries (53)	222.5	284.4	320.1	356.5	351.5	1.28
World (208)	*145.5*	*184.2*	*220.7*	*261.9*	*292.3*	*1.91*

Source: Pardey, Chan-Kang, and Wood (2000), table 14, p. 71.

Figure 1: *U.S. Wheat and Rice Yields, 1800-1996*

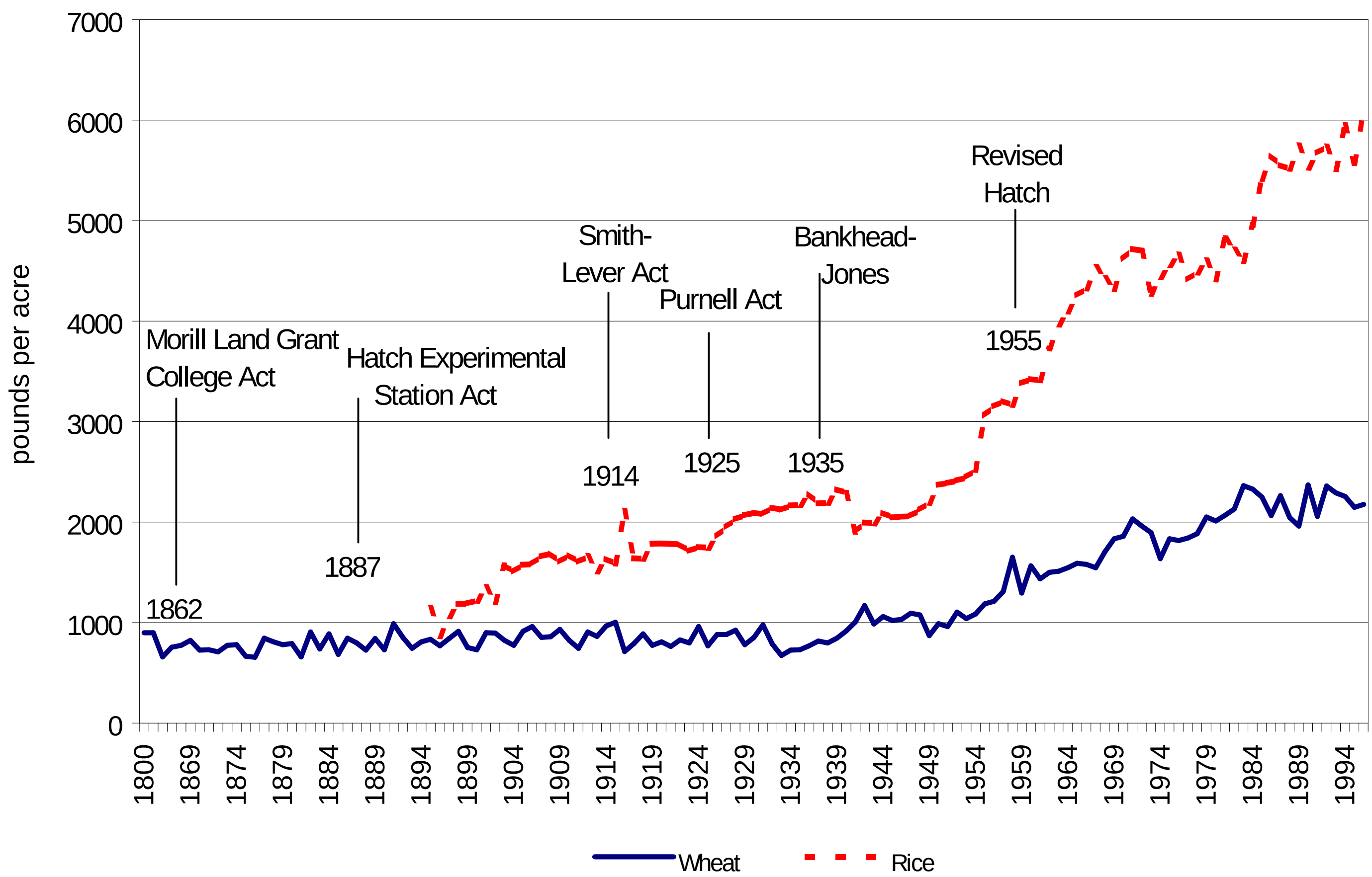

Figure 2: *World Wheat Yields, 1960-1996*

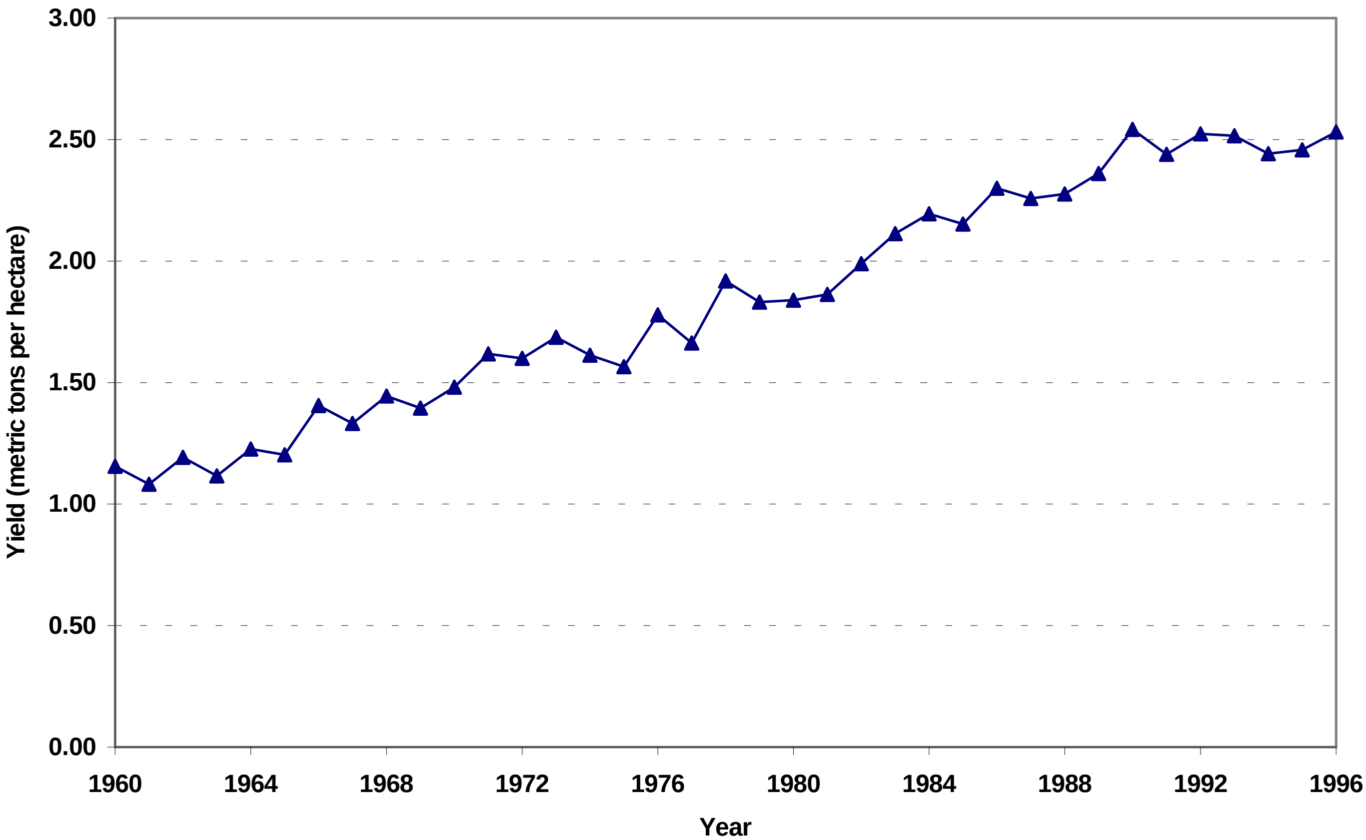

Figure 3: *World Wheat Production, 1960-1996*

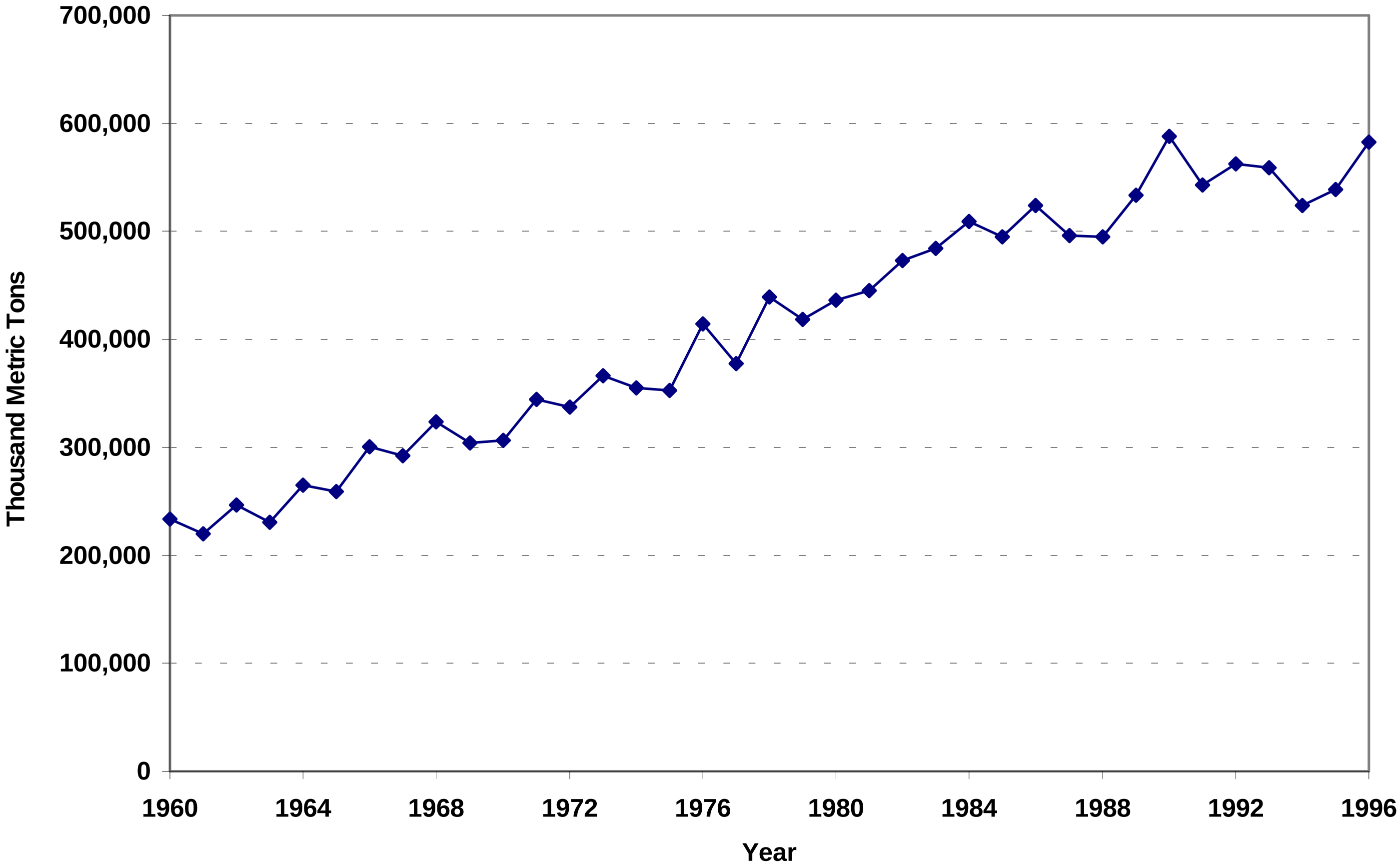

Figure 4: *U.S. Real Wheat and Rice Prices, 1899-1996 (1994 U.S. dollars)*

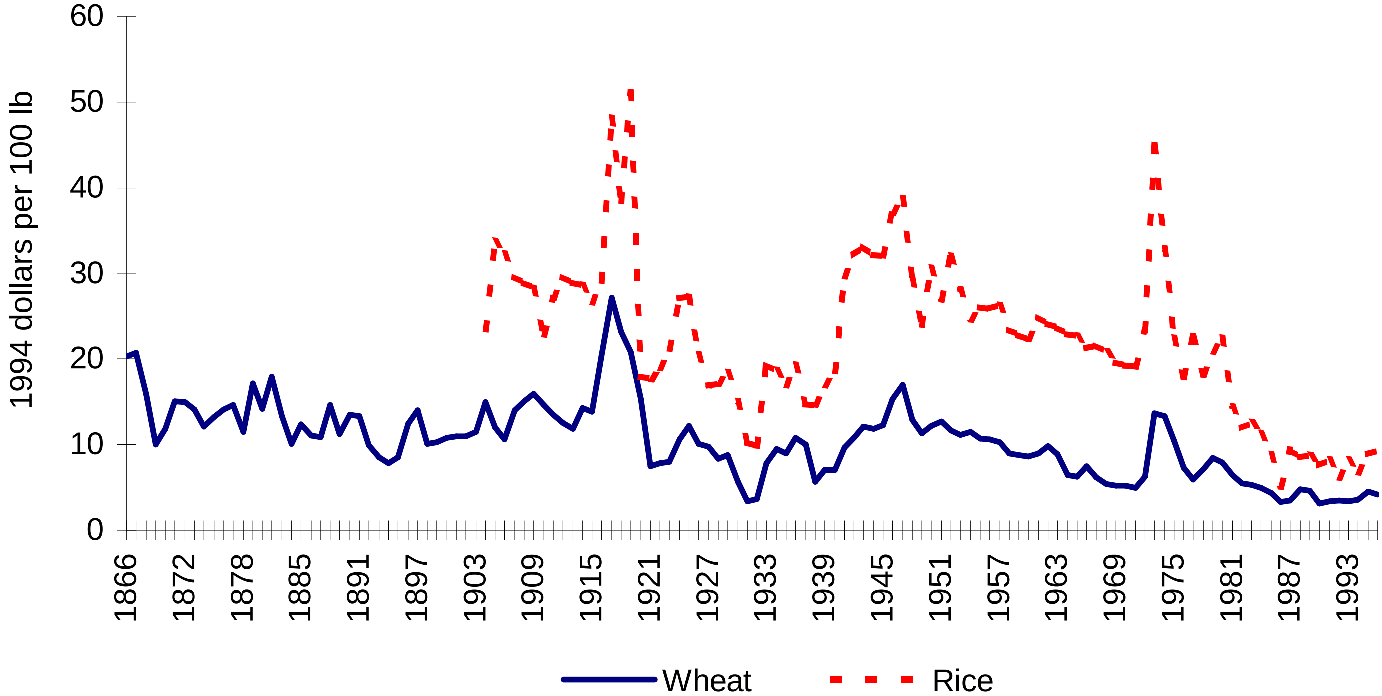

Figure 5: *Real World Food Price Index, 1959=100*

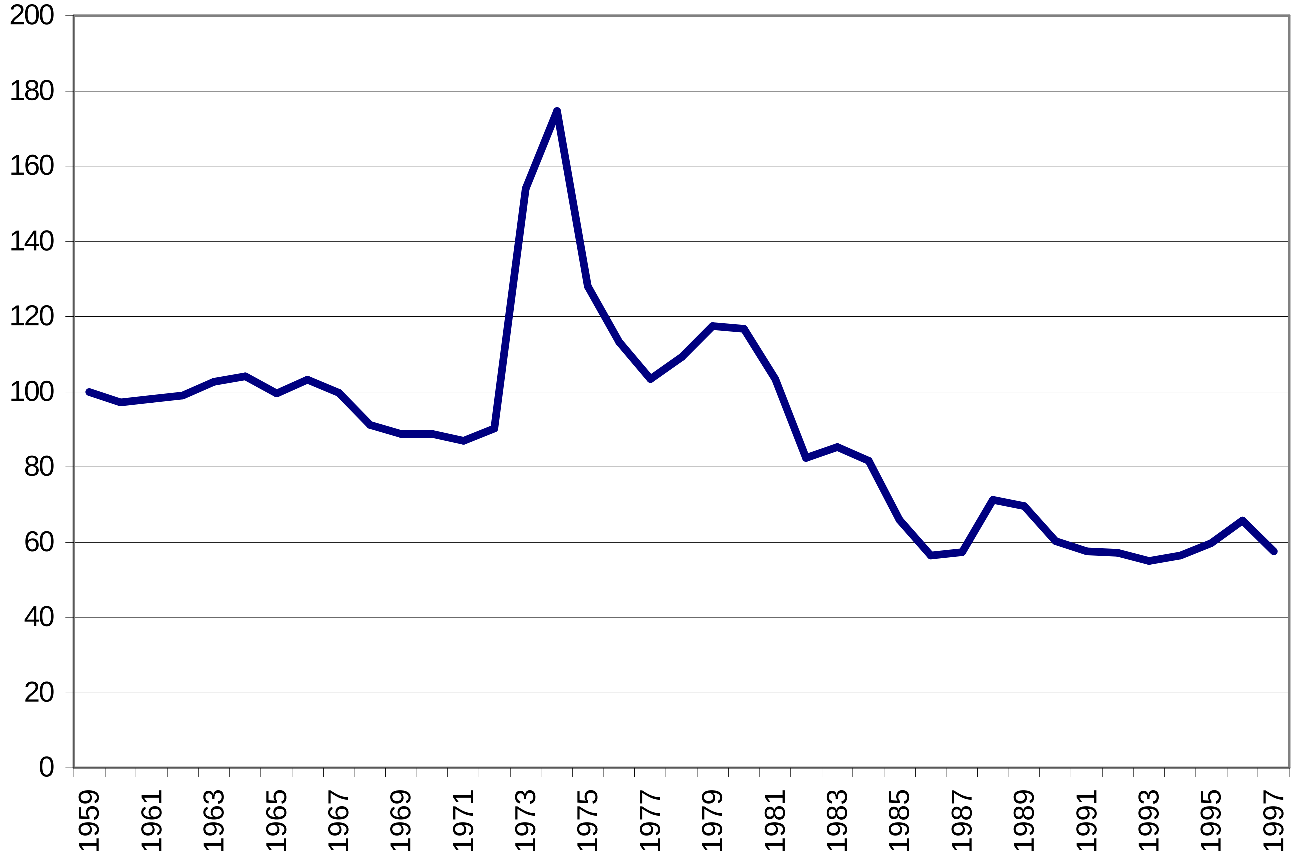

Figure 6: *Agricultural R&D and Household Income Distributions*

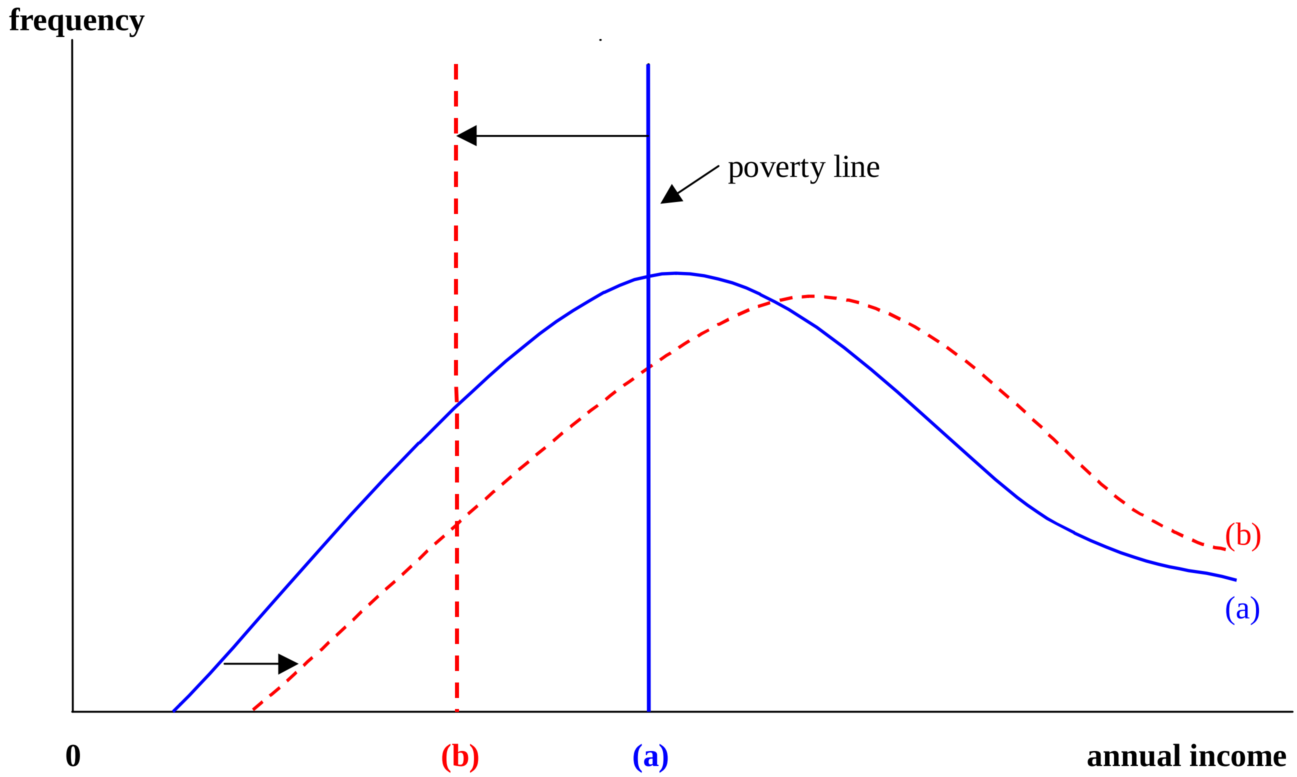

Figure 7: *Supply and Demand for Research, and Effects on Food Security*

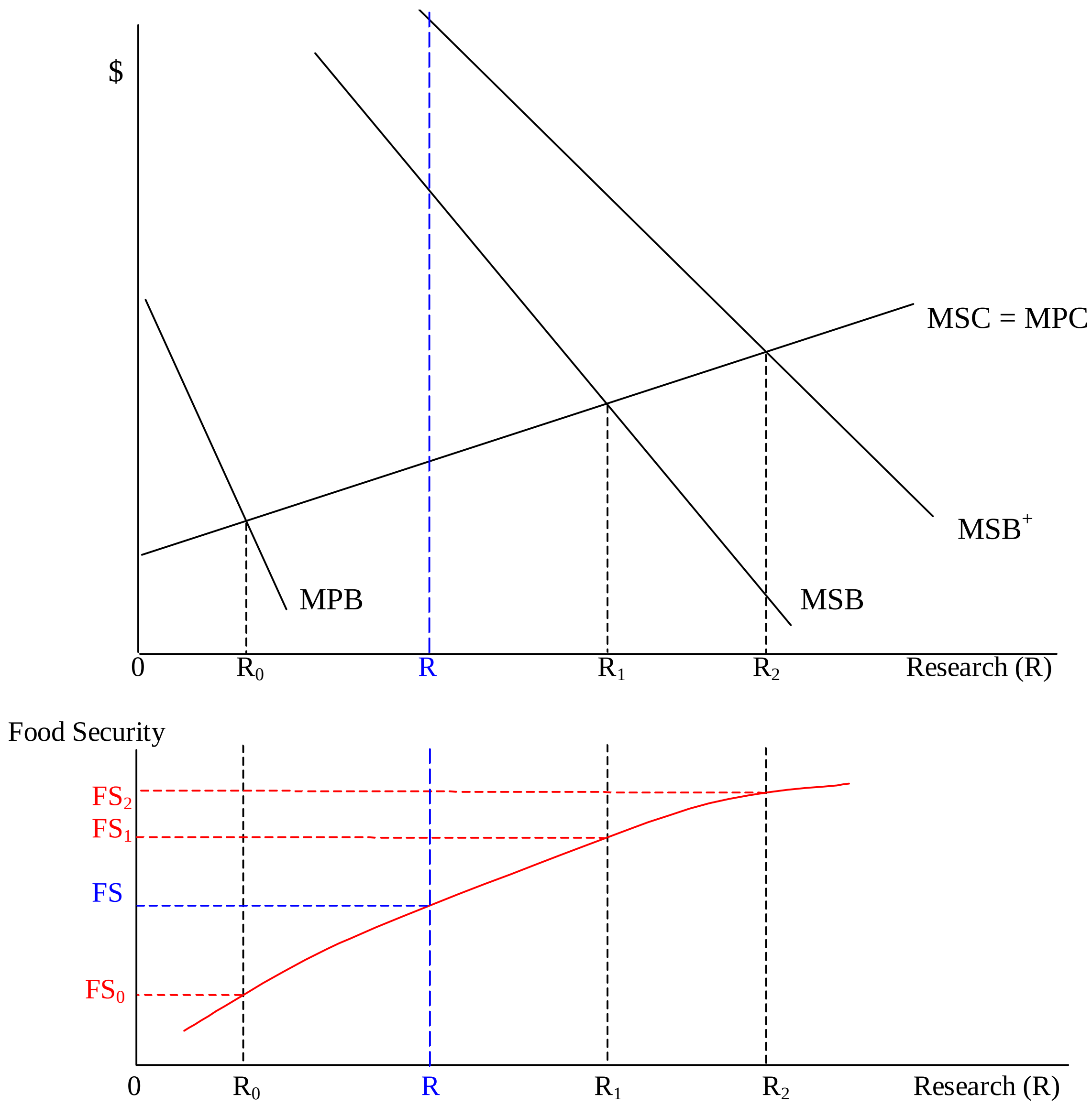

Figure 8: *A Trade-off of Equity and Efficiency using Research Policy Alone*

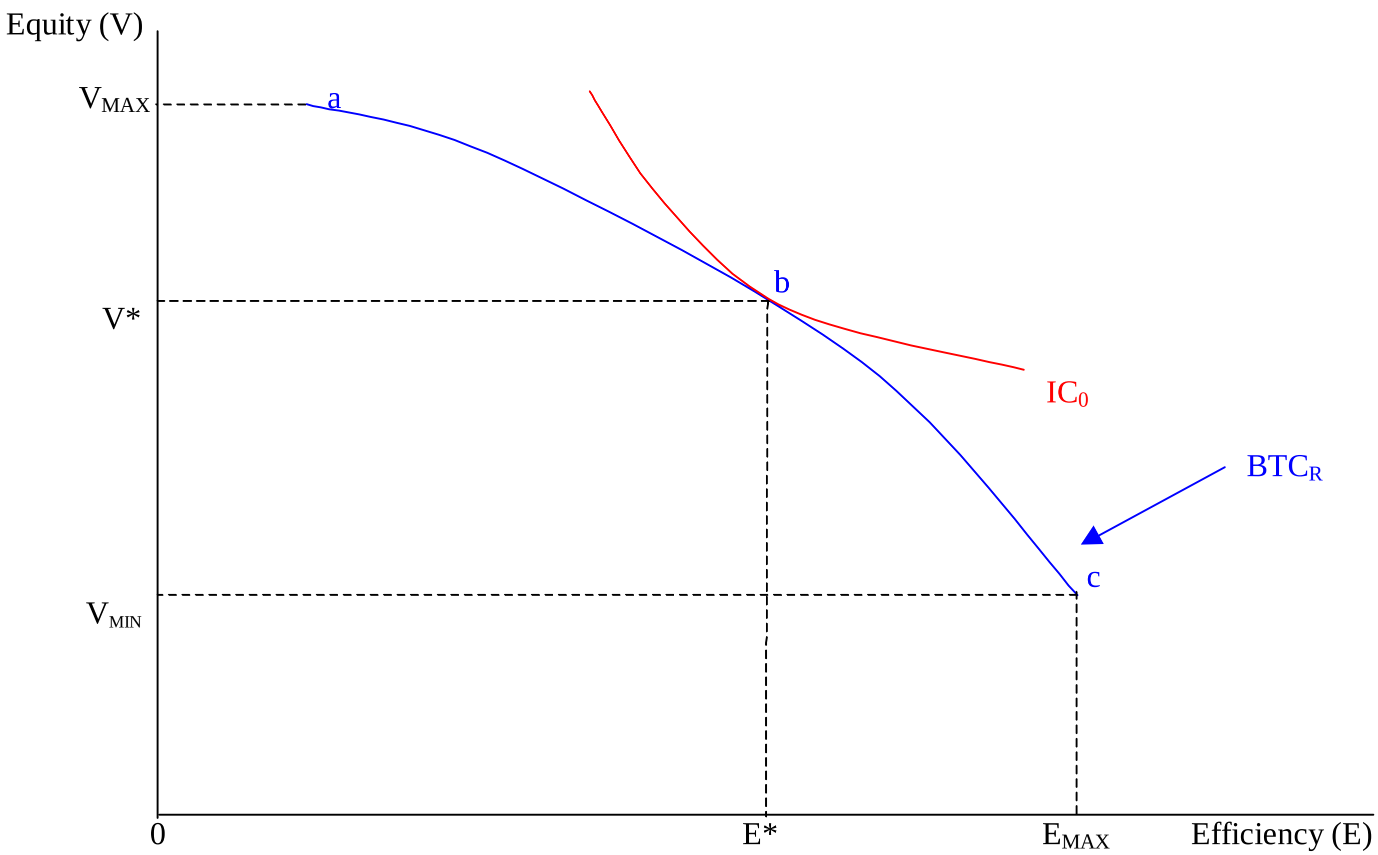

Figure 9: *Equity and Efficiency using the Least-Cost Policy Combination*