Prospects for Global Food Security

A Critical Appraisal of Past Projections and Predictions

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Foreword

During the last half century, a number of individuals and institutions, including the Food and Agriculture Organization of the United Nations (FAO) and IFPRI, have engaged in projections of future food demand, supply, and related variables. In this 2020 discussion paper, Alex McCalla and Cesar Revoredo compare projections with real-life outcomes. Projections forecast outcomes on the basis of certain underlying factors. If such forecasted outcomes are undesirable, changes may be made in the underlying factors so that the projections may not, in fact, come to pass. Many projections serve this precise goal. Therefore, the success of projections may not be that they match actual outcomes but that they avoid such outcomes by promoting action to change underlying variables. Unlike predictions, which are successful only if they match actual outcomes, projections that differ from actual outcomes may reflect either poor projection models or changes in underlying variables, possibly caused by the projections themselves.

In this discussion paper, the authors revisit the key projections and predictions about global food security of the last half century and assess the extent to which they materialized. They also critically review the factors that led to some projections and predictions being more on the mark than others. This assessment has produced important lessons for future crystal-ball gazing.

McCalla and Revoredo's comprehensive and critical appraisal of past projections and predictions of global food availability and needs offers useful insights not only to those who wish to better understand the efficacy of such exercises but also to those who will undertake projections and predictions in the future, and those who will respond by modifying policies and priorities in order to get closer to the goal of a food-secure world for all. We hope that this paper will contribute to an informed dialogue regarding the development and use of global food security projections and predictions.

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Director General, IFPRI

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1. The Charge, the Context, the Challenge, and the Approach

The Charge

Debates periodically spring up about whether the world is facing imminent food shortages or conversely whether it is swimming in food surpluses. These debates often swirl around projections or predictions about prospects for global food security. We were asked in this paper to address the accuracy of some of the projections and predictions made over the past 50 years about global food security.

Specifically our charge from the International Food Policy Research Institute (IFPRI) was to "critically review, compare, and contrast the most important and influential past predictions and projections regarding food, poverty, and the environment." We were to "revisit the key predictions and projections of the last half century or so, assess to what extent they materialized or not, and critically review what factors led to some predictions/projections being more on-the-mark than others. Out of this should emerge some lessons for *future crystal-ball gazing*" (emphasis added).

In this chapter we first place this charge in historical context. We then turn to questions of how to proceed with our task. This involves reviewing how others have evaluated projections and predictions. What we find is that the task is complicated. The chapter concludes with an outline of the paper.

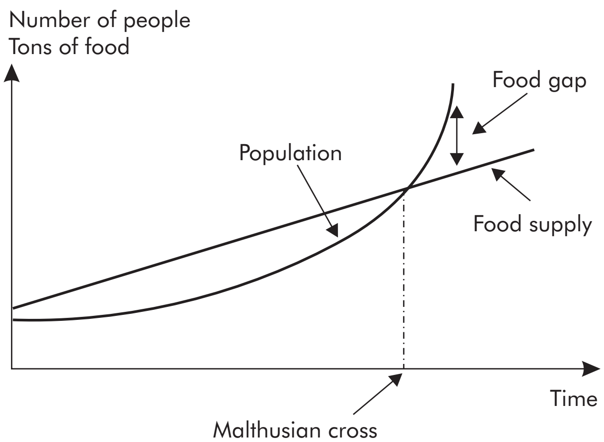
The Context

It is popular to associate concerns about the capacity of the world to feed a burgeoning population with the name of Thomas Robert Malthus. Malthus wrote the first edition of *An essay on the principle of population* in 1798 and will always be remembered for his proposition that human population, if left unchecked, grows geometrically (exponentially), whereas food supply grows arithmetically (linearly). From algebra we remember that a compounding function will always overtake a linear function; therefore population will inevitably press on the limits of food supplies (see Figure 1).

Malthus was not the first to express concerns about the world's capacity to feed itself, but he was the first to formalize the analysis into a "model": population growth rates, driven by the differences between birth and death rates, versus food production—land area times yield (yields were assumed basically constant). In subsequent editions of the *Essay* (six editions in total), Malthus modified his position, becoming less certain of the inevitability of shortfalls. He also became less sure that population growth is limited by food supply, admitting the possibility that they may be interdependent (Evans 1998, 2–3). On the other side of the question is the work of Ester Boserup (1965), who argues the opposite case to that of Malthus, namely that population growth stimulates agricultural production.

Malthus, of course, was not the last to express pessimism. One hundred years later, in 1898, Sir William Crookes titled his presidential address to the British Association for the Advancement of Science "The Wheat Problem," and predicted widespread starvation by the 1930s unless yields were increased substantially (Dyson 1996, 5). Since World War II there have been numerous predic-

Figure 1—The food gap



tions about the imminence of Malthusian doom: Paddock and Paddock, *Famine 1975!* (1967); Ehrlich, *The population bomb* (1970); Meadows et al., *The limits to growth* (1972); Brown, *By bread alone* (1974); Ehrlich and Ehrlich, *The population explosion* (1990); Brown and Kane, *Full house* (1994); Brown, Gardner, and Halweil, *Beyond Malthus* (1999), to name a few. These predictions frequently contained "doomsday" language: "In fifteen years the famines will be catastrophic and revolutions and social turmoil and economic upheavals will sweep areas of Asia, Africa and Latin America" (Paddock and Paddock 1967, 18); "The battle to feed all of humanity is over. In the 1970s the world will undergo famines—hundreds of millions of people are going to starve to death in spite of any crash programs embarked upon now" (Ehrlich 1970, 15); "In the early seventies the soaring demand for food, spurred by both continuing population growth and rising affluence, has begun to outrun the productive capacity of the world's farmers and fishermen" (Brown 1974, 3).

Competing with these pessimists have been a few who have basically seen no conflicts between rising populations and food supplies. They might be called optimists. We have already mentioned Boserup and her hypothesis that population growth stimulates food supply. Colin Clark, in his book *Starvation or plenty?* (1970), claims that there is plenty of land available to be improved for food production. Julian Simon, in his book *The ultimate resource* (1981), argues that the most productive resource in the world is the human mind. "Additional persons do, in fact, produce more than they consume, and natural resources are not an exception."

Nestled between the optimists and pessimists are a set of people and organizations who make estimates about future food, population, and natural resource interactions based on projecting recent history into the future. Our task is to determine how accurate these predictions and projections are. Those who make projections will be a major focus of the analysis, although we will also comment on some of those making predictions.

The Challenge

When we undertook the task, it seemed large and complex but doable. We first needed to clarify what would be accepted meanings of terms such as "projection" and "prediction." After various consultations we have adopted the following meanings, based in part on the Oxford English Dictionary:

- A *projection* is a *quantitative estimate,* often based on a model, of the future value of a particular aggregate such as population, income, or supply expressed as a point estimate, or a percentage change, or a range of values within confidence intervals.
- A *prediction* is a *qualitative forecast* or prophecy about a future outcome, for example widespread famine, rising prices, or supply shortfalls.

We hope we have used the terms consistently even if many others do not.

On the prediction side, we knew we would be comparing qualitative predictions with qualitative outcomes. Evaluation would thus necessarily be qualitative, relying mainly on judgment. On the projection side, we assumed we could look at successive projections from the Food and Agriculture Organization of the United Nations (FAO), the United States Department of Agriculture (USDA), the World Bank, IFPRI, the Food and Agriculture Policy Research Institute (FAPRI), and so on, and compare these projections with actual outcomes. We could then compare individual projections and present some statistical indicators of performance. Then we assumed we would be able to go back to the projection models and suggest why some models are better than others.

Review of Previous Studies

We initiated our search for an appropriate methodology by looking for literature on evaluation and specifically for reviews of global food projection models. Past attempts at such reviews have adopted one or more of the following approaches to model comparison.

The first approach reviewed the structure of models for consistency with appropriate conceptual or theoretical models. Relevant questions for comparison would be: Are they appropriately partial or general equilibrium? How do they treat potential substitution among commodities and inputs? Are static models appropriate or should they be recursive or dynamic? Are they consistent in the way they aggregate countries in regions, and is this aggregation optimal for the modeling goal? We found two studies of this sort—one by Sanders and Hoyt (1970), which compared food gap projection models of FAO, the Organisation for Economic Co-operation and Development (OECD), USDA, and the President's Science Advisory Committee (PSAC), and one by Thompson (1981), which evaluated a variety of international agricultural trade models, including some also used for projections.

A second approach, employed by Fox and Ruttan (1984), Meyers (1995), and, to some extent, Poleman (1975), basically compared the projections of the different models to the same *future* date but could not compare projected and *actual* numbers because the projection date had not yet arrived.

A third approach, adopted by the International Agricultural Trade Research Consortium (IATRC), compared the results from several trade models for a preset number of simulation scenarios (for example, the effects of rising oil prices or the impact of a major crop failure). The outcomes of each model's simulation were then compared. Meilke (in Liu and Seeley 1987) concluded that differences in model specification, commodity coverage, country aggregation, and the way in which policy was included rendered comparisons virtually meaningless.

The disappointing part of the search for critical reviews of our target set of models was that few dealt with the issue we had been asked to address, namely to compare past projections with actual outcomes. A partial validation of the results was done for selected variables within his model by Alexandratos (FAO 1995) and also by Tyers and Anderson (1992) in an intra-sample simulation, but we found none that had compared models over time or compared the forecasts of several models for specific dates with actual outcomes.

We did, however, discover early in our review a National Academy of Sciences/National Research Council panel review of population projections (National Research Council 2000). Their methodology was straightforward. Focusing on the few agencies that made global population projections (the UN Population Division, the World Bank, and the U.S. Bureau of the Census), they selected the most frequently used UN Population Division estimates and compared their projections, made over the period 1957–98, with a particular projection year, 2000 (see Table 1). They found that errors in predicting global population for 2000 had on average been off by less than 4 percent (see "World" column in Table 1), with the range being +7.1 percent to +0.5 percent. They found that *errors increased* (1) as the timeframe lengthened—4.8 percent for 5-year projections to 17.0 percent for 30-year projections (read up any regional column); (2) as the projections were disaggregated from global to region to country; (3) for developing countries compared with developed countries; and (4) for small countries (especially under 1 million) compared with large countries. Finally they noted that all global projections were systematically higher than the actual outcome; that is, the projections overshot but not by much.

The panel then disaggregated the projections into the critical components that had been

Table 1—UN forecast error of population by region in the year 2000 (percent deviations from actual)

	Region							
	Africa	Latin America	Northern America	Asia	Europe	Oceania	Former USSR	World
1957	–35.4	14.4	1.8	8.9	–0.5	–4.4	30.8	3.6
1963	–4.0	23.3	15.5	–2.6	–7.7	4.0	21.8	1.2
1968	–10.9	10.6	3.3	6.4	–0.4	5.8	9.1	7.1
1973	1.7	19.8	–3.4	2.4	–5.4	7.6	8.7	3.1
1980	6.6	9.3	–2.4	–0.1	–10.3	–2.2	7.0	1.0
1984	6.1	4.2	–2.8	0.6	–9.2	–1.1	8.2	1.0
1988	9.0	4.3	–3.8	4.1	–10.9	–1.7	6.2	3.1
1990	8.3	4.0	–3.8	4.5	–10.6	–1.7	6.4	3.3
1996	2.5	–0.6	0.7	2.2	–9.8	–1.3	–6.1	0.5

Sources: National Research Council (U.S.) 2000 and United Nations 1966, 1973, 1977, 1981, 1986, 1989, 1991, 1998, and 1999.

Notes: Based on the medium-variant population projection. Forecast error = 100 × (projected level – actual level)/actual level, expressed as a percentage. A positive value indicates that the projection is an overestimate, a negative value an underestimate.

forecast—fertility (crude birth rates), mortality (crude death rates), and migration—and analyzed why errors increased with length of time, disaggregation, and smaller country size. We tentatively adopted this as the methodology for our task and we turned to assembling as full a selection of projections as we could. We also assembled a sample of predictions.

A Preview of Comparison Difficulties

Over the past 50 years there have been at least 30 quantitative projections of world food prospects (supply and demand balances), as well as numerous predictions of dire shortages ahead. Predictions are more episodic, seeming to be tied to periodic, but infrequent, increases in agricultural prices as, for example, in the mid-1960s, 1972–74, 1988, 1995–96.

Focusing first on "projections," we thought one should be able to contrast and compare the 30 or more that have been done. As we reviewed the various studies we immediately encountered difficulties. We found that cross-model comparisons would be virtually impossible at the global level because of differences in

1. data sources and data completeness;
2. model specifications—for example static vs. recursive and treatment of prices;
3. the timeframe of projections—medium term (5–10 years) vs. long term (15–30 years);
4. commodity coverage and commodity aggregations—small grains vs. field crops vs. crops and livestock;
5. regional and country coverage—which varies across models and within models over time, so that world aggregates are almost always noncomparable;
6. units of projection—grains, cereal equivalents, calories, and so on.

Even more constraining was the fact that we could not even easily compare within the same organization over time. We use IFPRI as an example, but it is by no means unique. IFPRI has made three ventures into the projection business, projecting up to the year 2000 or before. The first study, published in 1977, made trend projections of supply of and demand for cereals in developing countries only, in cereal equivalents, to 1990 (IFPRI 1977). The second study, published in 1986 (Paulino 1986), made trend projections of supply of and demand for total food consumption, in cereal equivalents, to 2000 for more countries, but its commodity and country coverage differed from that of the 1977 study. The third study, starting in 1995, used the new IMPACT model (an early version of this model under the name of IFPTSIM can be found in Agcaoili and Rosegrant 1995), which is a recursive nonspatial global commodity trade model with prices endogenous to make projections to 2010 and beyond (see, for example, Rosegrant, Agcaoili-Sombilla, and Perez 1995). This model had further adjustments in country and commodity coverage.

The point is that, each time, the model was different, the universes of commodities and countries were different, and the units of projection were noncomparable. Even FAO, which has produced seven updated projections at 5–10 year intervals since the 1960s, has changed model specifications several times and has constantly adjusted country aggregations and commodity coverage.

The bottom line is that quantitative comparisons of model performance can be done only a model at a time, comparing the particular model projection with actual data for the projection year. This is quite limiting because we wanted to evaluate and compare changes in performance within a projection agency over time. We do attempt to make cross-comparisons at a subglobal level when we find comparable commodity definitions (for example, wheat) for comparable geographic aggregations. These cross-comparisons are useful because they confirm, as in the population study, that very large increases in deviations occur as one disaggregates, in terms of both commodities and regions/countries. We find that global projections may be quite close, say ±5 percent of actual, but one component region may be underestimated by 25 percent, whereas another is overestimated by 30 percent. The errors offset each other so that, globally, the projection looks quite good. But is it? Should the global projection be trusted when in reality it is the result of *being wrong twice,* once in each direction? This is a crucial question if the disaggregated components are used more frequently—for example, livestock in China—than the global aggregates. We return to this question later in Chapters 3 and 5.

Thus, unfortunately, the analysis that follows is necessarily fragmented and incomplete, at least in terms of quantitative comparisons of model performance. We try to augment our quantitative analysis with qualitative evaluations and, as a last resort, we make some assertions about what we believe to be the case. Clearly modeling global food security issues is an ever-evolving activity, constantly changing and growing larger, more complex, and more costly. The number of players in the projection business is diminishing. It is now basically down to FAO, FAPRI, IFPRI, and USDA. Of course, the number of players in the prediction business is larger and more fluid, with the numbers and severity of forecasts rising with periodic rises in global commodity prices or falls in global stocks. However, we do feel that the effort we report should provide feedback to modelers and model users alike. All need to understand the strengths and weaknesses of the point projections they discuss with such certainty.

Structure of the Work

In the remainder of the paper we focus on the analysis of world food security projections and predictions. Our analysis of natural resources constraints is limited to how resource stocks constrain food production. Given that many of the analyses of the 1980s and 1990s broadened concerns beyond agricultural yields, we will briefly analyze constraints related to energy, water, and land. We also comment briefly on projections of fish availability, because fish are a significant source of animal protein, especially in Asia.

On the demand side, we comment on poverty projections as an important complement to traditional projections based only on average per capita income. As argued by Johnson (1975), FAO (1977), and others, the current food problem is mainly a problem of affordability (access) rather than one of availability; therefore income distribution issues are important.

Specifically we proceed as follows. Chapter 2 provides a historical overview of the evolution of analytical approaches to the food challenge and a review of the landscape of predictions and projections since 1946 (FAO's first *World food survey* year). Chapter 3 describes and analyzes some of the more frequently used projection models. We look at two classes of models: (a) trend projection models, and (b) world commodity trade models, which are also used for projecting into the future. We close the chapter by comparing projections within agencies over time and by comparing across agencies as much as is possible.

Chapter 4 presents our evaluation of scenarios, surveys (that is, projections made in the context of world food surveys), and predictions about the global food situation and resource constraints. We ask why these appear to have a much higher likelihood of not coming true: is it that they are longer term, and their almost always dire predictions lead to corrective measures that prevent disaster from occurring; or do they underestimate people's capacity to substitute in production and consumption; or do they underestimate the power of the human mind to advance science and develop new technology; or are they simply bad predictors? We offer our conclusions and suggestions for future prognosticators in Chapter 5.

2. Half a Century of Projections and Predictions, 1946–2000: An Overview of the Landscape

The task of this chapter is to present an overview of the landscape of predictions and projections that have been made since World War II. The survey may not be exhaustive, but in our view it identifies the major players and a significant variety of approaches.

Overview of Projections and Predictions, 1946–2000

Before we begin the survey, a bit of context is appropriate. Agriculture in the twentieth century generally prospered up to and through World War I, except when production was disrupted by actual hostilities. In fact, productive capacity built up during World War I resulted in excess supplies and falling prices in the early 1920s. A world depression, which resulted in inadequate demand, led to excess marketable food supplies in the 1930s and trade and prices collapsed. Thus, the question in many minds after World War II was whether history would repeat itself, with surpluses and low prices, or whether there would be shortages because of more widespread devastation in Europe and Asia. To deal with initial concerns about falling prices, the governments of rich countries supported domestic prices. The Korean War (1950–53) held up prices longer. By the early 1950s, European production was restored and the concern, at least in the developed world, turned to surpluses and surplus disposal. Recall that U.S. food aid programs (for example, Public Law 480) originated in 1954 as an international surplus-dumping activity. In fact, FAO's 50-year review of the *State of food and agriculture* (2000b) characterizes the concerns of the 1950s and early 1960s as ones of excess supply, not shortage. Grain prices fell and stocks grew over most of the 1950s and early 1960s. Stocks, particularly U.S. stocks, were drawn down substantially in 1965–66 as the United States and others shipped massive amounts of grain to Asia, particularly to India, which had experienced two bad monsoons. Immediately after this shock, there was the rapid introduction of the so-called miracle wheats and rices (1967–70), which became the stuff of the "Green Revolution." Prices steadied and some optimism returned.

A coincidence of supply shortfalls and major Soviet grain purchases doubled and tripled grain prices in 1972–74, spawning many dire predictions. However, real prices were soon back on their long-term downward trend as production expanded. Except for brief run-ups in 1988 and 1995–96, real grain prices continue to fall. Prices at the end of the twentieth century were at a 100-year low in real terms. It is our submission that concerns about global food security heat up with rising grain prices and/or declining stocks. Predictions reflect the spirit of their time.

It is our purpose in this section to provide an overview of the landscape of projections and predictions since World War II. We have somewhat arbitrarily divided them into two general areas: (1) quantitative, model-based projections—these are presented chronologically in Figure 2 (a tabular presentation of model characteristics can be found in Appendix 1); and (2) global surveys and predictions (generally, qualitative forecasts of the future)—these are presented in Figure 3, again chronologically.

Quantitative Projections

The first three columns of Figure 2 are devoted to global projections of food supply and demand balances. Although the first quantitative estimates of food supply difficulties came from the Food and Agriculture Organization in three *World food surveys* (FAO 1946, 1952, and 1963), we choose not to call them projections. Rather they are survey-based evaluations of the growth rates of food supply needed to meet minimal nutritional standards. They are not projections of what would actually happen. We treat these normative need statements in some detail in Chapter 4.

FAO's first *Agricultural commodity projections* were prepared in 1962 for a Joint Session of the United Nations Commission on International Commodity Trade and the FAO Committee on Commodity Problems. This study differed from earlier FAO work in that it recognized that demand is related to income, prices, and population, not to nutritional standards. Production was estimated on a trend basis using data from the 1950s. FAO emphasized that the projections were estimates of future outcomes based on specific assumptions as to trends and policies. They were not targets of what we would like. This distinction was drawn perhaps to distinguish this approach from the earlier *World food surveys*. The 1962 projections began a series of medium-term projections, of 5–10 years ahead, which were published at regular intervals from 1962 to 2000. There are FAO projections for the following years: 1970, 1975, 1980, 1985, 1990, 2000, and 2005 (FAO 1962, 1967, 1971, 1979, 1986, 1994, 2000c). FAO has also produced three longer-term projections: *Agriculture: toward 2000* (1981) revised as *World agriculture: toward 2000* (1988); *Agriculture: toward 2010* (1993) updated as *World agriculture: toward 2010* (1995); and an interim document, *Agriculture toward 2015/30* (2000a).

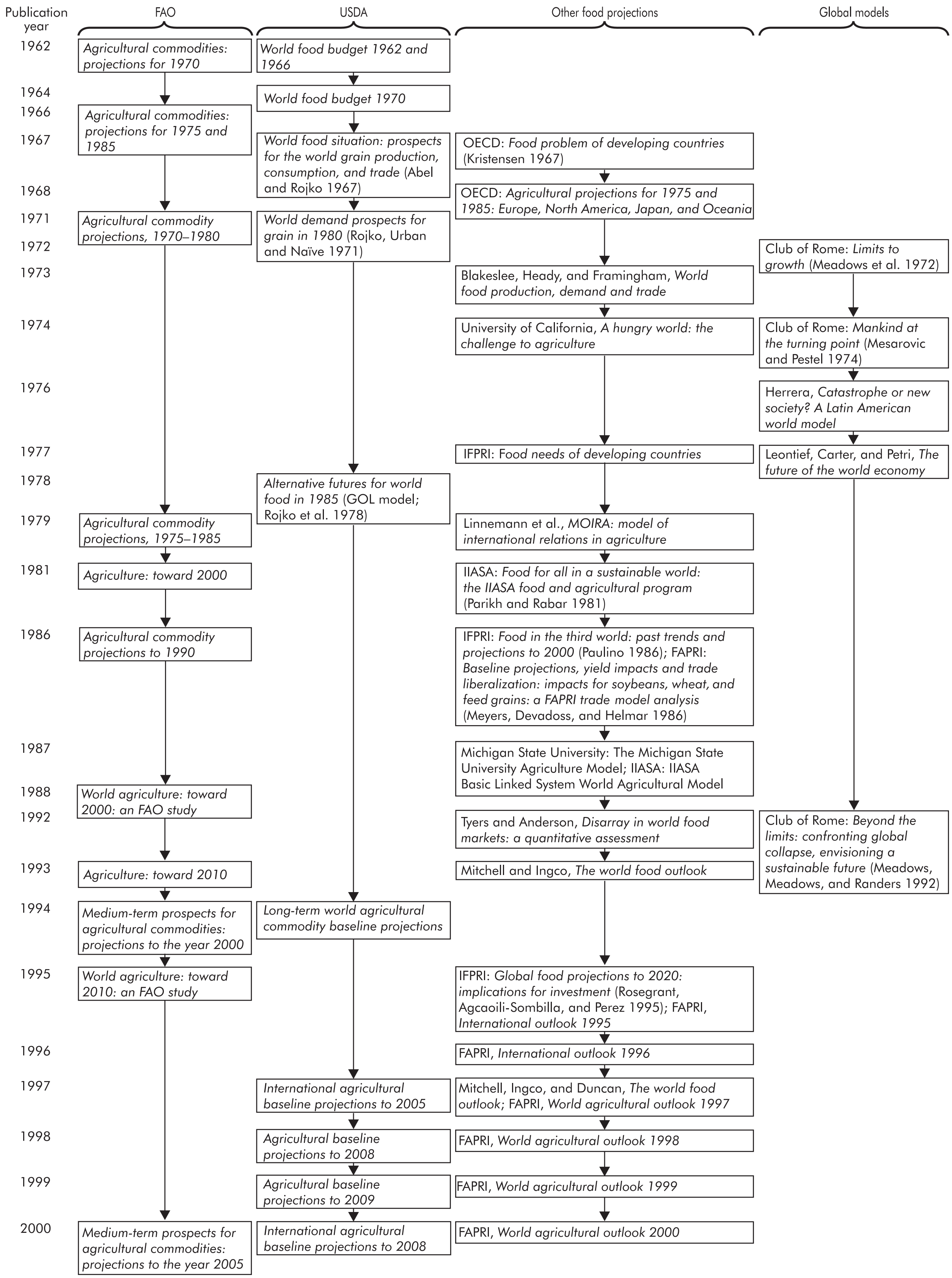
The USDA became a player with the publication of *The world food budget* (USDA 1961). However, as Poleman (1975) points out, it was more akin to FAO's *World food surveys* than to later USDA projections, which began in 1971. The Grains, Oilseed and Livestock Model (GOL) published in 1978 (Rojko et al. 1978) represented significant methodological advances. USDA continues to do short-term projections at regular intervals.

Others have also made periodic forays over the period. Some were short lived: the Organisation for Economic Co-operation and Development (OECD) (Kristensen 1967; OECD 1968); Iowa State University (Blakeslee, Heady, and Framingham 1973); and the International Institute of Applied Systems Analysis (IIASA) (Fischer et al. 1988). Others persisted longer: IFPRI (IFPRI 1977; Paulino 1986; Rosegrant, Agcaoili-Sombilla, and Perez 1995, and onward) and FAPRI (1986, in Liu and Seeley 1987; FAPRI 1995, and annually to 2000). A model developed at Michigan State University moved to the World Bank with Don Mitchell and resulted in two studies titled the *World food outlook* (Mitchell and Ingco 1993; and Mitchell, Ingco, and Duncan 1997).

Although the players used a variety of model specifications, they all have the common characteristic of being strongly rooted in historical trends. As we outline in Chapter 3, most produce moderately optimistic medium-term projections that aggregate production will be capable of meeting projected food demand. However, some project significant regional shortfalls in South Asia and more recently in Sub-Saharan Africa. These models are evaluated in Chapter 3.

The last family of models presented in Figure 2 are global simulation models of the Club of Rome type. These are large models that project forward various rates of resources consumption and determine if and when resource stocks will be exhausted. Most, including four Club of Rome projections (Meadows et al. 1972; Mesarovic and Pestel 1974; Herrera 1976; and Meadows, Meadows, and Randers 1992) and Global 2000 (Barney 1980–81), projected severe resource exhaustion if the then (1960s) current trends of consumption persisted. Therefore, they tended to be considered pessimistic. They have been heavily

Figure 2—Quantitative food supply and demand projections and global models



attacked on methodological grounds as well as being charged with not being grounded in empirical reality (Nordhaus 1973). In addition, there was the Leontief, Carter, and Petri modeling of *The future of the world economy* published in 1977, which was more optimistic. These models are evaluated in Chapter 4.

Qualitative Predictions

Figure 3 presents a chronological array of writings that predict rather than project. The first *World food survey* produced in 1946 by FAO was followed by five more (FAO 1952, 1963, 1977, 1987, 1996). The most recent ones are widely quoted because they estimate the number of undernourished people in the world.

We have defined the next two categories in Figure 3 as *pessimistic* and *optimistic* views of world food prospects (McCalla 1994; Dyson 1996). The more pessimistic ones were labeled neo-Malthusian by Dyson (1996) in his excellent critique. Pessimistic views tend to be clustered around perturbations in world markets in the middle 1960s (Paddock and Paddock 1964, 1967) and early 1970s (Ehrlich 1970; Paddock and Paddock 1976). Lester Brown began a long series of analyses with a piece in *Science* in 1967. It said the challenge of feeding a burgeoning and richer population would be very difficult for conventional agriculture. Brown became more optimistic briefly in 1970 with *Seeds of change,* much to the chagrin of the Paddock brothers (see the Preface of Paddock and Paddock 1976). Since 1974, Brown, with many different co-authors, has been firmly on the more pessimistic side from *By bread alone* (1974) to *Full house* (Brown and Kane 1995) and *Beyond Malthus* (Brown, Gardner, and Halweil 1999).

There was another cluster of concerns in the late 1980s and early 1990s: Ehrlich and Ehrlich (1990), Meadows, Meadows, and Randers (1992), Postel (1992), Brown (1995). However, many of these were now zeroing in on natural resource constraints as being the major constraint on global food supplies.

There also have been some interesting writings that have a degree of optimism: Russell (1954), Cochrane (1969), Clark (1970), Johnson (1975), Simon (1981), Simon and Kahn (1984), Avery (1995), and Evans (1998). This diverse set of literature is reviewed in more detail in Chapter 4.

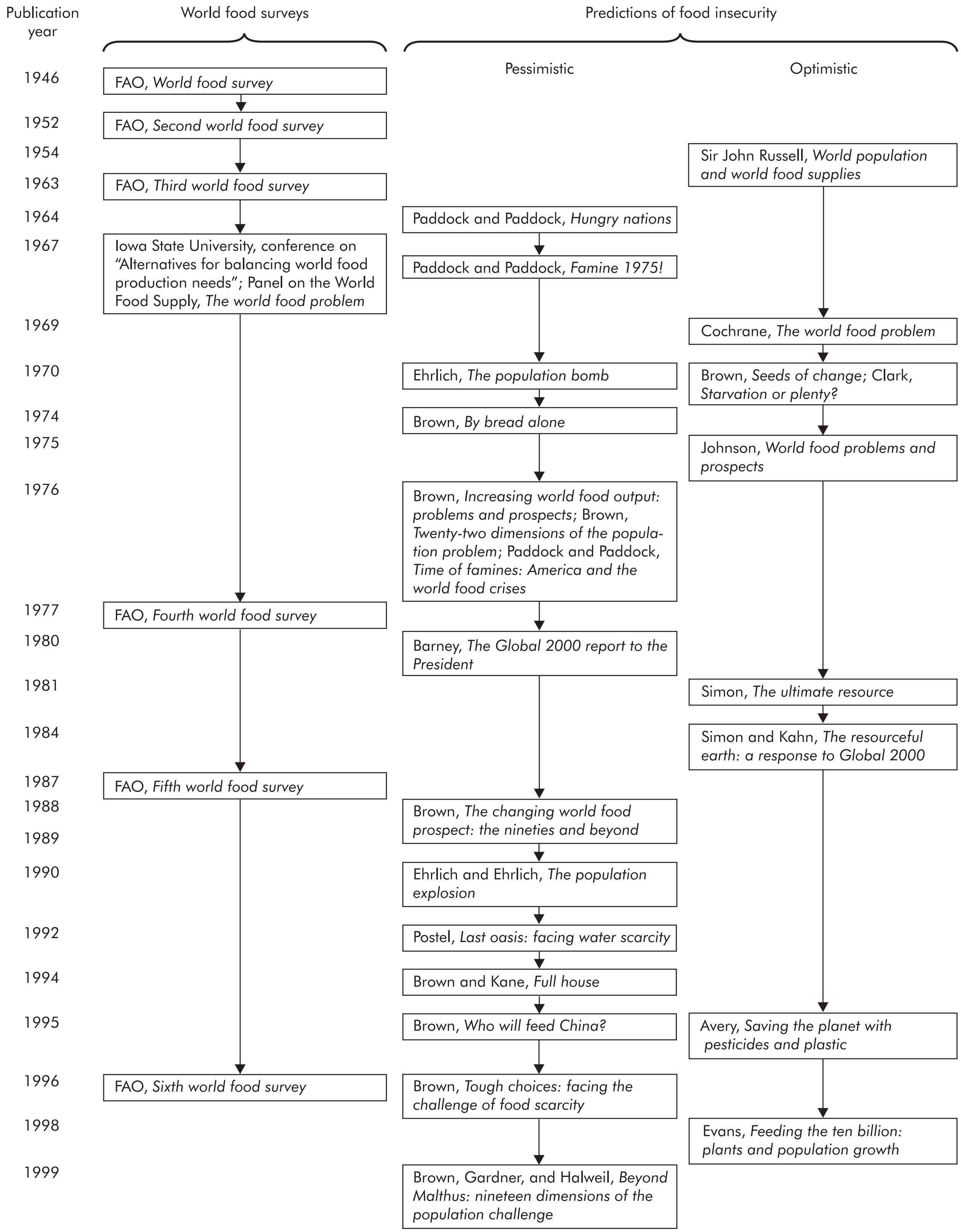
Growth in Complexity and Coverage

Over time our understanding of the global food security challenge has become more complete, but this completeness has made understanding the interactions among a greater number of variables more difficult and projecting outcomes more complicated. It is not enough just to project population to forecast demand. One also needs to know the rate of income growth and have good estimates of the evolution over time of how food expenditure changes as incomes rise. Demand models would be even more conceptually complete if changes in income distribution could be included for all countries. Supply predictions have graduated from trend projections of land area and yields to the need to project changes in production intensity, the relationship between yields and research investment, the degree to which stocks of resources—water, land, energy—potentially constrain output, and the impact of declines in fisheries on food security. Further questions of environmental constraints continue to emerge. The number of countries requiring analysis goes on rising, as does the demand for more complete commodity coverage.

Modelers have tried to respond to this increased complexity. The early models (Malthus) focused on a potential food gap by comparing rates of growth of population with land availability. Right after World War II the focus shifted to a requirements approach where minimum nutritional needs were multiplied by population to produce projected food needs. In the same period the potential of increasing yields of existing land was added to supply projections.

But by the 1960s we came to understand that food needs (normative) and demand (positive) for food are not the same. Efforts were made to project demand by including income and Engel

Figure 3—World food surveys and predictions of food insecurity



curves (that is, the statistical relationship between consumption and income).

The late 1960s and 1970s led to further complicating issues. On the supply side, the Green Revolution focused us on favored versus less favored areas. It also began to raise environmental and social issues about rapid increases in crop yields. In addition, the 1960s showed that, while modern medicine was cutting death rates rapidly, birth rates remained high, leading to population growth rates never before experienced. *The population bomb* (Ehrlich 1970) reflects this concern. Concerns about environmental issues and the depletion of nonrenewable natural resources also emerged in the 1960s and early 1970s. All of these issues—new varieties, population, and resource limits—were added to the issues of global food security.

To complicate the issue of modeling further, the price instability of the early 1970s illustrated that earlier models' assumptions of constant prices were clearly inadequate. Prices affect both consumers and producers and therefore own- and cross-commodity relationships were needed both in demand models and in supply projections to reflect changes in prices and the resulting substitution among commodities. Moreover, the price run-up illustrated that domestic policies significantly influence world markets. Therefore new models had to include domestic supply and demand, country by country, with appropriate cross-commodity relationships embedded and explicit recognition of policy built in. Then the net trade positions of all countries had to be integrated into a world trade model, which was used to determine equilibrium prices. These considerations caused a shift from supply and demand *gap projections* to global price equilibrium trade models, which greatly increased the size of models and their demands for data. All of these factors have led to a fuller understanding of the complexity of the issues but have made modeling that complexity more difficult and much more expensive.

Finally, it should be noted, that starting in the 1970s and strengthening in the 1980s and 1990s, there was expanded interest in poverty and income distribution. Given the prevalence of rural poverty in developing countries, linkages between food production and poverty became highlighted. Yet introducing explicit projections of poverty into models proved difficult; only the Model of International Relations in Agriculture (Linnemann et al. 1979) has attempted to incorporate income distribution.

In sum, the number of issues related to the supply and demand sides of the food balance equations has significantly increased. Modeling approaches have grown more sophisticated, clearly much larger, and more expensive. This makes their evaluation, the task to which we turn in Chapters 3 and 4, more challenging. Further, history's boneyard is full of nice models that kept growing and eventually died because no one kept (or perhaps could afford to keep) them up. We will return to the issues of cost and complexity in Chapter 5.

3. Evaluation of Projections about the Food Situation

The purpose of this chapter is twofold—first to review the evolution of the modeling used to project the world food situation, and second to evaluate the accuracy of these projections by comparing them with observed figures. Therefore our analysis is limited to projections up to the year 2000.

In terms of the models selected for review, we have included only those models used for quantitative projections, concentrating our attention on multi-region/country commodity models, and leaving aside the two-country agricultural trade models that have a long tradition in agricultural economics (that is, models that consider only one country or region on one side, and aggregate the rest of the world on the other side). Hence, we centered our review on two types of models: trend projection models and world trade models. A brief review of the characteristics of the main models is presented in Appendix 1.

The Evolution of Analytical Approaches

At least since the development of sedentary agriculture 11,000 years ago, there have been periodic discussions about the tensions between agricultural production capacity and the number of people to be fed. In fact, some argue that hunters and gatherers were forced to adopt sedentary agriculture to increase food supplies to feed a growing population. In early debates, the issue was seen simply as a race between population growth and available land for cultivation of crops and for growing livestock fodder. However, the debate became more formalized with the writings of Malthus, which is the beginning point for discussing models.

Modeling Supply

The model formalized by Malthus was, until the twentieth century, basically population growth versus land area growth. With improvements in biological understanding—genetics and agronomy—and the development of synthetic agricultural chemicals, substantially increased yields per unit of land became an alternative to just expanding land area in the late nineteenth and twentieth centuries. Furthermore, genetically altering plants to mature earlier allowed a greater number of crops per year. Irrigation development led to an increase in both yields and cropping intensity. Thus, by the middle of the twentieth century, the supply side of the model had become more sophisticated.

The annual percentage growth in supply (ΔS) equals the percentage change in area (ΔA) plus the percentage change in yield (Δye) plus the percentage change in cropping intensity (ΔI), or

$$\Delta S = \Delta A + \Delta ye + \Delta I.$$

All three elements were sources of growth in supply in the twentieth century. However, the importance of land area expansion declined substantially after World War II. The importance of intensification (ΔI) peaked in the 1980s with the slowing down of the rapid expansion of irrigation in developing countries. Thus, changes in yield (Δye) were, by the end of the century, the dominant source of supply growth. Thus, what one hypothesizes as to how these growth rates will change in the future will make significant differences in one's predictions/projections, especially as the timeframe lengthens. If, for example, one believes resource stocks of land and water are limiting, then one might assume ΔA and ΔI will be low and possibly negative in the future. If, in addition, you believe that chemical enhancement of yields is subject to increasing environmental constraints, you would perforce be a supply pessimist. If, on the other hand, you saw modern science as an inevitable savior you would be optimistic about future yield increases (Avery 1995).

Modeling Demand

The modeling of food demand has also moved beyond the projection of population growth rates. Clearly, the number of mouths to feed remains a powerful element in determining food demand. However, we know that people at different income levels eat different diets and that, as people become better off, they eat a more diversified diet including more protein and less starchy and high-carbohydrate foods. Therefore, income levels and income distributions also influence demand.

The first approach used was to assume coincidence between food needs and food demand. This was done early on by FAO by estimating per capita nutritional needs for representative individuals, stratified if possible by geography, sex, and age, and multiplying these needs by estimated population growth. However, this approach did not yield the actual demand for food and was abandoned in favor of income- and price-based approaches in later FAO projections.

Thus, most economic projection models have the same basic demand specification (the so-called Ohkawa equation [Ohkawa 1967]): the percentage change in the demand for food (ΔD) equals the percentage change in population (ΔP) plus the percentage change in income (ΔY), modified by how much of the additional income will be spent on food (the income elasticity of demand η), or

$$\Delta D = \Delta P + \Delta Y(\eta),$$

which says demand will grow with population and income but the impact of income growth will diminish as incomes rise (Engel's law). More sophisticated models could use the distribution of income in a country rather than average per capita income. Hence, the more recent concerns about building poverty into models.

Linking Supply and Demand

Given these two basic conceptual components, there still remain several questions about how they can be integrated and utilized to address issues of global food security. These questions fall into two categories: first, how are global supply and demand numbers to be estimated; and, second, how will the differences between supply and demand in each country/region be reconciled.

The estimation of actual global supply and demand numbers or of empirical demand and supply functions is a nontrivial task. All start at the country level, with estimates of supply of and demand for selected commodities for some future date. On the demand side, the first basic need is a population estimate. All of the projection models (except sometimes USDA) tend to use the same exogenous source—the UN Population Division, medium-variant. Estimating per capita consumption is more difficult. If one has solid baseline data on past and current consumption, then one needs only to estimate how consumption will change with changes in income (the income elasticity of demand) and enter an estimate of how fast income will grow. A more sophisticated model would include how the income distribution would change with growth over time (taking poverty into account). In this way, given baselines of population and consumption and appropriate growth rates of population and income, one can project increases in aggregate demand.

If there are no reliable data on consumption, the problem is more difficult. In fact, in many cases, consumption is measured as the residual left after estimated net trade, losses, seed use, and animal feed have been subtracted from estimated production. FAO, in its early projections of food needs, used a nutritional minimum standard (for example, 2,600 calories per day) to compute per capita nutrient requirements. This number was then compared with estimated per capita availability to produce a per capita food gap (surplus), which could then be multiplied by estimated population to generate a national food gap.

Estimation of the supply side is more problematic. The traditional way would be to start with historic baselines of area planted (or harvested) of each commodity and yields per unit of land. The product of area times yield would produce a baseline of national production. Forecasting ahead would require estimates of how much land would enter or leave production over the projection period and estimates of how much yields would change. Most models compute trends in these variables and then project the trends into the future. A final variable sometimes projected is changes in land use intensity—that is, the average number of crops per year.

Given these baselines of production and consumption (or proxies for these); hypotheses about rates of growth of population, income, land area, crop and animal yields, and cropping intensity; and estimates of the income elasticity of demand, one can project national and global aggregate supply and demand in the form of point estimates. More sophisticated models would estimate supply and demand functions and then apply these rates of growth as factors shifting these functions over time.

There are at least three ways to answer the question of how we put supply and demand together.

First, for trend projection models, simply add up surpluses and shortages to determine projected shortfalls (gaps) or surpluses at regional and global levels. This approach assumes prices are constant. Early models by FAO, IFPRI, OECD, and USDA were of this sort. Projected world food gaps were reported directly.

The second method is to enter the country's surplus or shortage into a model that minimizes the cost of moving surpluses to shortage locations. This is the so-called transportation model, which estimates how food would *flow* between countries. This is called a spatial model because it estimates actual trade flows over geographical regions (that is, space). There are still no prices and there could still be an overall shortfall or surplus.

The third method is to use the estimated supply and demand functions for each country/region (as opposed to trend projections of specific numbers). These country functions can be netted to produce country excess supply or demand functions, which can then be aggregated into a world market. In the world market, prices will adjust until global supply equals global demand. This is called a nonspatial price equilibrium global trade model. It should be noted that it is theoretically and computationally possible to add a transportation model to this nonspatial model and compute projected trade flows that would allocate country surpluses from specific origins to specific deficit destinations (Takayama and Judge 1971). However, the modeling and computational cost of doing this for large numbers of countries and commodities has rendered this approach exceedingly costly and little used.

How these various models can be used to report on food security issues is quite different. The "gap models" report actual estimated food gaps; for example, projected global demand in 2010 exceeds projected supply by 50 million metric tons of grain. On the other hand, global trade models cannot have global gaps (with the exception of small amounts due to changes in stocks). Rather their indicator of "food problems" would be increasing world prices. Of course, all models allow us to look at particular countries or regions in terms of whether there is an excess of supply or demand.

In sum, all models require estimation of supply and demand by commodity, by country, or by region. These estimates may be based on simple trend projections or on sophisticated supply and demand models for each country/region. The gaps in terms of actual quantities, or estimated excess supply and demand functions, can be added up globally. In the most complicated form, excess supply and demand functions can be integrated into a global spatial equilibrium model, such as the USDA's World Wheat Trade Model (Dixit and Sharples 1987).

We have one final comment on model evolution. Early projection models were static. Let us explain. Given a baseline of production and consumption and projected rates of change in critical parameters, an estimate is made for a particular point in the future, for example 2020. This conditional projection says, given projected population in 2020 and appropriate trends or growth rates, we can project supply and demand in 2020. The model gives us a point estimate for the future but does not tell us anything about the path to that point. An alternative approach would be to move toward that final year by estimating the model a year at a time and moving *recursively* toward the end point. Sometimes these models are called dynamic in that the path of adjustment can be observed.

Evaluation of Food Balance Projections

The purpose of this section is to evaluate the accuracy of projections to the year 2000 by different agencies. We use the first method proposed by Theil, which was also used by the National Academy of Sciences. This is to directly compare the projected number with the actual figures for the projection year (for a brief review of the methods used to compare models see Appendix 2).

We started the comparison by computing the percentage error of the projection, which is defined as how much, in percentage terms, the projection overstated or understated the actual outcome. The formula is given by:

$$\text{Error} = \frac{(\text{Forecast} - \text{Actual})}{\text{Actual}} \times 100.$$

A positive number indicates that the projection overstated the observed figure and a negative one that it understated it. We omitted the percentage error in cases where the absolute numbers were very small and the percentage error was greater than 100 percent (for example, if the prediction is 0.3 and the actual figure is 0.1, it means that the actual number was overestimated by 200 percent, which is meaningless since the absolute figures are quite small).

While constructing the comparison tables, we faced a number of problems that illustrated the heterogeneity of the models. We believe that this heterogeneity reduces the usefulness of models to policymakers. A policymaker would like to compare models that offer different opinions (similar to the use of scenarios within an agency model). Often, as argued by Liu and Seeley (1987), individual models are designed as special tools for the agencies' own purposes. Thus policymakers who want projections must decide first which agency, among the available ones, deserves more confidence and then use that model.

We found the comparisons difficult to perform because of problems related to units of measurement, commodity and country coverage, and different base periods used for the projections. Nevertheless, we were able to construct two types of comparisons: within projections made by a single agency (for example, for projections made by FAO, USDA, and IFPRI) and across agencies (for projections made by FAO, USDA, and Iowa State University to 1985, and by FAO and FAPRI to 1990). For a detailed description of all models considered, see Appendix 1.

The comparison of projections within and across agencies proved to be an arduous task, and in many cases was not feasible because of the format in which models were presented. Although most of the models reviewed claimed to have based their projections on disaggregated commodities and countries or regions, the models are often presented in an aggregated format. This makes consistent comparisons across models difficult because each model has its own unique set of aggregations.

With respect to the aggregation by commodity, it is typical to produce projections by commodity (for example, wheat, coarse grains, and rice) and then aggregate them as cereals (for example by adding up the three mentioned commodities) or grains (that is, wheat plus coarse grains). The aggregation called "food" used by IFPRI (IFPRI 1977; Paulino 1986) changed over time. In the 1977 work, IFPRI defines food as cereals, roots and tubers, and pulses; in 1986, IFPRI added cassava and plantains to the previous definition. This way of aggregating makes projections produced by IFPRI not comparable with other projections made to 1990 and 2000.

The different coverage of countries also proved to be a major difficulty in making effective comparisons. Models have evolved over time, incorporating more countries, as better data became available. Whenever the presentation included country-level information, we built homogeneous regions for both projections and actual data to make the appropriate comparisons. In other cases, when the information was reported as aggregated figures, we had to build the comparison table to match that aggregation. For instance, in the case of FAO, projections made in 1979 to the 1985 period are presented only as regional aggregates; since the other FAO projections were presented at a country level, it was possible with effort to replicate the 1979 regional aggregates for the comparison.

Discrepancies in the data source used were another cause of divergence. Two main databases are used for agricultural statistics: the FAO database (FAOSTAT) and the USDA (PS&D) database. For wheat, both databases show similar figures (with the exception of the information for some countries such as the USSR and China); in the case of coarse grains, however, FAO uses a larger number of coarse grains than USDA. In addition, FAO reports paddy rice and USDA milled rice. Because of this, we estimated the projection errors using the same underlying data as were used in the projection. Thus, FAO projection errors were constructed based on FAO current data, whereas USDA projection errors were compared with USDA data. For other agencies, we followed the same methodology that they used in their studies; for instance, IFPRI (1977) mixed USDA data on cereals (wheat, rice, and coarse grains) with FAO data on roots and tubers and pulses, and transformed the latter into cereal equivalents. We chose to compare the most homogeneous commodity possible when making comparisons among agencies. Thus, when possible, we chose to compare wheat projections rather than grain or cereals projections.

In addition, to soften shocks from a particular year and make the actual data more comparable with the data used in the models, we averaged three years of actual data centered on the projection year. Thus, for instance, the "actual" datum for the year 1985 used in computing the projection error is the average for the years 1984, 1985, and 1986.

A final problem when comparing the models is the number of years projected by the different models. This problem could not be addressed because the models (with the exception of FAPRI's model) report results only for the final forecast year and not for the intermediate years, so there is no possibility of matching forecasts with different terminal years using intermediate-year results of other models.

Comparison of Food Balance Projections within Agencies over Time

We constructed three comparison tables to analyze FAO, USDA, and IFPRI performance in projecting consumption and production over time. Because of their size, we have placed the detailed tables (which include projection errors as well as the actual figures and projections) in Appendix 5; here we present summary tables showing only the projection errors. The heading "year1/year2" denotes the year the projection was published (year 1) and the projection year (year 2). We have used the publication date instead of the base year of the projection because of the lack of information about what base year was actually used in many of the projections analyzed. In any case, the difference between the publication year and the base year of the projection is normally not more than a year or two.

Table 2 presents a comparison of projection errors for FAO (details are provided in Appendix 5, Table 15). We compare wheat production and consumption projections made in 1963 to 1970, in 1967 to 1975, in 1971 to 1980, in 1979 to 1985, and in 1986 to 1990.

With respect to their *accuracy over time,* the results for FAO show that aggregate projections seem to become accurate over time. Thus, the 1986 projections to 1990 of world wheat production and consumption show a small error (–1.3 and –0.3 percent, respectively). This also appears to be true for their projections for developing and developed countries when considered as an aggregate. However, it is important to use caution in

Table 2—FAO projection errors: Wheat production and consumption, 1963–86 (percentages)

Regions	1963/1970[a] I	1963/1970[a] II	1967/1975[a] Low	1967/1975[a] High	1971/1980	1979/1985[a] Basic	1979/1985[a] Suppl.	1986/1990
World								
Production	n.a.	n.a.	–18.9	–12.7	–10.8	–12.4	–11.1	–1.3
Consumption	n.a.	n.a.	–36.6	–17.3	–15.0	–11.4	–9.8	–0.3
Production								
Developing	n.a.	n.a.	–33.3	–19.4	–15.2	–24.8	–16.1	–0.5
Latin America	4.5	3.6	–1.3	8.7	9.6	–6.0	5.0	10.3
Africa	23.6	58.7	–13.1	3.9	34.8	5.0	22.6	–23.1
Near East	8.5	11.3	–56.2	–43.3	–16.8	–2.2	4.9	–5.4
Far East	–37.0	–17.2	–34.0	–3.5	–4.9	–20.8	–10.5	5.3
Asian CPE	n.a.	n.a.	–33.9	–30.8	–32.6	–41.7	–34.7	–3.1
Developed	n.a.	n.a.	–11.7	–9.2	–8.3	–4.1	–7.8	–2.0
North America	5.5	5.5	–12.9	–12.9	–30.6	–19.9	–34.9	4.4
Western Europe	–3.0	–3.0	15.4	16.3	–12.6	–26.1	–25.7	–18.3
Eastern Europe and USSR	n.a.	n.a.	–25.9	–20.6	11.8	29.0	33.6	1.0
Oceania	–30.6	–30.6	–11.5	–11.5	–2.0	–19.0	–40.1	37.3
Consumption								
Developing	n.a.	n.a.	–47.3	–24.4	–23.4	–22.7	–19.7	–0.4
Latin America	–1.0	5.3	–76.2	–12.2	–8.6	–3.3	1.5	22.8
Africa	27.4	43.8	–49.5	–28.9	–25.9	–13.9	–9.0	15.4
Near East	–14.6	–12.1	–90.4	–49.1	–28.0	–17.0	–17.5	–1.0
Far East	–9.9	3.2	–27.0	–15.1	–10.2	–9.2	–4.0	–1.0
Asian CPE	n.a.	n.a.	–22.8	–19.7	–35.1	–41.3	–38.9	–7.9
Developed	n.a.	n.a.	–28.7	–12.2	–7.6	0.8	0.8	–0.3
North America	–10.5	–13.6	7.0	7.5	–14.0	–28.5	–31.1	–13.5
Western Europe	–7.2	–7.7	–42.4	20.0	8.1	–14.7	–16.0	–7.4
Eastern Europe and USSR	n.a.	n.a.	–32.3	–33.4	–13.0	17.2	18.7	6.2
Oceania	–10.9	–10.9	–3.8	–4.4	5.1	14.8	10.5	4.8

Sources: Actual data are from the FAOSTAT Database. Projections are from FAO 1963, 1967, 1971, 1979, and 1986.
Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate. Shading is for ease of reading only.
n.a. = not available. CPE = centrally planned economies.
[a] Scenarios assuming low and high per capita income growth, respectively.

judging these results, since this last set of projections covers a projection interval considerably shorter than the previous ones (four years ahead against six to nine years ahead). Errors are higher for earlier years where the projection interval is longer. However, there appears to be a declining trend in global errors.

With respect to how well FAO forecasts *production and consumption at the global level,* we find that FAO projections systematically tend to underestimate both production and consumption. This is also true when we observe projections at the disaggregated levels of developed and developing countries (the one exception to this is the consumption projection for developed countries made in 1979 for 1985). Also note that, at even more disaggregated levels, the errors are substantially higher than those observed at the global level, and they seem to increase the smaller is the region. For instance, projections for Africa contain substantial errors, with both over- and underestimates being high. This type of error seems associated with *data quality* and the fact that, at a more disaggregated level, *country-specific shocks* are more important but they cannot be forecast. Finally, African production of wheat is small relative to other regions, which would contribute to larger percentage errors. It is interesting to note that, whereas projections for regions such as the Near East, the Far East, and the Asian centrally planned economies (Asian CPE) show some evidence of declining errors over time, this is not the case for Latin America because it has higher projection errors at the end of the period (10.3 percent for production and 22.8 percent for consumption). It is often argued that poor data quality explains larger errors in developing regions. However, the errors in projections for both North America and Western Europe (regions assumed to have good-quality data) are also substantial. In these cases, the effects of domestic commodity policy may be a more important factor.

It should be pointed out that, when there are scenarios accompanying the baseline projections (1967/1975 and 1979/1985), the scenarios do not necessarily encompass the full range of values the projected variables could take. Thus, for instance, at a global level both FAO scenarios underestimate production and consumption. This is because the high and low values of the exogenous variables used to create the scenarios (for example, per capita income) are also subject to errors, and these errors are reflected in the projection of the endogenous variables (for example, consumption). This point is important because it reminds us how dependent these world projection models are on exogenous projections of nonagricultural variables such as exchange rates, nonagricultural prices, nonagricultural output, population, per capita income, and GNP growth, to name a few.

Projection errors over time for USDA are presented in Tables 3 and 4. In Table 3, we evaluate wheat projections made in 1961 to 1962 and to 1966, in 1964 to 1970, in 1971 to 1980, in 1978 to 1985. In Table 4, we evaluate the baseline wheat projections made by USDA in 1987 to 1990, 1995, and 2000 as published in Liu and Seeley (1987). The full data sets are provided in Appendix 5 (Tables 16 and 17). We present the 1987 projections in a separate table because they are projections of demand for and supply of wheat, instead of consumption and production (that is, they include projections of wheat stocks), and because they represent only a subset of countries.

Looking at Table 3, several things seem clear. First, in terms of *accuracy over time,* projection errors tend to increase, with projections made to 1985 having higher errors than earlier projections. This is particularly true for production. Second, projections consistently underestimate both production and consumption. In fact, only scenario II-A (see 1971/1985 projection) slightly overestimates both production and consumption; all the others underestimate them. Third, at a more disaggregated level, the errors are less systematic and much higher for some regions. Fourth, among developed regions, projections for Western European production are underestimated for all periods (with substantial errors in the 1978/1985 projections). These results suggest a problem of incorporating agricultural policies into the models. Similarly, the results for North America, which we might expect to be more accurate, show that errors are not only high but also nonsystematic. For instance, projections to 1980 in most of the scenarios substantially overestimate U.S. consumption whereas the next projections to 1985 switch to significantly underestimating U.S. consumption. On the other hand, U.S. production is almost always underestimated.

With respect to projections for developing countries, they seem to follow an established pattern—the smaller the country/region, the worse the projection. The clearest examples are for Central and East Africa. Even in the case of Latin America, one needs to look beneath the relatively small errors at the regional level because they are large offsetting errors for the subregions. North Latin America, Central America, and the Caribbean are significantly underestimated, whereas South Latin America is overestimated.

In Table 4, we present the errors for supply and demand projections to 1990, 1995, and 2000, published by USDA in 1987. These projections include changes in stocks. The errors in projection are high compared with earlier projections, which considered only production and consumption. This suggests difficulties in forecasting long-term stock movements. Note that, whereas the EC-10 countries are underestimated (both supply and demand), almost all other projections are overesti-

Table 3—USDA projection errors: Wheat production and consumption, 1961–78

Regions	1961/ 1962	1961/ 1966	1964/ 1970	1971/1980[a]					1978/1985[b]			
				I	II	II-A	II-B	III	I	II	III	IV
Aggregate[c]												
Production	–5.1	–9.5	–13.6	–16.7	–6.7	0.1	–3.0	–24.9	–15.8	–11.1	–19.1	–9.1
Consumption	–4.1	–7.0	–13.5	–11.9	–6.1	2.9	–0.4	–16.9	–9.4	–4.2	–12.4	–4.3
Production												
North America	–5.5	–22.0	7.0	–28.7	–30.3	–3.6	–12.6	–27.5	–9.1	10.9	–26.0	–1.1
Canada	–6.8	–26.8	15.1	–8.9	–13.8	34.1	19.0	–5.5	–15.2	–3.1	–23.2	–11.6
United States	–5.0	–19.6	4.2	–34.8	–35.4	–15.3	–22.4	–34.3	–6.7	16.5	–27.0	3.0
Western Europe	–3.7	–10.5	–25.9	–18.6	–18.9	–20.3	–24.1	–18.6	–34.9	–41.3	–27.8	–43.4
Africa and Middle East[d]	1.9	–0.1	–3.4	–19.9	–11.6	–13.5	–12.0	–24.9	3.8	6.7	2.5	21.4
North Africa and Middle East	5.8	3.9	3.7	–18.8	–10.1	–11.1	–10.4	–24.8	3.2	5.7	2.0	22.1
Central Africa[e]	–	–	–	–	–	–	–	–	–	–	–	–
East Africa	–86.0	–88.5	–85.1	–24.9	–15.5	–15.5	–15.5	–15.5	–52.4	–50.5	–53.4	–44.4
South Africa	–12.1	–1.4	–35.8	–33.8	–33.8	–49.1	–33.8	–33.8	9.4	17.9	5.0	11.6
India	–7.8	14.6	–33.3	–6.6	20.9	20.9	20.9	–28.6	–12.4	–12.0	–12.4	2.6
Latin America and Caribbean	1.1	7.2	8.5	8.2	20.3	9.6	13.6	–3.8	–16.0	–9.9	–19.9	–7.5
Upper Latin America and Caribbean	–10.0	–11.5	13.4	18.5	48.1	44.4	44.4	–0.0	–37.1	–32.6	–39.3	–24.2
Lower Latin America	3.1	11.4	7.4	6.0	14.1	1.9	6.8	–4.6	–10.3	–3.8	–14.8	–3.0
Consumption												
North America	1.8	–2.6	–1.2	–1.4	8.9	46.1	26.2	–8.8	–16.5	–17.6	–18.0	–14.2
Canada	15.9	12.8	28.5	–18.8	–11.2	77.6	39.8	–24.4	2.9	4.3	0.2	6.3
United States	–1.6	–6.2	–7.6	2.8	13.8	38.4	22.9	–5.0	–20.1	–21.7	–21.4	–18.0
Western Europe	–3.9	–5.3	–19.2	–8.1	–5.8	1.8	1.5	–9.9	–11.6	–9.5	–14.8	–7.7
Africa and Middle East[d]	–0.6	–5.2	–3.8	–15.0	–9.3	–8.3	–9.7	–19.4	–8.3	–3.5	–11.1	–6.4
North Africa and Middle East	–1.6	–6.0	–3.7	–18.1	–12.5	–11.9	–12.1	–21.4	–9.7	–6.9	–12.5	–7.9
Central Africa[e]	—	—	—	—	—	—	—	—	—	—	—	—
East Africa	–69.5	–71.0	–55.0	–17.6	–12.1	–6.6	–6.6	–23.1	–58.8	–19.2	–59.6	–57.7
South Africa	4.7	–9.5	3.8	–6.8	–6.8	–1.7	–32.7	–32.7	–4.7	–4.2	–5.8	–4.0
India	–3.2	–4.4	–15.7	–13.4	–0.5	1.7	0.6	–18.1	–6.4	10.4	–10.8	8.9
Latin America and Caribbean	3.7	0.7	–6.1	–2.5	–8.4	5.6	4.3	–16.0	–1.4	1.7	–3.4	1.1
Upper Latin America and Caribbean	–3.7	–12.0	–16.0	–8.8	–33.7	6.1	4.5	–55.2	–27.6	–22.8	–30.9	–22.8
Lower Latin America	5.8	4.5	–3.1	–0.1	1.1	5.5	4.2	–1.4	9.9	12.2	8.4	11.4

Sources: Actual data are from the USDA PS&D Database. Projections are from Rojko et al. 1978. Shading is for ease of reading only.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate. Shading is for ease of reading only.

[a] I = Continuation of policies and moderate gain in productivity in developing countries. II = Higher productivity and economic growth than in I in developing countries. II-A = Major exporters maintain their share in the world grain market. II-B = Major developed importers adjust their domestic prices with international prices. III = Lower agricultural production and economic growth in developing countries than in scenario I.

[b] I = Continuation of the trend in terms of economic growth and policies. II = High economic growth that leads to higher level of imports. III = Low income growth that reduces import demand. IV = Moderately higher productivity in developing countries in the context of high income growth and strong world import demand.

[c] Error computed considering only the countries presented in the table (that is, not the entire world).

[d] Includes only those countries considered in the projection.

[e] Greater than 100 percent.

mated. Finally, we note that for North America (Canada and the United States) errors in supply projection errors are very high compared with demand projection errors. We do not have a good explanation for these large discrepancies.

Table 5 presents food production projections for a group of developing countries made by IFPRI in 1977 to 1990, and in 1986 to 2000. More detailed data are contained in Appendix 5 (Table 18). Demand projections were not considered be-

Table 4—USDA projection errors: Demand for and supply of wheat, 1987 (percentages)

	1987/ 1990	1987/ 1995	1987/ 2000
Aggregate[a]			
Supply	2.4	22.5	22.3
Demand	–2.4	21.2	22.1
United States			
Supply	40.5	65.3	53.7
Demand	22.3	47.5	29.8
Canada			
Supply	13.3	41.1	58.5
Demand	0.1	13.6	23.2
Australia and New Zealand			
Supply	46.0	40.8	17.0
Demand	14.0	22.7	–13.6
Argentina			
Supply	8.1	9.3	–6.0
Demand	–2.6	3.9	19.4
EC-10			
Supply	–26.7	–23.0	–29.2
Demand	–24.9	–26.4	–34.2
Japan			
Supply	14.9	100.4	120.4
Demand	12.7	22.8	34.5
USSR			
Supply	–10.6	22.9	44.1
Demand	–3.8	51.6	89.6
Brazil			
Supply	0.4	64.1	101.7
Demand	34.5	27.2	18.4
Mexico			
Supply	–9.9	12.6	38.1
Demand	18.2	16.7	22.0

Sources: Actual data are from the USDA PS&D Database. Projections are baseline projections from Liu and Seeley 1987.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate. Supply includes beginning of year stocks and demand includes end of year stocks.

[a] It considers only those regions and countries projected.

cause they were normative (that is, to satisfy requirements). IFPRI's trend supply projections typify a frequent outcome: the aggregate projection appears to be very accurate but the components have substantial offsetting errors. At the aggregate level (that is, all the developing countries in the study) the projection errors are quite small (0.1

Table 5—IFPRI projection errors: Food production, 1977 and 1986 (percentages)

	1977/ 1990	1986/ 2000
Developing countries	0.1	2.6
Asia	–6.5	0.6
China[a]	41.4	–1.7
South Asia	–9.4	0.3
East and South East Asia	–0.5	7.0
North Africa/Middle East	–15.2	13.8
Northern Africa	–1.5	–2.2
Western Asia	–22.3	20.7
Sub-Saharan Africa	–3.8	–20.0
West Africa	–20.0	–51.0
Central Africa	68.0	29.8
Eastern and Southern Africa	–8.7	12.2
Latin America	31.8	29.1
Mexico, Central America, and Caribbean	37.3	51.5
Upper South America	22.9	27.0
Lower South America	45.3	13.0

Sources: Actual data are from the FAOSTAT and USDA PS&D databases. Projections are from IFPRI 1977 and Paulino 1986.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate.

[a] Only Taiwan for 1990; Taiwan plus People's Republic of China for 2000.

and 2.6 percent). However, at the regional level in, for example, the 1990 projections, three regions—Asia, North Africa/Middle East, and Sub-Saharan Africa—are underestimated, while Latin America overshot by 32 percent. Similarly, within regions (for example, Sub-Saharan Africa) larger subregional errors in both directions partially offset each other. It is not the intent to single out IFPRI; rather we use IFPRI results to illustrate a very common characteristic of most projections as they are disaggregated.

Comparing the results obtained from the analysis of projections made over time by the three agencies, we postulate some conclusions:

1. Global projections are generally more accurate than projections of more disaggregated regions, subregions, and countries.
2. Generally, the smaller the country or the region, the higher are the projection

errors. Africa's projections are the typical case, and we attribute this result to data problems and the presence of many shocks specific to small countries.

3. At least in the cases of FAO and USDA, projections consistently seem to underestimate global production and consumption.

4. We were surprised at the size of errors in projecting production and consumption for developed countries, especially in the cases of Western Europe and the United States, where data problems should not be an issue. We hypothesize that these outcomes reflect the difficulty of incorporating complex domestic policies into the analysis.

5. We hypothesized that agencies doing many projections sequentially over time should learn and improve their accuracy. There is some evidence to support this hypothesis with respect to FAO. However, the opposite appears to be the case for USDA.

Comparison of Food Balance Projections across Agencies for the Same Year

We constructed three tables for comparisons across agencies. Table 6 presents cereal projections by FAO, USDA, and Iowa State University (ISU) made in about 1974 to the forecast year of 1985; Table 7 evaluates wheat projections by FAO and FAPRI made around 1985 to the forecast year of 1990; and Table 8 reviews cereal projections made in the mid-1990s by FAO, IFPRI, USDA, and the World Bank to forecast year 2000. Parallel detailed data are given in Appendix 5 (Tables 19, 20, and 21).

First, supporting our earlier analysis, global projection errors are consistently smaller than those at a more disaggregated level. Therefore, the global aggregate alone is likely to be a poor indicator of the accuracy of the model. The ISU results in Table 6 illustrate this clearly in the low-growth scenario where the underestimate of con-

Table 6—FAO, ISU, and USDA cereal projection errors to 1985 (percentages)

	FAO	USDA: 1974/1985[a]				ISU: 1973/1985[b]	
Item	**1974/1985**	**I**	**II**	**III**	**IV**	**Low**	**High**
World							
Consumption	6.7	–2.9	1.5	–5.8	3.1	–8.0	–0.7
Production	n.a.	–5.9	–1.6	–8.7	–0.1	–5.8	–5.8
Developed countries							
Consumption	2.9	14.3	19.0	9.8	20.1	–25.9	20.9
Production	n.a.	4.4	10.5	–0.2	5.2	–4.7	–4.7
Developing countries							
Consumption	10.2	–18.1	–14.0	–19.6	–11.9	n.a.	n.a.
Production	9.8	–17.7	–15.6	–18.5	–6.2	n.a.	n.a.
Developing market economies							
Consumption	22.0	–10.9	–4.7	–13.3	–1.7	31.8	48.9
Production	36.7	–10.1	–6.7	–11.4	8.6	–7.6	–7.6
Asian centrally planned[c]							
Consumption	–8.3	–30.9	–30.3	–30.8	–30.0	n.a.	n.a.
Production	–18.4	–29.8	–29.8	–29.8	–29.8	n.a.	n.a.

Sources: FAO data are from the FAOSTAT database and USDA data are from the USDA PS&D database. Projections are from USDA 1974.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate. ISU = Iowa State University. Shading is for ease of reading only.

[a] I = Assumes initial slow growth, but resumed in the late 1970s and early 1980s. II = Assumes high world demand situation. III = Assumes low demand and stagnation. IV = Assumes faster growth of production in developing countries.

[b] Iowa State assumes high (H) and low (L) scenarios for demand resulting in two possible balances.

[c] FAO includes China, People's Democratic Republic of Korea, and Vietnam; USDA includes only China.

Table 7—FAO and FAPRI wheat projection errors to 1990 (percentages)

	FAO	FAPRI
	1986/1990	1986/1990
Total production	–3.9	–1.9
Australia	36.5	43.8
Canada	–20.1	–19.6
EC-10	–24.7	–12.6
India	3.3	–5.2
United States	16.3	13.6
Total consumption	–6.1	–4.6
Australia	8.3	–3.8
Canada	–14.8	–35.3
EC-10	–16.3	–3.0
India	1.4	–6.0
United States	–13.2	–12.8
USSR	–2.5	–0.7

Sources: Actual data are from the FAOSTAT database. FAPRI projections are from Meyers, Devadoss, and Helmar 1986; FAO projections are from FAO 1986.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual data used are three-year averages centered in the reported year. A positive value indicates that the projection is an overestimate, a negative value an underestimate.

sumption in developed countries (25.9 percent) almost offsets a significant overestimate of consumption in developing market economies (31.8 percent). Reference to Table 19 shows that this is also true in absolute terms. Second, both USDA and ISU underestimate production at the global level. In the case of USDA, this result is due to underestimates of production in developing countries only, whereas for ISU it is due to underestimates of production in both developed and developing countries. Third, comparing the projections made for developing countries by FAO and USDA, USDA (in all variants) underestimates both production and consumption in developing countries, whereas FAO overestimates them. Fourth, most of the USDA underestimation problems in developing countries come from the errors generated by large underestimates of both consumption and production in Asian centrally planned economies. This likely reflects difficulties in projecting Chinese production and consumption.

Table 7 presents projections to 1990 by FAO and FAPRI, both made around 1985 and both using world nonspatial trade models (in the case of FAO, the projections obtained from the model are further adjusted by FAO experts). The projection errors observed in both cases are quite similar and both agencies underestimate production and consumption. As in the previous analysis, the small global errors cover up larger offsetting errors at the country level. Both have real problems in projecting North American and EC-10 production and consumption. In the case of the United States, both agencies overestimate its production by well over 10 percent, while Canadian production is underestimated by some 20 percent. In addition, North American consumption is significantly underestimated.

Table 8 displays the calculated projection errors from cereal projections made by FAO, IFPRI, USDA, and the World Bank to 2000 based on nonspatial world trade models. The data used to calculate the errors are contained in Appendix Table 21. In the case of IFPRI, we consider projections from two models: the IFPTSIM (Agcaoili and Rosegrant 1995) and the IMPACT model (Rosegrant, Agcaoili-Sombilla, and Perez 1995). These two models are similar in construction, the main difference being that IMPACT contains many updated elasticity values. In the case of the IMPACT model we present two projections: the first one, called interpolation, was computed by applying the projected annual growth rates for the period 1990–2020 to the period 1990–2000, in order to calculate the 2000 figure. The second IMPACT projection was generated by running the original IMPACT model to the year 2000. Unfortunately, it was not possible to compute the errors for projections about consumption for the models using FAO data, because these were not yet available.

It is important to note that in the absence of actual 2001 data, the errors in Table 8 were computed using actual figures only for 1999 and 2000, instead of the three-year centered average used in our analysis of projections to years earlier than 2000. This was necessary because most of the models reviewed provide a projection only for

Table 8—FAO, IFPRI, USDA, and World Bank cereal projection errors to 2000 (percentages)

		IFPRI				
			IMPACT[a]			
	FAO	IFPTSIM	Interpolation	Dynamic run	World Bank[b]	USDA
	1994/2000	1995/2000	1995/2000	1995/2000	1993/2000	1997/2000
World						
Production	8.9	8.9	6.8	7.3	5.9	2.8
Consumption	n.a.	n.a.	n.a.	n.a.	4.5	2.6
Production						
Developed countries	10.8	20.0	10.6	9.9	8.2	5.9
Eastern Europe and former USSR	54.0	67.1	47.2	45.4	47.6	20.7
Developing countries	7.3	–0.3	3.3	5.1	4.0	0.3
Latin America	3.8	–2.5	–0.1	–5.7	–4.8	–2.4
Sub-Saharan Africa	8.1	–3.2	3.2	1.4	41.3	8.0
Asia	4.3	–3.1	–0.1	2.2	–0.9	0.3
Middle East/North Africa	44.5	36.1	37.6	44.7	33.0	–2.3
Consumption						
Developed countries	n.a.	n.a.	n.a.	n.a.	2.8	1.6
Eastern Europe and former USSR	n.a.	n.a.	n.a.	n.a.	43.9	20.7
Developing countries	n.a.	n.a.	n.a.	n.a.	5.6	3.3
Latin America	n.a.	n.a.	n.a.	n.a.	–4.9	–4.8
Sub-Saharan Africa	n.a.	n.a.	n.a.	n.a.	25.0	1.6
Asia	n.a.	n.a.	n.a.	n.a.	3.5	9.3
Middle East/North Africa	n.a.	n.a.	n.a.	n.a.	17.3	–20.4

Sources: Actual data are from the FAOSTAT and USDA PS&D databases. Projections are from FAO (1994), IFPRI [IFPTSIM results are from Agcaoili and Rosegrant (1995); IMPACT results are from Mark Rosegrant (private communication, 2001)], World Bank (Mitchell, Ingco, and Duncan 1997), and USDA (1997). The structures of the IFPTSIM and IMPACT models are similar; the main difference is that IMPACT includes many updated elasticities.

Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projection year." Actual figures used to compute the errors are only the average of 1999 and 2000 figures in the absence of the 2001 figure. A positive value indicates that the projection is an overestimate, a negative value an underestimate. Shading is for ease of reading only.

n.a. = not available.

[a]Publication year corresponds to the model version, since the figures have not been published before.

[b]Publication year corresponds to the year when the figures were originally published.

the year 2000. Therefore we did not have the option of using a 1998–2000 three-year centered average. However, given that all models were treated the same way, the analysis still provides valid comparisons.

These projections, published in the mid-1990s, have as many similarities as they have differences. This is yet another case where the aggregate results are more accurate than the components that make them up. All the projections overestimate global production, as they do the production of developed and developing countries. The one exception is IFPTSIM, which slightly underestimates developing-country production.

First, we analyzed production projections where we could compute errors for all the models. In the case of developed countries, IFPRI's IFPTSIM model has the highest projection error (20.0 percent), followed by FAO (10.8 percent), IFPRI's IMPACT (10.6 and 9.9 percent), and World Bank (8.2 percent). USDA's projection error is the lowest (5.9 percent); however, this model also has the shortest projection horizon of 3 years. In the case of developing countries, FAO has the highest error (7.3 percent) followed by IFPRI's IMPACT "dynamic run" projection (5.1 percent), World Bank (4.0 percent), and IFPRI's IMPACT "interpolation" projection (3.3 percent). IFPRI's IFPTSIM and USDA have the lowest errors (–0.3 and 0.3 percent, respectively).

Second, we looked at regional components of the two large country blocks (developed and developing) and noticed, as in our previous analysis, that the errors seem to worsen at this level. In general, all the models have difficulty projecting Eastern Europe and the former USSR, for both production and consumption. This may illustrate that mathematical trade models have difficulty in reflecting a rapidly changing (deteriorating) economic situation. It is likely, however, that older trend projection models would have had even worse results than the trade models. In addition, all of the models, except USDA's projection for production, show large overestimates for the Middle East/NorthAfrica region. (For production, the errors go from the World Bank with 33.0 percent to IFPRI's dynamic run with 44.7 percent; for consumption, the World Bank projection error is 17.3 percent and USDA's is –20.4 percent.) The World Bank substantially overestimates Sub-Saharan African production (41.3 percent). Latin America and Asia in general show errors below 5 percent, although some models overestimate the actual figure and others underestimate it.

In concluding this review across models, we find that modest projection errors at the global level often hide larger errors when we analyze the projections of the component parts. The proposition that the smaller the country or region, the worse the projection seems to be supported when looking across models. Finally, the analysis identifies data problems as a major cause of error. This suggests the need for increased attention to obtaining better data if modelers are interested in producing better projections, especially for developing countries. For developed countries, the major issue seems to be modeling complicated domestic policies, including quantitative border restrictions.

4. Evaluation of Surveys, Scenarios, and Predictions about the Food Situation and Resource Constraints

In this chapter we evaluate the remainder of the literature surveyed. We start by reviewing population versus food supply predictions. This review looks at the nutritional needs-based surveys of FAO and USDA; appraises a number of generally pessimistic predictions made in the 1960s and 1970s and in the late 1980s and 1990s about population growth and famine; and briefly looks at Club of Rome models. The second part of the chapter reviews selected predictions—both negative and positive—about energy, water, and land, as well as fisheries. The chapter closes with a comment on poverty and income distribution issues.

Population versus Food Supply

In this section we discuss three related topics: early food needs surveys, qualitative predictions, and global simulation models.

Nutritional Needs and Food Supply Constraints

Immediately following World War II there was a great deal of uncertainty about whether there would be food shortages or surpluses. It was in this context that FAO undertook the first of six *World food surveys*. Given the complete breakdown of statistics during the war, the approach used was to estimate a baseline of pre-war calorie availabilities and compare them with postulated minimum nutritional standards. The baseline conclusion was that over half of the world's population had access to less than 2,250 calories per day, one-third had access to more than 2,750 calories per day, and the remainder were in between. Thus, between half and two-thirds of the world population were undernourished before the war. The analysis concluded that things were worse after the war. FAO then formulated minimum postwar nutritional targets and from them computed the production required to feed all to a minimum standard. This analysis suggested the need for greatly expanded production. Recognizing that production increases of that magnitude would take time, the year 1960 was selected as the "planning year." The sum of the amount of food needed to feed the existing population properly, and the additional needs of the 25 percent projected population increase, provided some startling numbers regarding required increases in production—cereals 25 percent, roots and tubers 27 percent, pulses 80 percent, fruits and vegetables 163 percent, meat 46 percent, and milk 100 percent. The remainder of the slender report discussed, in very general terms, the possibilities for production increases. The conclusion was distinctly Malthusian: more than half the world was undernourished, massive increases in food production would be required to feed them, and there was obvious pessimism about meeting the target.

The *Second world food survey* completed in 1952 presented an even more alarming picture. Using still fragmentary data on food availability, the first conclusion was that the situation had worsened since the 1946 survey. By preparing food availability budgets for some but not all countries, FAO estimated acreage, yields, and production. Adjusting for losses and seed and feed utilization, per capita availability was estimated by country. By aggregating across countries, world output was estimated. Output of all grains, except for maize, was still, in 1949–51, below pre-war levels, as was production of potatoes and pulses. Only sugar and maize had an index exceeding 100. Comparing these per capita supplies with updated nutritional standards led to the conclusion, based on a standard of 2,600 calories/capita/day, that over two-thirds of the world's population was undernourished. This represented a deterioration from 1946.

Using the nutrition targets to compute the additional supplies needed to bring everyone up to 2,600 calories, plus the needs for the estimated increase in population, yielded the food "gap" for 1960. Converting the gap into required rates of increases in production allowed comparison against recent actual experience. The required rates of production growth were in most cases 50 percent above the post-war recovery rate, which led to the conclusion that "viewed in this light the prospects are not at first sight promising" (FAO 1952, 26).

The *Third world food survey* was published in 1963. It followed a generally similar approach, only now food supply balance sheets were computed for many more countries. Nutritional requirements were adjusted by country and region, and then compared with food availability. The results were that the situation was better than the immediate post-war period, but only slightly above the pre-war situation. The conclusion, less startling than before but still dire, was that "10–15 percent of [the world's] people are undernourished and up to a half suffer from hunger or malnutrition or both" (FAO 1963, 9). Projecting to 1975, food supplies would need to increase 35 percent to sustain the "present unsatisfactory diet" (FAO 1963, 9). For all to be up to minimum levels of nutrition, world food supplies would need to increase by 50 percent.

In a critique of analyses of the world food situation, Thomas Poleman (1975) is very critical of FAO for approaching world food issues with a strong Malthusian bias. He similarly lumps the USDA's first foray into global food security analysis, *The world food budget, 1962 and 1966* (USDA 1961), in the same category. The study concluded that two-thirds of the world (that is, 1.9 billion people) had diets that were "nutritionally inadequate, with shortages in protein, fat, and calories" and, further, that there was "no likelihood that the food problem soon will be solved" (USDA 1961, 5).

The approach used by both FAO and USDA necessarily underestimated food availability and overestimates needs. It underestimated production because of incomplete country coverage. It overestimated needs because it assumed that the needs for every human were the same. Further, the levels of nutritional requirements specified were higher than later analysis suggested was necessary. Subsequent to these "normative" analyses, both FAO and USDA initiated parallel positive projections of supply and demand, which we have already discussed in Chapter 3. FAO continued to produce the *World food survey* periodically in 1977, 1987, and in 1996. Calculations continued to be made of the number of undernourished people in the world. Following the downward adjustment of protein requirements in the 1970s, the numbers dropped. Between the fifth and sixth surveys, absolute numbers dropped marginally from over 900 million to 841 million and the share of the population undernourished dropped substantially. There has continued to be controversy about how to measure hunger; Uvin (1994) contains an interesting comparison of alternative measures.

Qualitative Predictions—Pessimistic, Optimistic, and Other

FAO and USDA were not the only ones concerned about food security in the 1960s and the early 1970s. The demographic transition from high birth and death rates to low birth and death rates was proceeding unevenly. Death rates were dropping and life expectancy increasing, but birth rates remained high. The result was rates of increase in population never before experienced in Africa, Asia, and Latin America. Concern about the capacity of the world to feed burgeoning numbers emerged from outside the traditional food and agriculture establishment. William and Paul Paddock first expressed concern in their book *Hungry nations* published in 1964. The book contains a sequence of examples of poverty and undernourishment in the recently independent countries of the developing world. Two bad monsoons in South Asia (India) in 1965 and 1966, and the subsequent massive shipments of food aid (30 million tons), which staved off famine, triggered further pessimism. Lester Brown and USDA expressed the view that the capacity of U.S. agriculture to save the world from future larger shortfalls would be problematic after the middle 1980s (Brown 1970). The Paddock brothers' second book—*Famine 1975!*—predicted just that: "in fifteen years the famines will be catastrophic" (Paddock and Paddock 1967, 18).

After two years of falling per capita food supplies (1965–66), however, per capita food availability was again rising, more rapidly now because the Green Revolution was gaining strength. Lester Brown was cautiously optimistic in *Seeds of change* (1970) and Colin Clark (1970) was very optimistic—the world should be able to feed 35 billion, ten times the then population.

But, if food and agricultural people were becoming more optimistic, ecologists and demographers were not. Paul Ehrlich predicted massive and long-term famines in *The population bomb* (1970). The Club of Rome produced the first of three studies (Meadows et al. 1972) that predicted the exhaustion of many nonrenewable natural resources, with serious consequences for food security.

Growing optimism about improved global food prospects was suspended by the doubling and tripling of grain prices in 1972–74. Lester Brown became more pessimistic, publishing *By bread alone* in 1974. The Paddock brothers reissued *Famine 1975!* as *Time of famines* in 1976. Pessimism persisted for some in the late 1970s with *The Global 2000 report* in 1980 (Barney 1980–81). But optimism returned with D. Gale Johnson's book *World food problems and prospects* (1975).

By the late 1980s and early 1990s sporadic dire predictions began to surface again: Brown (1988); Ehrlich and Ehrlich, *The population explosion* (1990); Postel, *Last oasis* (1992); Brown and Kane, *Full house* (1994); and Brown, *Who will feed China?* (1995). Most of these new concerns were focusing on natural resources constraints and on the depletion of fisheries. We look explicitly at these resource issues in the last section of this chapter.

Finally, there are some who attribute persistent world hunger and undernutrition not to supply and population issues at all, but to the unequal distribution of resources and income and to the concentration of economic and political power in the hands of the rich and the elite (Lapp´e, Collins, and Rosset 1998). However, this is a topic for another paper.

As the twentieth century ended, grain prices were at a 100-year low, stocks were building, and reasonable scholars were writing about *Feeding the ten billion* (Evans 1998). Massive famines had not occurred on the scale forecast by Ehrlich or the Paddock brothers. Serious food insecurity did occur in a number of developing countries, but these events were almost always associated with civil strife, not with persistent food shortages. In fact, Amartya Sen won a Nobel Prize, in part, for his analytical conclusion that policy failure was the cause of most famines (Sen 1981). He could find no recent famines that originated with shortfalls of food production. Lastly, D. Gale Johnson (1975) has argued several times that the world is now capable of moving fast enough to permanently remove natural shortage-induced famines as a serious issue.

Why then has the pessimistic view not been generally confirmed? First, because most predictors do not use formal models, they are free to focus on a subset of variables that particularly concern them—land loss, or water constraints, or slow improvements in yield growth, and so on. As more of these partial components turn negative, there is a tendency to project them individually, add up the partial sums, and see serious problems ahead. In reality, however, these individual variables are part of a much larger complex of tightly interrelated variables, many of which have some degree of substitution (trade-offs) among them. On the other hand, using models rooted in historical trends forces a broader and more integrated look at the picture.

Second, widely publicized predictions inevitably bring responses. Early projections of significant long-term food gaps, made assuming constant prices, never materialized because, as shortages emerged, prices rose, producers responded positively, and consumers responded negatively. The world, whether we like it or not, is like a giant general equilibrium model. Some have argued that Lester Brown's book *Who will feed China?* (1995), widely criticized for proposing possible grain imports of between 280 and 369 million metric tons by 2030, nevertheless intensified the debate about China's long-term food strategy.

Third, it may be that these authors are not making predictions but rather producing pessimistic scenarios with the explicit purpose of pushing the policy process in particular directions. Ehrlich discusses this strategy in *The population bomb* (1970) and it is explicitly the objective of the Club of Rome studies. What clearly are being made are conditional forecasts, conditioned on variables that particular authors are concerned about. Thus their objective is to reduce the chances that their predictions will come true.

Furthermore, most are predicting far enough in advance that they expect no one will be around to check up on them 50 years later. The one exception was the Paddock brothers, who re-released *Famine 1975!* in 1976 when widespread famine clearly had not occurred.

Finally, a word needs to be said about the optimists. Although we have reviewed only a small sample, it is clear that their optimism comes from very different sources: Russell and Clark are convinced that there are great unused soil resources; Simon sees increased numbers of human minds as the ultimate renewable resource; Evans is optimistic about biological technology; and Avery, Johnson, and Cochrane are all optimistic about the power of science to increase agricultural productivity. All, of course, have one thing in common: history has not yet proven them wrong.

If dire predictions seldom, if ever, come true and optimistic predictions are not able to be tested, are these qualitative prediction exercises of no value? Models focus on regularities and historical interdependencies. Most of the writers reviewed in this section have focused on possible shocks that could upset the regularities of the models. Therefore, they could have significant impacts but, by virtue of being exogenous, they are difficult to predict. Further, many of these "shocks"—resource depletion, price run-ups, and adverse policy choice, as in the underinvestment in research—are correctable by appropriate policy/human choice. Therefore, negative/doomsday scenarios, if based on critical variables and reasoned analysis, may provide useful inputs at critical stages in the policy debate. Of course, if the prognosticator has frequently been wrong in the past, the $n + 1$ prediction may have less impact.

Global Simulation Models of Resource Constraints

We now turn to a class of global simulation models that try to simulate the interrelationships between population growth, food demand, natural resources degradation, and food supply. They add to more traditional supply and demand projections, the interrelationships between population growth, environmental degradation, and natural resource availability to project impacts on food production. Traditional projection models treat population as an exogenous variable and natural resources as an exogenous constraint, if they are considered at all. There are no feedback loops.

Examples of these global models are the works initiated under the sponsorship of the Club of Rome, including the models by Forrester (1971), Meadows et al. (1972), the World Integrated Model (Mesarovic and Pestel 1974), and the Latin American World Model (Herrera 1976). According to Fox and Ruttan (1984), who reviewed these global models, it is possible to include in this group the World Input/Output Model formulated by Leontief, Carter, and Petri (1977) for the United Nations, even if the characteristics of this model differ substantially from the mentioned global models.

The main motivation of these global models was the apparent conflict between high growth rates of population, expanded economic activity and resource depletion in the post-war era, and the finite resource capacity of the planet. Thus, according to the first publication of the Club of Rome, *Limits to growth,*

One [objective] was to gain insight into the limits of our world system and the constraints it puts on human numbers and activity. Nowadays, more than ever before, man tends toward continual . . . growth . . . blindly assuming that his environment will permit such expansion, that other groups will yield, or that science and technology will remove the obstacles. . . . A second objective was to help identify and study the dominant elements, and their interactions that influence the long-term behavior of world systems. . . . Our goal was to provide warnings of potential world crisis if these trends are allowed to continue, and thus offer an opportunity to make changes in our political, economic, and social systems to ensure these crises do not take place. (Meadows et al. 1972, 186)

The results of the initial models (that is, Forrester's and Meadows' models) were severely criticized in terms of their construction and assumptions, particularly their lack of empirical support for the different relationships included in the models. It was argued that this lack of empirical basis would reduce the robustness of the predictions formulated with the models.

Nordhaus (1973) pointed out three critical weaknesses of the *Limits to growth* models. First, the functional relationships used by Forrester in his model were purely conjectural and not derived from data or empirical studies. It is important to note that correction of this weakness was tried by Meadows in the subsequent models, but the requirements in terms of information were quite difficult to meet. Second, the models lacked an economic framework that could serve as support to the structure of the model. There was no price system or any structure of incentives that could guide resource use in response to increasing resource scarcity. Third, the results were not robust to changes in the parameters of the model. In fact, by slightly modifying the model assumptions, it was possible to go from a doomsday prediction to just the opposite conclusion.

As is noted by Fox and Ruttan (1984), the criticisms of the initial Club of Rome models influenced the subsequent global models (that is, Mesarovic and Pestel 1974; Herrera 1976), which were formulated in a less aggregative way and with a better economic structure. The functional relationships in the models were also validated empirically and the length of the projection period was substantially reduced (ranging from 5 to 20 years). Although large general equilibrium global simulation models are still alive (see Brecke 1993), most subsequent approaches continued to consider these three components (that is, food supply and demand, natural resources, and population) separately. The authors of the *Limits to growth* (Meadows et al. 1972) did update their model, and 20 years later published a new analysis entitled *Beyond the limits.* They used a simulation model to analyze 13 scenarios about how different population and environmental policies would affect human well-being in the future. In addition, comparing their current results with the original ones, they found that, "in spite of the world's improved technologies, the greater awareness, the stronger environment policies, many resource and pollution flows had grown beyond their sustainable limits" (Meadows, Meadows, and Randers 1992, xiv).

Predictions about Resource and Systems Constraints to Food Security

In terms of natural resource constraints on terrestrial farming systems, our analysis is limited to how selected resource stocks potentially constrain food production. We briefly analyze constraints related to energy, water, and land. Regarding broader food system constraints, we consider predictions about fisheries as an additional source of food. Finally, on the demand side, we briefly analyze poverty projections, because changes in the incidence and distribution of poverty have impacts on demand. Poverty implies a constraint in terms of the affordability (access) of food and therefore would have an impact on demand.

In the case of both natural resources and poverty, a straightforward validation is not possible in every case because predictions are sporadic and sometimes made for years beyond 2000. Our methodology is, when possible, to compare the prediction with the actual observed outcome. Thus we were able to compare projections about land, poverty, and fisheries with observed figures. If this comparison was not possible, we compared the key assumptions used to project the natural resource availability with the observed figures. This was the case with energy. A third type of comparison was to compare older estimates of the natural resource availability with the most recent projections, which we assumed would be closer to the actual figure. This method was applied for the evaluation of earlier projections of fresh water demand.

Some writers follow the practice of presenting natural resources in per capita terms. Resources such as land, oil, or water are generally finite and do not grow. Therefore, when expressed in per capita terms, they will *always* show a decreasing trend. This in itself is not necessarily bad. What is important is the capacity of those resources to produce needed goods. To the extent they can be used more efficiently or substitutes are found, declining per capita availability should not be alarming per se.

Energy

Is the world running low on energy resources, particularly oil, that are needed to serve the increasing population? This question is frequently asked because shortages of petroleum (and high prices) have implications for many dimensions of food security. For food production, it affects the supply and prices of fertilizers, fuel, and pesticides, and fuel prices affect the processing and transportation of food. There are two sides to the debate. One side is represented by Lester Brown, who in several publications has raised concerns about decreases in per capita oil production. The other side, for our purposes represented by Julian Simon, presents a positive view of the energy problem based on the existence of possible substitutes for oil. Brown's position can be characterized in the following quote from *Resource trends and population policy: a time for reassessment.*

If projected population growth materializes, a 1 percent growth rate in oil production would lead to a steady per capita decline. Between 1978 and 1990, overall production would increase by some 12 percent but production per person would fall from 5.23 barrels to 4.66 barrels. . . . As oil reserves dwindle and as more countries try to stretch out their remaining reserves, total oil production is likely to turn down around 1990, declining slowly from that point onward. As overall output declines, production per person falls rapidly, dropping from 4.66 barrels in 1990 to 3.55 barrels in 2000. Whether world oil production follows the exact path projected here is not of overriding importance. What is important is not only that the period of rapid growth in per capita oil output has ended but that the oil produced per person at the end of the century will be far less than it is today. (Brown 1979, 23)

Simon and Kahn take a more global view about energy resources and permit the possibility of substitution among different energy sources. This position may be characterized by the following quote taken from *The resourceful earth.*

The availability of energy has been increasing and the meaningful cost has been decreasing, over the entire span of humankind's history. We expect this benign trend to continue. . . . Barring extraordinary political problems we expect the price of oil to go down. Even with respect to oil, there is no basis to conclude that the price will rise until the year 2000 and beyond. . . . But no matter what the conditions, the market for oil substitutes probably constitutes a middle-run ceiling price for oil not much above what it is now; there could be a short-run panic run-up, but the world is better protected from that now than in the 1970s. And if free competition prevails, the price will be far below its present level. (Simon and Kahn 1984, 25)

Table 9 compares Brown's (1979) projections to 2000 with the most recent data. In terms of the trend, production seems to be slightly increasing not decreasing, as in Brown's projections. Furthermore, this increase of production has kept the per capita figure roughly constant.

On the other hand, Simon and Kahn's predictions about oil prices appear generally on track. Figure 4 represents the evolution of oil prices from

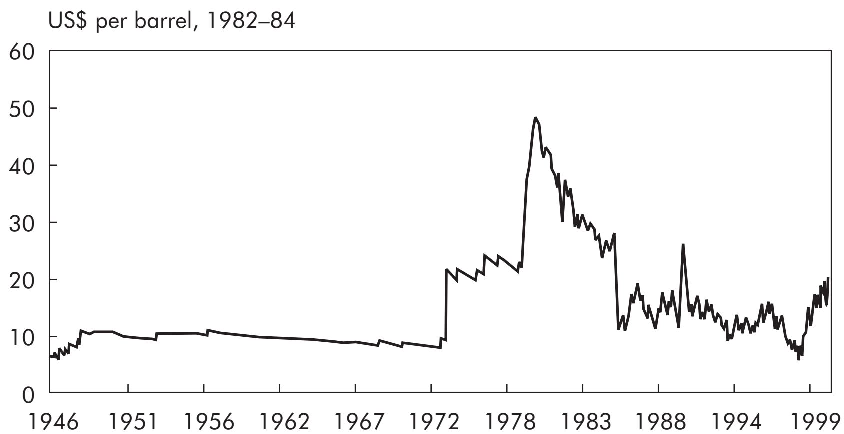
Table 9—World oil production, total and per capita, projected to 2000

Year	Population (original estimates) (billion)	Actual population (billion)	Worldwatch data: Oil production (billion barrels)	Worldwatch data: Oil production per person (barrels)	Actual oil production (billion barrels)	Actual oil production per person (barrels)
1978	4.21	4.29	22.00	5.23	22.70	5.29
1980	4.37	4.44	22.30	5.10	22.60	5.09
1985	4.82	4.84	23.40	4.85	20.45	4.23
1990	5.28	5.27	24.60	4.66	23.19	4.40
1995	5.76	5.67	23.40	4.06	23.98	4.23
2000	6.25	6.07	22.20	3.55	25.30[a]	4.23[a]

Sources: Population projections are from United Nations 1979; oil projections are from Brown 1979. Actual population is from United Nations 1998; oil data are from BP Amoco 2001.

[a]Actual figures for production and production per capita are for 1999.

Figure 4—Real price of West Texas intermediate crude oil, 1946–2000



Source: Bureau of Labor Statistics, U.S. government.

1946 to 2000 in 1982–84 dollars per barrel. As shown, after reaching a peak in 1980, oil prices seem to follow a decreasing trend, as predicted by Simon, though there is a turn upward in 2000. However, it is too early to tell whether this is a reversal of trend or a temporary spike.

Brown's projections about oil underestimated future oil production. Thus, prices and per capita supplies have not responded as sharply as he suggests. This case is a good illustration of forecasting a long-term future trend on a significant but short-term perturbation (Brown used oil prices in 1978–79) as opposed to using long-term trends (Simon and Kahn used data from the period 1946–82).

Fresh Water

Fresh water is an important input in agriculture and its scarcity could be a major constraint for agricultural production. Predictions about the future of fresh water resources again reflect at least two different ways of looking at the reality. One approach, used by Lester Brown, is to make predictions by extrapolating recent trends and leaving little room for people to adjust to the scarcity of the resource. According to Brown,

> . . . in the final quarter of this century, the lack of fresh water rather than land may be the principal constraint on efforts to expand world food output. Indeed, in the

Green Revolution countries, it is already the dominant constraint on increasing the area planted on high-yielding seeds. . . . Competition for water among countries with common river systems has become increasingly intense in the past two decades. (1974, 8)

On the other side, Simon and Kahn criticize views about water in Barney's *Global 2000 report* (1980–81):

In the previous decade or so, water experts have concluded that the "likelihood of the world running out of water is zero." The recent UN report of the World Environment, for example, tells us not to focus upon the ratio between physical water supply and use, as Global 2000 does nevertheless, and emphasizes making appropriate social and economic as well as technological choices. From this flows "cautious hope from improved methods of management." That is, an appropriate structure of property rights, institutions, and pricing systems, together with some modicum of wisdom in choosing among the technological options open to us, can provide water for our growing needs at reasonable cost indefinitely. (Simon and Kahn 1984, 24)

Lester Brown's position is based on estimates and projections to 2000 of fresh water availability and use made by Shiklomanov (1993). Although we have not been able to find actual observed figures to compare with Shiklomanov's projections, we found a more recent estimate of use of fresh water made by the State Hydrological Institute/UNESCO (1999), directed also by Shiklomanov, with projections to 2000. It is important to note that, according to Shiklomanov, the projections are not very accurate, especially because of the quality of the data. To evaluate the 1993 projections to 2000 we compare them with projections to 2000 published in 1999. We assume that the more recent forecast can be regarded as a better approximation of the actual figure. Thus, we constructed Table 10, which presents the projection error in the 1993 forecast to 2000. A positive value for this error implies that the earlier projection exceeded the more recent estimate of the total use of water.

As shown in Table 10, projections made in 1993 to 2000 are consistently and significantly higher than the 1999 to 2000 projections, implying that the 1993 projections used by Brown to support his conclusion have been adjusted downward by the original author, Shiklomanov.

Table 10—Projection errors in water use by activity

Water use[a]	1993/2000 (km^3/year)	1999/2000 (km^3/year)	Error (%)
Agriculture			
Withdrawal	3,250.0	2,605.0	24.8
Consumption	2,500.0	1,834.0	36.3
Industry			
Withdrawal	1,280.0	776.0	64.9
Consumption	117.0	87.9	33.1
Municipal supply			
Withdrawal	441.0	384.0	14.8
Consumption	64.5	52.8	22.2
Reservoirs			
Both	220.0	208.0	5.8
Total[b]			
Withdrawal	5,190.0	3,973.0	30.6
Consumption	2,900.0	2,182.0	32.9

Sources: Shiklomanov 1993, SHI/UNESCO 1999.
Notes: "Year 1/Year 2" in the column headings correspond to "publication year/projecting year."
[a] Withdrawal stands for total water withdrawal; consumption stands for irretrievable water loss.
[b] Total water use figures are rounded off.

Land

The fears about land availability as a constraint to feeding an increasing population can be traced as far back as Malthus's *Essays on population.* The debate is still about whether a finite resource such as land is or will become a constraint to meeting future food needs. Again, we chose the writings of Lester Brown to represent the thinking that it will be difficult to add additional agricultural land to increase food production.

There are essentially two ways of increasing the world food supply from conventional agriculture. One is to expand the area under cultivation. The other is to increase output on the existing cultivated area. From the beginning of agriculture until 1950, expanding the cultivated area was the major means of increasing the world's food supply. Since that time, raising output on the existing cultivated area has accounted for most of the increase. An estimated four fifths of the annual rise in the world food output achieved in the early seventies was due to the intensification of cultivation. . . . As human population growth has continued its steep ascent, the cropland per person has declined until today there is only one acre for each of us. (Brown 1974, 76)

On the other side, we have those who consider that yields can be substantially increased to compensate for the slowing growth of rates of land availability (Evans 1998). Clark (1970) represents the most optimistic view about the substantial possibilities to expand production on new lands:

There still persists among some people the extraordinarily erroneous idea that any further additions to the world's supply of agricultural land must be very limited. . . . poor soils can be improved out of recognition by cultivation and fertilization; and it is assumed that the world is willing to do this. . . . The potential agricultural area of the world, it is seen, could provide for the consumption, at these very high standards, of 35.1 billion people, or over 10 times the world's present population. (1970, 154–157)

Simon and Kahn address the issue that arable land may be decreasing by erosion, thus implying future constraints to food production. According to them,

soil erosion is not occurring at a dangerous pace in most parts of the United States, contrary to much recent publicity. In most areas topsoil is not being lost at a rate that makes broad changes in farming practices economical from either the private or public standpoint, though recent advances in tillage may change the picture somewhat. Regulating or subsidizing particular tillage practices portends greater social cost than benefit in the long run. (1984, 21)

To answer the question about agricultural land growth or contraction, we present FAO data (Table 11) showing the evolution of agricultural land by use from 1985 to 1998. If there is any trend, it seems to be that total agricultural area is increasing very slowly, while arable land is static. Of course, given population growth, per capita availability will, by definition, be declining, but this statistic by itself has little meaning.

In addition, in Table 12 we compare the projections of irrigated cropland presented by the Worldwatch Institute in the *State of the world, 1990* with actual data, and compute the projection error. The projection slightly overestimates the

Table 11—Agricultural area by use, 1985–98 ('000 million hectares)

	Agricultural area			
Year	**Total**	**Permanent crops**	**Permanent pasture**	**Arable land**
1985	4.81	0.11	3.34	1.37
1990	4.91	0.12	3.41	1.38
1995	4.93	0.13	3.42	1.38
1996	4.93	0.13	3.42	1.38
1997	4.93	0.13	3.42	1.38
1998	4.94	0.13	3.43	1.38

Source: FAOSTAT database (FAO 2001).

2000 figure by 2.8 percent. On the other hand, as shown in the table, the actual growth rates of land under irrigation are smoother than those projected, but in both cases the area of irrigated land has been growing at decreasing rates.

Again, actual data to 2000 substantiate neither a rosy picture of increased availability nor a pessimistic picture that land available for agriculture production is declining. Further, as argued by Evans, the real issue has to be sustaining or accelerating the rate of yield increases.

Fish

Fisheries are important because they represent a major additional source of food. The debate on fisheries is whether or not fish production can increase to keep pace with the increasing demand for food. Like previous projections, we note two polar positions. On the more pessimistic side, we have Lester Brown and Gerald Barney. According to Lester Brown in *Full house,*

. . . we expect that the seafood catch in 2030 will be roughly the same as in 1990. Uniformly good management could raise this somewhat, but equally likely is a continuation of the irresponsible management that is now managing so many fisheries. This means that the per capita seafood catch would drop from the historical peak of more than 19 kilograms per person in 1990 to 11 kilograms per person in 2030. The effect this will have on seafood prices deserves far more attention than that is getting. (Brown and Kane 1995, 189)

Table 12—Projection errors in world gross irrigated area, 1960–2000

Year	Actual total irrigated cropland (million ha)	Growth (%)	Projected per capita irrigated cropland (million ha)	Growth (%)	Error (%)
1960[a]	139	—	136	–	–2.2
1970	168	20.7	188	38.2	12.0
1980	210	25.0	236	25.5	12.5
1990	244	16.5	259	9.7	6.0
2000[a]	271	11.1	279	7.7	2.8

Sources: FAOSTAT database and Worldwatch Institute 1990.
Notes: An error with a negative sign indicates an underestimate.
[a] The actual value for 1960 was approximated with the 1961 value, and the 2000 value with the 1998 value.

Similar concerns can be observed in Barney's *Global 2000 report to the President.*

Unfortunately, the world harvest of fish is expected to rise little, if at all, by the year 2000. . . . The world catch of naturally produced fish leveled off in the 1970s at about 70 million metric tons [mmt] a year (60 million metric tons for marine fisheries, 10 million metric tons for fresh water species). Harvests of traditional fisheries are not likely to increase on a sustained basis. . . . It seems unlikely . . . that the generally accepted annual potential of 100 mmt of traditional marine species will be achieved on a sustained basis. It is more likely that the potential is nearer the present catch, or about 60 mmt. (1980–81, 105)

On the "optimistic" side, Wise in his chapter about the future of food from the sea in Simon and Kahn's *The resourceful earth* (1984) gives a different view about the future of fisheries.

What then can we say realistically about the prospects of increased food supply from the sea by the year 2000 and beyond?

Production will probably continue to grow for the next 20 years at close to the present rates, which are equal to, or higher than, the rate of human population growth. It will reach the predicted 100–120 million tons of conventional species around the turn of the century.

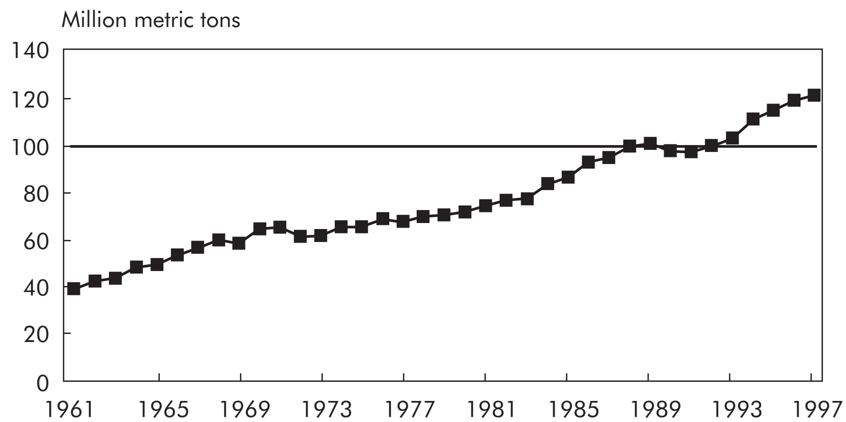
If practical ways are found to fish the Antarctic krill and to turn it into commercial products, total production may well double. Other unconventional species may make large contributions, and the possibility of discovering ways to utilize species now used for fish meal directly as human food offers the chance of yet another large increase. Elimination of discards at sea, and more efficient processing with less spoilage and wastage, could lead to substantial increases in food production even without increases in fishing. It is evident that tripling or even quadrupling the present level of production of food from marine sources before the end of the twenty-first century is a reasonable possibility. (1984, 123)

To address this issue we checked actual data to determine whether a catch of 100 million metric tons is a ceiling for the system. We have constructed Figure 5 based on the most recent data from FAOSTAT about fish catch for the 1961–97 period. It is clear from the graph that 100 million metric tons is not a limit; on the contrary, total catch has surpassed that limit and kept growing. This, at least until 2000, lends support to a more optimistic view than that expressed by Barney.

Poverty

Poverty is a major constraint to food security because it limits access to food and therefore limits the demand for food. The model presented in Chapter 2 forecast total consumption/demand as per capita consumption times population. The model assumes that all the population can afford the average per capita consumption, since it assumes that everybody receives the average per capita income. In reality, we know that is not true and that income distribution is a relevant issue. Furthermore, groups with different income levels consume different combinations of goods, therefore the same commodity probably has a different income elasticity for each income group.

Figure 5—World total fish catch, 1961–97



Although it is theoretically feasible to incorporate the distribution of income into consumption estimation, empirically it is quite challenging because of the lack of adequate data. On the other hand, estimating the number of poor (understanding this group as those who cannot afford a targeted consumption bundle) allows us to broaden our view, normally based only on average consumption, about the part of aggregate demand that is under more risk of food insecurity.

World poverty projections are sporadically provided by the World Bank, through its *World development reports*. In Appendix 4, we review the methodology for forecasting poverty based on the work of Anand and Kanbur (1991). They analyzed the World Bank methodology used to project the number of absolute poor to 2000.

The World Bank presented baseline projections and alternative scenarios for the level of absolute poverty in 2000 in its *World development reports* of 1978, 1979, and 1990 (World Bank 1979, 1980, 1991). In all the cases the projections showed a decrease in the number of poor from a figure of 770 million in 1975 to a range between 260 million (projected in 1978 assuming a high GNP growth rate) and 710 million (projected in 1979 assuming a low GNP growth rate) in the year 2000.

In Table 13 we compare the World Bank projections of absolute poverty to the year 2000 with the most recent estimate of actual poverty reported in the *World development report 2000* (World Bank 2001). We also show how that number has evolved since 1975, using an income of US$1 per day as the poverty line. We should, however, urge caution in making too much of year-to-year comparisons because country coverage has changed over time.

The differences between the projections and the observed figures are substantial. The discrepancy is not only at the world level but also shows up when regions are considered. It may be that the 1978 and 1979 projections were biased because the GNP per capita projections used could not have anticipated the economic downturn in the1980s. However, the same explanation is not satisfactory for the 1990 projections, which underestimated poverty by almost 375 million, a projection error of –31 percent.

However, it is not clear from the text that accompanies the projections whether they should be considered as normative simulations (that is, the results from a reduction in the number of poor *if* appropriate national and international policies are applied), or they are meant to represent the most likely scenario, and therefore could be considered as projections. The confusion can be seen in the following paragraph from the 1990 *World development report:*

> The projections in this chapter are intended to show what might be achieved *if the recommended strategy*

Table 13—World Bank projections of number of absolute poor in developing countries to 2000 (million)

	Actual data							Simulated results to 2000					
								1978 simulation		1979 simulation			
	1975	1985	1987	1990	1993	1996	1998[a]	Baseline	Alternative scenario	Baseline	High-growth scenario	Low-growth scenario	1990 simulation
Developing countries	770	1,125	1,183	1,276	1,304	1,191	1,199	600	260	600	470	710	825
By income level													
Low-income countries	630	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	540	260	440	340	520	n.a.
Middle-income countries	140	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	60	. . .	160	130	190	n.a.
By region													
Sub-Saharan Africa	n.a.	180	217	242	273	289	290	n.a.	n.a.	n.a.	n.a.	n.a.	265
East Asia	n.a.	280	418	452	432	265	278	n.a.	n.a.	n.a.	n.a.	n.a.	70
Of which China	n.a.	210	303	360	348	210	213	n.a.	n.a.	n.a.	n.a.	n.a.	35
South Asia	n.a.	525	474	495	505	532	522	n.a.	n.a.	n.a.	n.a.	n.a.	365
Latin America and the Caribbean	n.a.	75	64	74	71	76	78	n.a.	n.a.	n.a.	n.a.	n.a.	60
Others[b]	n.a.	65	10	13	23	29	30	n.a.	n.a.	n.a.	n.a.	n.a.	65

Sources: World Bank 1979, 1980, 1991.

Notes: . . . = negligible; n.a. = not available.

[a] Preliminary.

[b] Residual category that includes Eastern Europe, Central Asia, the Middle East, North Africa, and other European countries.

gained wider acceptance. They do not assume that all countries will fully adopt the strategy. They do assume that where it is in place, countries will at least move in that direction. More specific details on domestic policy are discussed below, region by region. The projections are based on relatively favorable assumptions about global economic conditions described in chapter 1—growth in industrial countries of about 3 percent a year, falling real interest rates, rising commodity prices over the decade, and successful conclusion to the trade talks at the Uruguay Round of the GATT and other forums. This is the *Report's assessment of the most likely outcome.* But fear remains that the problems of the 1980s will persist. *The projections should be interpreted, therefore, as indicating what can reasonably be expected.* It would be possible to do somewhat better—or much worse. (World Bank 1991, 138; emphasis added)

The conclusion must be that the models used to project poverty seem weak. They are based on unreliable data and are conditional upon methodological assumptions about the functional forms used, projections of population and income, the transformation of income distributions from quintiles to deciles, and the computations of the population under the poverty line.

Some improvement in projections could come from the methodological recommendations suggested by Anand and Kanbur (1991). However, the data needed are substantial. Also needed are better income distribution data, based on surveys in developing countries, which also provide information about how consumption patterns change with changes in the income distribution.

5. Conclusions, Conjectures, and Closing Comments

One final type of prediction deserves mention—*hindsight prediction*—because it (and it alone) is 100 percent successful. It is the prediction of an event after it has already occurred. All that is necessary to apply the method are the ability to make ambiguous (or even contradictory) remarks and a talent for selective amnesia. (Irwin D. J. Bross, 1959, 38)

Our conclusions, in and of themselves, are limited. However, we also make some conjectures about a broader set of propositions before closing with some brief comments. We begin with conclusions about the validity of formal, quantitative projection models. We then make some conjectures about projection models compared with more qualitative predictions. It is our conclusion that many people making "forecasts" of future negative outcomes are really engaging in scenario analysis, not prognostication. We conjecture why they might do this. If most of the "doomsday" predictors are engaging in scenario analysis, then they hope their predictions will not come true. This, of course, begs the question of what they contribute to the policy debate if we all know their "predictions" are scenarios designed to move the debate in a particular direction.

On the Accuracy (Validation) of Projections

Conclusions from our analysis of formal, quantitative projection models are limited if conclusions are defined as only those that meet the requirements of formal statistical significance. We can however reaffirm what others have found:

1. Projections with 5–10 year horizons are more accurate than those for longer periods (15–30 years). Given that most of the projection models reviewed develop their forecast using historical data, trends are least likely to change in the short run.
2. Projections are more accurate for aggregations of components—regions/countries, commodities—than for the component parts themselves. Projections of global supply of and demand for grains are more accurate than projections for wheat in North America or the United States.
3. There are significant differences between projections for large versus small countries, with those for small countries generally being less accurate.
4. There are significant variations between regional projections in terms of their accuracy. The most erratic projections are for Sub-Saharan Africa, a region made up of many small countries and often characterized as having inadequate data. This confirms that the quality of data is important.
5. Given that most global food projection models are recursive, nonspatial, price endogenous trade models, differences in model specification seem to explain fewer of the differences in the performance of models than do choices about data sources, base years, the nature of commodity and country aggregations, and methods of including domestic policy. Thus, it is model construction decisions rather than econometric specifications that lead to differences.
6. Finally it seems clear that models using past growth rates of a range of critical variables to predict the future do better than those

that, in an ad hoc way, insert significant hypothesized changes in one or a limited set of critical parameters. There is an interesting example in the population projection business. Iowa State University sponsored a conference in 1967 on "Alternatives for balancing world food production needs." They invited two demographic analyses. The first, by Dudley Kirk and Gavin Jones (see Iowa State University 1967) basically projected population to 2000 (33 years hence) using trend data of birth rates, death rates, and migration. This was the standard approach and their projected population for 2000 was 6.1 billion people. The second paper, by Donald Bogue (see Iowa State University 1967) argued persuasively that things were going to change radically in the next 30 years and that the past would be a bad predictor. He inserted his conjectures about birth and death rates and concluded that world population in 2000 would be just 4.5 billion. A check of actual numbers shows that world population reached 6 billion in late 1999 and that it had exceeded 4.5 billion by 1982. This seems to be the major difference between traditional projection models and more qualitative prediction models. The latter project major recent changes in a few variables, whereas the former average these short-term perturbations into longer range trends.

Some additional hypotheses were tested, for which the conclusions are less clear. First, we hypothesized that projections of global demand would be more accurate because all the models used basically the same exogenous source for population projections, thus leaving only two variables—per capita income and income elasticity—to be generated (in some cases, only the elasticity). On the supply side, in contrast, three trend variables needed to be set within the model: land use, yield, and intensity. The evidence on this is mixed at best. During some periods, models appear to do better on demand projections, whereas during other periods production projections are better. None of the models analyzed was consistently better at projecting one side of the equation compared with the other.

Secondly, we expected that practice would lead in the direction of perfection, that is, those in the business longer would improve over time. Although there appears to be some support for this proposition in the recurring FAO short-term commodity projections, there is less support elsewhere.

In concluding this brief section, we raise a troubling (for us at least) issue. If one looks only at global outcomes, most of the formal models do very well in the 5- to 10-year projection range. But when they are disaggregated into component regions/countries or commodities, the accuracy deteriorates, in some cases substantially. Yet the most frequent use made of global models appears to be to evaluate countries or regions, not the global outcomes, as for example in IFPRI's detailed analysis of China. Should we declare a model valid when the global projection is within ±5 percent, but when some of the components are off by 30–50 percent in opposite directions? Our conclusion is that this characteristic of most of the models reviewed should raise serious questions about the validity of the overall model.

Models versus Ad Hoc Qualitative Predictions

Whereas in the previous section we were discussing how close projection models came to the actual outcomes, in this section we look at more ad hoc qualitative predictions. The first obvious conclusion is that these "qualitative" predictions of global negative outcomes (for example, massive famines) find limited support in actual outcomes. There have been no significant global or regional famines since World War II induced by persistent supply shortfalls. Thus the most stark predictions of Ehrlich, the Paddock brothers, and the Club of Rome fortunately never occurred. The persistent predictions by Lester Brown and his colleagues at the Worldwatch Institute of imminent food shortages and rising long-term real food prices have not yet come true. Price spikes in the 1970s and 1990s were quickly deflated by expanded production, and long-term real grain prices resumed their 100-year downward trend. Although some authors might argue that their predictions are mainly for years yet to come, there is no evidence of emerging trends pointing in the direction of significant rises in real food prices.

Why then do models seem to do better? Here we provide some possible answers:

1. Building a model, which can be solved, requires consistent and clearly defined relations among all variables. Ad hoc models have no similar constraint.
2. Estimating models based on trends has two advantages. First, it transfers to the future the structure of interrelationships among variables, which was consistent in the past. Second, it builds in many complex and not fully specified cross-relationships among variables. Ad hoc predictions have no built-in ways to check consistency, prevent double counting, prevent arbitrary weighting of a particular variable, or force a convergence to a stable equilibrium.
3. Modeling allows the simultaneous and managed interaction of many variables and the maintenance of consistent weights.
4. Clearly, systems of equations, managed in a computer program, allow the organized and consistent treatment of massive numbers of variables and large amounts of data. Ad hoc, partial, qualitative approaches, even when used by the most brilliant minds, cannot do this consistently.
5. Most models are explicitly based on tested theoretical or conceptual underpinning. Ad hoc models, even if computer simulated, can perform poorly (see Nordhaus's critique of the Club of Rome models, 1973). Although qualitative predictions, such as those of Lester Brown, Paul Ehrlich, and others, must be based on the conceptual framework they use to analyze complex scenarios, these "implicit models" are seldom formalized and therefore cannot be replicated.
6. Most of the currently used projection models are equilibrium models, which, by construction, implies continuous adjustment to produce consistent stable conclusions. Ad hoc approaches involve extrapolation of particular variables of interest and do not have equilibrating factors such as prices and elasticities built in.
7. Finally, let it be noted that formal modelers eschew the very long run because they understand how small initial errors can exponentially blow up a model as the timeframe lengthens. Longer-term predictors on the other hand seem to be driven by exponential explosions and use them to make their case.

Projections, Predictions, and Scenarios

There is perhaps a more basic question that needs to be raised. Are we really evaluating projections of an expected (positive) outcome in the future (as we clearly are in population projections)? Or are people making conditional forecasts of possible future outcomes, based on alternative assumptions about crucial exogenous and endogenous variables (for example, income growth or yield growth)?

It is likely that many people engage in futurology to explore the consequences of business as usual compared with alternative assumptions about income growth or water availability, for example. Clearly, most of the USDA "projections" are explicitly scenarios based on alternative assumptions about income or trade. People also engage in scenario analyses to explore what would be required to bring about a desired (normative) future result. The first three *World food surveys* by FAO are clearly of this type. In addition, models and ad hoc predictions provide vehicles for exploring the sensitivity of potential outcomes to particular parameters. The IFPRI IMPACT model (Rosegrant, Agcaoili-Sombilla, and Perez 1995) has productivity growth as a function of research expenditure. Thus IFPRI can "explore" (not project) the consequences of significant reductions in research investments. Finally, models allow us to test the capacity of systems to withstand shocks, and recursive models allow us to observe the path of adjustments to those shocks.

If most predictions, and many projections, are indeed conditional forecasts of possible future outcomes (scenarios), then they are by definition *normative* models (implicitly or explicitly). They are not *positive* modeling attempts. The implication is that attempting to validate these models by comparing projected outcomes with actual outcomes is inappropriate. A more appropriate test may be whether or not the analysis enriched the policy debate. In fact, "failure to come true" could be considered by the authors to be a sign of success because an undesirable outcome was avoided.

Thus we conclude that "failure to come true" is not always a negative conclusion. Quantitative projections are useful in forecasting actual outcomes given a continuation of past trends and should be judged as we have done in this paper, that is, by how close they came to actual numbers. Others who explicitly model scenarios and those who predict negative outcomes if action is not taken (scenarios) also can contribute to an improved future. They may well alert policymakers and citizens to major issues that need attention. This conclusion is similar to that of David Wilson in his interesting and provocative book *The history of the future.*

> The whole idea of forecasting the future is fraught with so many problems and perils that it is not worth pursuing. Still, the idea of speculating about where we might be going, how we feel and think about such directions, and what we might do to change or continue our course is not only healthy but essential to our survival and development as a species. It is in this spirit, together with a sense of humility, an awareness of complexity, a deep distrust for utopian solutions, and a skeptical attitude towards apocalyptic scenarios, that we should, on my view, approach the unknown world of the future. (Wilson 2000, 258)

Appendix 1. Brief Description of Food Projection Models

Table 14—World food projections: Summary

Agency	Year	Title	Model type	Demand	Supply	Trade	Closure	Estimation	Projection year
FAO	1962	*Agricultural commodities: projections for 1970. Special supplement*	Separate projection of supply and demand balances	Demand depends on population growth, income, and income elasticity of per capita consumption	Projections made extrapolating growth rates for land, yields, and livestock numbers	No trade is projected; difference between supply and demand gives idea of trade pattern	The model is not closed and assumes constant prices	Estimates income elasticity of per capita demand	1970
USDA	1964	*World food budget*	Nutritional requirements model, similar to FAO's World Food Surveys	Based on projections of population and per capita consumption	Projected extrapolating trends of 1954–63	Trade is not considered	The model is not closed and assumes constant prices		1970
FAO	1967	*Agricultural commodities: projections for 1975 and 1985*	Separate projection of supply and demand balances	Demand depends on population growth, income, and income elasticity of per capita consumption	Projections made extrapolating growth rates for land, yields, and livestock numbers	No trade is projected; difference between supply and demand gives idea of trade pattern	The model is not closed and assumes constant prices	Estimates income elasticity of per capita demand	1975 and 1985
OECD	1967	*The food problem of developing countries* (Kristensen 1967)	Exogenous projections of demand and supply	Projected based on population, level of income, and the income elasticity of demand	Projected assuming a growth rate based on a discussion of expected production conditions	No projections of trade	The model is not closed and assumes constant prices	Elasticities are taken from FAO 1962	1975 and 1985 Projections for developing countries by region
USDA	1967	*World food situation: prospects for the world grain production, consumption, and trade* (Abel and Rojko 1967)	Model of production, demand, and trade of grains	Demand depends on population growth, income, and income elasticity	Production is projected based on assumed growth rates	Trade is projected as a residual of demand and supply	The model is not closed and assumes constant prices	Elasticities and constant growth rates estimated based on historical data	1970 and 1980
OECD	1968	*Agricultural projections for 1975 and 1985: country studies*	Exogenous projections of demand and supply	Projected based on population, level of income, and the income elasticity of demand	Projected assuming a growth rate based on a discussion of expected production conditions	No projections of trade	The model is not closed and assumes constant prices	Estimates income elasticities to estimate consumption	1975–1985 Agricultural projections for developed countries

FAO	1971	*Agricultural commodity projections, 1970–1980*	Commodity and trade division, considering alternative scenarios for income and population growth	Demand depends on population growth, income, and income elasticity of per capita consumption	Projections made extrapolating growth rates for land, yields, and livestock numbers	No trade is projected; difference between supply and demand gives idea of trade pattern	The model is not closed and assumes constant prices	Estimate income elasticity of per capita demand	1970–1980
USDA	1971	*World demand prospects for grain in 1980, with emphasis on trade by less developed countries* (Rojko, Urban, and Na¨ive 1971)	Two models: (1) a simultaneous model for the world grain economy; (2) a spatial world trade linear programming model that uses model (1)	Linear demand that depends on consumer prices (own and cross), population, and income	Linear supply that depends on producer price, fertilizer use, and technology (the last two are exogenous)	Only model (2) considers trade. It predicts a spatial pattern minimizing transportation costs	Model (1) closes equilibrating prices between supply and demand. Model (2) closes equilibrating trade flows and prices in regions	Some of the demand relationships are estimated econometrically; supply relations are from other studies	1980 Countries are divided into producers and consumers
Iowa State University	1973	*World food production, demand and trade* (Blakeslee, Heady, and Framingham 1973)	Spatial world trade model	Consumption based on population and income elasticities	Projected based on trend equations for land and yields	Predicts spatial patterns of trade	Minimizes transportation cost subject to availability and the requirements of the regions. Availabilities and requirements are exogenously projected	Equation by equation	1985 and 2000 Only cereals are in trade model
IFPRI	1977	*Food needs of developing countries: projections of production and consumption to 1990*	Trend projections of supply and demand	Projected for high and low income growth, and only population growth. Constant per capita consumption at 1969–71 levels	Production is projected based on historical trend growth	No trade is considered	The model is not closed and assumes constant prices	Parameters estimated based on historical data	1990 Only developing countries. Variables expressed in cereal equivalents
USDA	1978	*Alternative futures for world food in 1985* (Rojko et al. 1978)	Nonspatial trade model for grains, oil seeds, and livestock (GOL). It is a simultaneous equation model	Depends on own and cross prices, per capita income, and tastes	Production is estimated as land times yields (but yields are exogenous). Livestock production depends on prices and productivity	Predicts net trade but no destination	The model closes by equaling total exports and imports. Prices and quantities are adjusted	Relies on elasticity estimates from other works	1985

continued

Table 14—World food projections: Summary *(continued)*

Agency	Year	Title	Model type	Demand	Supply	Trade	Closure	Estimation	Projection year
FAO	1979	*Agricultural commodity projections, 1975–1985*	Nonspatial world commodity trade model	Demand depends in the first stage only on income and population growth; in the second stage prices are relaxed to reduce the gap between supply and demand	Production was projected based as the product of land and yield. Land was projected based on time trend, real price, and lagged area. Yields were forecast using a time-series model. Slaughter rates were projected using a time-series model but the number of animals modeled in order to simulate observed cycles	In the first stage, net import requirements and net export availabilities were projected assuming constant relative prices. In the second stage, prices were allowed to change in order to obtain a more realistic indication of trends in international trade	Projections are made first under the assumption of constant prices and based on income projections; then prices are relaxed to reduce the gap between supply and demand	Elasticities were estimated based on FAO balances data	1985 The projections from the model can be considered a first stage, since they were adjusted to take into account other factors such as commodity policies and biological and physical constraints
University of Amsterdam	1979	*MOIRA: Model of International Relations in Agriculture* (Linnemann et al. 1979)	Nonspatial world commodity trade model	Depends on own and cross prices, per capita income, and tastes. Also considers income distribution	Production is estimated as land times yields (but yields are exogenous). Livestock production depends on prices and productivity	Predicts net trade but no trade source or destination	Prices are flexible. They close the model	Elasticities are estimated	The model was not used for projections
IIASA	1981	*Food for all in a sustainable world: the IIASA food and agriculture program* (Parikh and Rabar 1981)	Several agricultural national models linked by trade	Demand at the national levels is derived micro-economically	Production at the national levels is derived micro-economically. It includes adaptive expectations	Predicts net trade but no destination, as in all the nonspatial world trade models	The model closes at the international level, adding up to zero all the excesses of demand and determining international prices for selected commodities assumed tradables	National models are estimated econometrically	1990, 2000 Constructed more as a tool than for continuous analysis
IFPRI	1986	*Food in the third world: past trends and projections to 2000* (Paulino 1986)	Trend projections of supply, demand, exports and imports	Demand depends on population growth, income, and income elasticity of per capita consumption	Production is projected based on historical trend growth	Projection of exports and imports based on historical trend	The model is not closed and assumes constant prices	Estimation of income elasticities for each country	2000 Only developing countries. Variables expressed in cereal equivalents

World Bank and Michigan State University	1987	*The international agricultural trade consortium: agricultural trade modeling, the state of practice and research issues* (Liu and Seeley 1987)/*The world food outlook* (Mitchell et al. 1997)	Nonspatial world wheat, coarse grain, and soybeans model	For importers, domestic consumption is estimated as a residual. For exporters, it is estimated as a function of income and prices. Year-end stocks are estimated as a share of consumption and prices	Production is obtained as the product of harvested area and yields. Area harvested is projected in two stages: (1) total area harvested and (2) distribution of area among crops according to lagged revenue. Yields depend on lagged crop prices, fertilizer prices, area planted to high-yielding varieties, and linear trend representing technology	Imports depend on per capita imports and population. Per capita imports depend on income, domestic supply, and border prices in real terms. Net exports of exporting economies are a residual from supply available (harvest plus initial stocks) minus consumption	The model is closed, equilibrating prices. Grain prices are modeled as single grain prices and are expressed as border prices in real terms by converting to domestic currency and deflating by each economy's consumer price index	The model is estimated by OLS. The latest version was estimated using data for the 1960–88 period	2010 The model has been modified since its original formulation in 1985
FAPRI (Iowa State)	1986	*The FAPRI modeling system at CARD: a documentation summary, 1986* (Devadoss et al. 1989)	Nonspatial world commodity trade model (considers only major participants)	Total demand is projected based on income and prices	Supply depends on prices	Equilibrium of total flows of trade	Prices and quantities are endogenous	Elasticities are from other studies	1990 Includes projections only of wheat, feed grains, and soybeans
Tyers and Anderson	1992	*Disarray in world food markets: a quantitative assessment*	Nonspatial world commodity trade model. There are two versions of the model: static and dynamic (this can be stochastic or deterministic—the former considers random shocks and the results are the average of a number of runs)	Consumption demand depends on population growth, income, and prices (own and cross). Feed demand is tied to production through input–output coefficients. Demand for stocks considers private (based on expected profits) and public (policy variable) components	Production is modeled based on partial adjustment. Technology is approximated based on a trend. Yields are assumed subject to random shocks	Trade is projected as a residual of demand and supply (excesses). World prices are related to domestic consumer and producer prices but including policy coefficients, exchange rates, and trade cost factors	Sum of excesses of demand is equal to zero (no global excesses of demand)	The model considers parameters from other studies where available and some own estimations	2000 The model is used to analyze different policy scenarios. It does not present a baseline projection

continued

Table 14—World food projections: Summary *(continued)*

Agency	Year	Title	Model type	Demand	Supply	Trade	Closure	Estimation	Projection year
FAO World Food Model	1993	*Agriculture: toward 2010*	Nonspatial world commodity trade model. The results of the model are compared with trend projections by country and commodity. The final projection comes from the judgments of different experts	In the World Food Model, per capita commodity demand depends on per capita income, and own commodity price and cross prices. In the latest version, prices include parameters to estimate the effect of consumption policies	Production is projected as area harvested times yield for crops and number of animals slaughtered (or producing milk) times yield for livestock (or dairy). The variables depend on producer prices and policy variables	Equilibrium of total flows of trade	Prices close the model. World prices imperfectly influence domestic prices because of "policy wedges" that depend on the country and change to generate different scenarios	The model takes elasticities from past versions	2010 It is important to note that the results from the model are not the final forecasts. The results go through a process of judgment by experts
IFPRI (Impact Model)	1995	*Global food projections to 2020: implications for investment* (Rosegrant, Agcaoili-Sombilla, and Perez 1995)	Nonspatial world commodity trade model. The model is recursive	Total demand for the commodity is the sum of demand for food, feed, and other uses. The demand for food is the product of per capita food demand (which depends on income, own and cross prices) times population. Demand for feed is a derived demand that depends on feed prices and output. Other demand is assumed at the same growth of the other demand components. The model does not consider demand for stocks separately	Production is the product of area times yield or number of animals slaughtered times yield. Area and yield of crops depend on producer prices, input prices, and growth (yield growth is computed exogenously depending on a number of factors). Slaughter of livestock depends on producer prices and input prices, and yield is assumed to grow exogenously	Equilibrium of total flows of trade. The adding up of net excesses of demand has to be equal to zero	Prices close the model. World prices imperfectly influence domestic prices because of "policy wedges" that depend on the country. Consumer prices include assumptions of CSE and producer prices about PSE	The model takes elasticities from other studies	2020 The main contribution of the model is to consider a separate model for yield growth depending on market and non-market factors (therefore R&D investment can be included)

Note: CSE = consumer subsidy equivalent; PSE = producer subsidy equivalent.

Appendix 2. Overview of Models Used to Project Food Situation

The models selected for evaluation fall into two categories: (1) trend projection models and (2) world trade models.

Trend projection models forecast the gap between consumption and production for a country or region, assuming that relative prices over time are constant. Both components, production and consumption, are projected separately according to their historical trend. In the case of production, which is expressed as the product of land area and yields, projections are made by applying their historical growth rates to each component. In the case of consumption, this is expressed as the product of per capita consumption and population. Whereas population projections are taken from elsewhere (usually, United Nations projections), per capita consumption is projected based on its association with (that is, as a function of) per capita income. Projections of per capita income also can be taken from elsewhere (for instance, from the International Monetary Fund or from the World Bank), or can be projected by applying its own historical growth rate to baseline data. Then, assuming an income elasticity (that is, a coefficient that measures how much of the increase in income is spent on food), it is possible to project per capita consumption and then, by multiplying per capita consumption and population, to obtain total consumption. We found two types of trend projection models in the literature. In *pure trend projection models* (which encompass most of the models we found in this category), the difference between projected consumption and projected production generates a gap, which if positive indicates a shortage of the commodity or if negative a surplus of the commodity. The *extended trend projection models* start by generating the projected gap, as in the pure trend models, and then use this information to build a spatial trade model to distribute the surpluses or deficits among regions/countries.

The second category includes world trade models, which allow for the interaction among countries and regions through trade. Each region in this model is characterized by a demand and a supply function, which relate quantities to prices. Demand is shifted by changes in income and in population and supply is shifted by changes in yields and land area. The difference between supply and demand in each region generates an excess of supply or demand for the commodity, which, when aggregated into a world market, allows the determination of a market clearing world price (that is, at the equilibrium world price the total amount of required imports will be equal to the total amount of available exports). Because of this feature, these models are called *flexible prices* or *price endogenous* models. Therefore these models not only predict trade volumes but also predict commodity prices. All the current models used to project the world food situation fall into this category.

We will briefly review two types of world trade models: *nonspatial* and *spatial* world trade models. The nonspatial models predict only the net trade position of the country (say, net importer or exporter) without specifying import sources or export destinations; the spatial models make two predictions, that is, the region's net trade and trade flows by sources and destinations. It is important to note that these are not the only types of agricultural trade models but are the types commonly used for projecting the food situation. A specific survey of agricultural trade models can be found in Thompson (1981). In addition, in Appendix 1 we present a summary table with a brief description of models and projections.

Trend Projection Models

In this category we consider models that make projections of consumption and production based on the historical growth rates. Both consumption and production are independently projected without allowing for interaction between them. The final output of this type of model is the food gap (positive if there is a deficit of the commodity or negative if there is a surplus). We differentiate between two types of models: *pure trend projection models,* which follow the previous description, and the *extended trend projection models,* which include a second stage in which they analyze how to distribute commodity surpluses and deficits among regions through trade.

Pure Trend Projection Models

This subcategory encompasses most of the trend projection models produced from the early 1960s to the mid-1980s, such as FAO's projections from the 1960s to early 1980s, IFPRI's 1977 and 1986 projections, the OECD's 1960s projections, and USDA's 1960s projections.

Equation (1) represents the final output of this type of model, that is the "food gap" or "gap," defined as the difference between consumption and production. The gap can be for a specific commodity (for example, wheat) or for a group of commodities (for example, cereals or food).

$$\begin{aligned} Gap_{i,j,t} &= \text{Consumption} - \text{Production} \\ &= Q^{pc}_{i,j,t}(INC^{pc}_{i,t}, \eta_{i,j,t}) \times POP_{i,t} - AC_{i,j,t}(t) \times YC_{i,j,t} \quad (1) \end{aligned}$$

The sub-indices *i, j, t* denote the country, the commodity, and the year, while the supra-index "pc" stands for per capita. The commodity consumption is expressed as the product of the per capita consumption (that is, $Q^{pc}_{i,j,t}$) and the population (that is, $POP_{i,t}$). In these models, per capita consumption varies (in the form of a function) according to two components: the per capita income, $INC^{pc}_{i,j,t}$ and the income elasticity (that is, a coefficient that indicates the portion of an increase of 1 percent in the per capita income is destined to consumption).

Per capita income in these models is projected either by applying the observed historical growth rate to a starting per capita income or by taking projections made by another agency, such as the International Monetary Fund or the World Bank. It is important to point out that, if the income per capita is projected using trend techniques, the results are highly sensitive to the choice of the initial point (that is, starting period) and to the assumed growth rate for the variable, because lower or higher than normal initial values or too low or too high growth rates would produce deviations from the base income per capita that tend to increase substantially over time.

The income elasticity, $\eta_{i,j,t}$, can change *by country* (for example, we expect income elasticity to be lower for developed countries than for developing countries, because developing countries spend a higher proportion of the increase of their per capita income on food than do developed countries), can change *by commodity* (for example, not all the commodities have the same importance for all the countries; it depends on their specific consumption bundles—for instance, the elasticity for rice should be lower in some countries than the elasticity for wheat), and also can change *with time* (for example, countries' consumption evolves over time and the importance of some commodities increases or decreases).

Population is assumed exogenous. It is customary to take the most likely projection scenario from the agencies that prepare population projections, such as the United Nations (the U.N. medium-variant population projection is the most common choice), the U.S. Department of Commerce (Census Bureau), or the World Bank.

Production in trend models is represented by the product of two components ($AC_{i,j,t}$), which stands for the harvested area (in the case of crop production), or by the number of slaughtered animals (in the case of meat production), or by the number of animals producing milk, times the appropriate yield ($YC_{i,j,t}$). This yield can be a crop yield per unit of land, meat yield per animal slaughtered, or quantity of milk per animal. The projection of total production is then made by projecting each component based on its historical trend and just multiplying the projected land (or animals in the case of livestock) and yields.

It is important to note that, in these types of models, there is no interaction between the consumption and production of the commodity. For instance, according to economic theory, one would expect that, if consumption exceeds production, price would tend to rise, increasing production and constraining demand. In these models, since prices are assumed constant, growing exogenous variables (that is, population and per capita income) could result in a gap that tends to grow unbounded over time.

Owing to the sensitivity of the model to the starting point and to the assumed growth rates for consumption and production, agencies normally present additional projection scenarios, typically based on different growth rates of per capita income, such as low and high per capita income growth. In addition, they might present other scenarios of a normative character, such as the required growth to reach a targeted food security goal (for example, IFPRI's models).

The same methodology used to project production and consumption can be applied to the projection of trade (that is, the projection of imports and exports). For instance, IFPRI (Paulino 1986) projected trade based on its historical trend, and included the result as part of the gap calculation (for example, imports are part of the total supply of the commodity in the country and exports reduce the amount of commodity available in the country for consumption). It is important to note that the application of the methodology to exports and imports may produce acceptable results only in cases where the country is a typical net importer or exporter of the commodity. However, if the country is on the margin of self-sufficiency and is switching between trade positions over time (that is, from importer to exporter and vice versa), then this methodology will perform less well.

Extended Trend Projection Models

Under this category we include the model by Blakeslee, Heady, and Framingham (1973), which was used to project production, demand, and trade for 1975, 1985, and 2000. This model is a hybrid between the described trend projection models and the spatial world commodity models, which are models that explain the geographical (that is, spatial) pattern observed in trade.

Projections in this model are built using a two-stage procedure. In the first stage, commodity consumption and production are projected, as in the trend projection models, producing the food gap (recall that the gap can be positive if the country requires more commodity or negative if the country possesses the commodity in excess). Blakeslee, Heady, and Framingham projected the production and consumption of cereals, raw sugar, root crops, pulses, fruits and vegetables, oil crops, meat, milk, and eggs. The second stage used a spatial trade model formulated only for cereals, and taking as input the cereal requirements and surpluses estimated for each country in the first stage.

The spatial trade model is an optimization model intended to compute the best possible set of trade flows (that is, imports and exports) among countries or regions, in such a way that the total cost of transporting the commodity from a region with commodity surplus to a region with commodity deficit is the minimum possible. Transportation costs are shipping costs (which normally depend on the distance between two locations), insurance, and freight. The Blakeslee et al. model looks in addition for the set of trade flows that generates the minimum total cost of production of the commodity destined for export and domestic consumption. It also considers the cost of expanding the production capacity. The previous problem (that is, the optimal trade flow) is solved considering the requirements and availability of resources to produce fertilizers.

World Commodity Trade Models

The essential characteristic of these models is that commodity prices and trade volumes are determined within the model and all the regions in the model are interconnected. In some cases, the models also present interconnections among commodities through the cross price elasticities, allowing for substitution, for instance, between different grains.

The impetus for building multi-region price endogenous models to forecast the world food situation came from the instability of commodity prices experienced during the early 1970s. The sudden rise in commodity prices, on one side, made the assumption of constant relative prices inadequate for projection purposes, and, on the other side, made commodity prices an interesting variable to be forecast within the models. In the world trade models, domestic prices are linked in a perfect or imperfect way to international prices, depending on whether or not the existence of border policy measures (such as tariffs or quotas) or domestic policies (such as price supports) influences the transmission of international prices.

The world trade models used for projection of production and consumption fall into two categories: *nonspatial* and *spatial* trade models. For other types of agricultural trade models see Thompson (1981). Nonspatial trade models predict the net trade position of the region but not the flow of trade (the source of imports or the destination of exports). Spatial trade models predict the source and destination of trade flows as well.

We will briefly review only the nonspatial and spatial trade models, because of their importance in forecasting the world food situation. For references about market share models, see Thompson (1981).

World Nonspatial Trade Models

This category includes all the current models used for projecting commodity balances, prices, and trade. Examples are USDA's GOL model (Rojko et al. 1978), the different versions of FAO's World Food Model (see Yanagishima 2000 for a recent description of the model), IFPRI's IMPACT model (see Rosegrant, Agcaoili-Sombilla, and Perez 1995), FAPRI's commodity models (see Meyers, Devadoss, and Helmar 1986), the IIASA World Agricultural Model (Parikh and Rabar 1981), the Free University of Amsterdam's Model of International Relations in Agriculture (MOIRA) (Linnemann et al. 1979), and the World Bank model (Mitchell, Ingco, and Duncan 1997).

It is important to note that there are many differences among the models in this group. A first difference is whether the model is recursive or static. A model is static if, given a baseline of production and consumption and projected rates of change in critical parameters, an estimate is made for a particular point in the future (that is, a target year). It is important to note that this model gives us a point estimate for the goal year but does not tell us anything about the path to reach that point. An alternative approach would consist of moving toward that final year by estimating the model a year at a time and moving *recursively* toward the final year. Sometimes these models are also called dynamic because they allow the simulation of the dynamic trajectory of the variables over time. All the current models used for projections (that is, FAO's World Food Model, FAPRI's World Agriculture Outlook Model, IFPRI's IMPACT Model, and USDA's Baseline Projections Model) are recursive, which may be interpreted as an interest in observing the dynamics of the model's core variables. In addition, the presence of lags in the models is useful for introducing the presence of adjustment costs in the relationships.

A second difference is whether the equations of the model are linear or are constant elasticity equations (these being the two functional forms used most frequently in the literature). An equation is said to be constant elastic if for instance, in the case of the consumption equation, it indicates that consumption always captures the same proportion of an increase in per capita income regardless of the level of income. Constant elasticity functions are used in current models, whereas linear functions were used in the earlier models. The reason behind this change is that linear models represent changes in the variables well when their values are clustered around their equilibrium value. However, if a shock (such as a negative weather shock that reduces the harvest) is such that it makes prices deviate significantly from their historic equilibrium values, the resulting prediction is distorted because elasticities change from small to large or vice versa along a linear demand or supply function. A constant elasticity function overcomes this problem. Another way to understand the effect of linear demand projection models is by noting that, if the income elasticity of demand is less than one (as it is for food), the share of total expenditures devoted to the commodity declines as real per capita incomes increase. But it is also true that, as per capita income increases, the income elasticity of demand for food declines. How these aspects of the demand for food are treated in models obviously affects projections of the future adequacy of food supplies relative to demand. The decline both in the rate of population growth and in the income elasticity of demand has produced the low and declining rates of growth in the demand for food in the future. This in turn reduces the required food supply growth.

A third methodological difference is in the number of equations modeled, for instance, if commodity stocks are modeled explicitly, such as in the World Bank model, or if they are modeled as part of the demand (that is, stocks plus current utilization).

Despite the noted differences, in general it is possible to represent these models by the following expression, which also allows us to compare them with the trend projection models.

$$\begin{aligned}\sum_i Gap_{i,j,t} &= \text{Consumption} - \text{Production} \\ &= \sum_i Q^{pc}_{i,j,t}(t, INC^{pc}_{i,t}, \eta_{i,j,t}, P_{i,j,t}, \varepsilon_{i,j,t}) \times POP_{i,t} \\ &- AC_{i,j,t}(t, P_{i,j,t}, \sigma_{i,j,t}) \times YC_{i,j,t}(t, P_{i,j,t}, \varphi_{i,j,t}) \equiv 0 \qquad (2)\end{aligned}$$

There are two main differences in equation (2) compared with equation (1). The first difference is the presence of $P_{j,t}$, the domestic commodity prices, and $\varepsilon_{i,j,t}$, $\sigma_{i,j,t}$, $\varphi_{i,j,t}$, which are the price elasticities of per capita demand, yields, and acreage, respectively. In addition, it should be noted that the functions embedded in equation (2)—that is, per capita demand, acreage, and yield—might also include the price of other substitute or complementary commodities. The second difference is that the sum of all the gaps or surpluses faced by each country has to add up to zero (that is, to clear the market). It is important to note that this is the most significant difference from the trend projection models because it allows for the determination of the changes in price implied by projected changes in supply and demand.

These models can accommodate changes in tariffs over time fairly well, but they have problems incorporating country-specific trade barriers (for instance, the minimum access of commodity imports from China to the United States) since they do not predict trade flows. This feature may be important for projections made during a trade liberalization period such as the current period.

World Spatial Trade Models

There are two main motivations for these types of model. First, they predict trade flows. Second, based on the first motivation, they allow nontariff trade barriers such as quotas to be accommodated directly (even if this advantage may be partially reduced after the "tariffication" of international quotas and other nontariff trade barriers). Examples of these types of model in the literature are the second model presented in Rojko et al. (1971) and Dixit and Sharples' (1987) model for the wheat market.

The typical structure of spatial trade models consists of the minimization of the total transportation costs of trade among regions, subject to constraints that represent the characteristics of the different regions. For a detailed description of these models see Takayama and Judge (1971) and Thompson (1981).

It is important to note that spatial models do not predict trade flows well. In reality the predicted trade flows differ substantially from the observed flows. The reasons advanced to explain this phenomenon are the presence of quantitative trade barriers, the heterogeneity of commodities in terms of characteristics and seasonality, which makes commodities from different sources imperfect substitutes, and risk diversification strategies being pursued by importers.

Given that the prediction of trade flows has little value in long-term projections, these models are seldom used for that purpose. Thus we do not review them further.

Appendix 3. Overview of Methods Used to Validate Models

According to Theil (1961), the exercise of validating a model by comparing the projected figures with actual data can be performed in three different ways.

The first is to compare the projection directly with the actual figure. This is the most straightforward way, and does not require major explanation.

The second is to replace the projected value of exogenous variables in the model with the actual value at the projection end point, and run the projection of the endogenous variable (for example, consumption) again. Then we can compare this new projection with the observed actual value of the endogenous variables. This would eliminate the error introduced from projecting the exogenous variable (for example, from projecting the income).

The third method can be illustrated with an example. Let us consider world trade models. In these models, consumption depends on income and on prices. Whereas income is an exogenous variable to the model, prices are determined inside the model (that is, they are an endogenous variable). What Theil proposes in this third method is to replace not only income, as in the second method, but also the prices that enter into the consumption equation on the right-hand side of the equation with actual values. Again, this procedure will produce a third estimate of consumption, which can be compared with the actual value. Theil recognized that the requirements in applying the three procedures increase from the first, which requires only projections and the actual values of the endogenous variables, to the third, which requires the values of the endogenous and exogenous variables plus the structure of the model. In our case, constraints in terms of information about models made the first method the only feasible evaluation method.

Appendix 4. Review of the Methodology to Forecast Poverty

The World Bank methodology presented in Ahluwalia, Carter, and Chenery (1979) consisted of four steps:

1. Estimation of the income level of each country for the past (1960–75) and the projection of this level for the future (1975–2000).
2. Estimation and projection of population by country for the same periods.
3. Estimation and projection of income shares by deciles for each country, obtaining, with this, the level of income for each decile group.
4. Determination of the number of people below the absolute poverty line.

The crucial step in the methodology is the projection of the income distribution to year 2000. This step is addressed using the methodology developed by Ahluwalia (1976), which consisted of regressing the income share of a given quintile for a country on the logarithm of the country's per capita GNP, the squared logarithm of the country's per capita GNP, and a dummy for socialist country. It is important to note that, in a first stage, the methodology computes the income distribution in quintiles, which are interpolated to create income deciles. The equation estimated by Ahluwalia (1976) for a cross-sectional data set of 60 countries is

$$Q_i = \alpha + \beta(\log Y_i) + \gamma(\log Y_i)^2 + \delta D_i + \varepsilon_i \qquad i = 1, 2, \ldots, 60,$$

where Q_i is the income share of a given quintile for country i, Y_i is the country's per capita GNP, D_i is a dummy variable for socialist countries, and ε_i is a random error term.

Clearly, whether the methodology is accurate or not, it relies importantly on the quality of the data: population, GNP, and income distribution. Of the three variables used, the last two are particularly subject to major errors, especially for developing countries. In addition, the presence of a country in the sample depended on whether the country has data on income distribution, a factor that excluded an important number of countries from the sample and, of course, reduced the representativeness of the sample used to infer the world's number of absolute poor.

Regarding the methodology, which is based on the relationship between income distribution and growth (that is, Kuznetz' "U hypothesis"), Anand and Kanbur (1991) found two problems: first, it was dependent on the functional form used to estimate the income share; and, second, the regression estimated should have been a limited-dependent variable regression, even if this last point would be troublesome only for countries with extreme income distributions. In addition, they constructed confidence bounds for the poverty estimates and found them too wide to be useful, since they could imply either an increase or a decrease in the number of poor.

In conclusion, Anand and Kanbur found "that their projections [Ahluwalia, Carter, and Chenery] of poverty are not robust to reasonable changes and improvements in the methodology: in some cases even the time trend of the projections is reversed. Analysts and policy makers should, therefore, treat such global poverty forecasts with caution" (1991, 1).

Appendix 5. Detailed Tables

Table 15—Comparison among FAO wheat projections (million metric tons)

Regions	Actual data[a]					1963 projections to 1970[b]				1967 projections to 1975[b,c]				1971 projections[b]		1979 projection to 1985[b]				1986 projections	
	1970	1975	1980	1985	1990	I	Error[c] (%)	II	Error[c] (%)	Low	Error	High	Error	1980	Error (%)	Basic	Error (%)	Suppl.	Error (%)	1990	Error (%)
World	4.6	−16.9	0.6	−12.4	−7.4	n.p.	—	n.p.	—	−76.8	—	−31.5	—	−18.0	—	−5.5	—	−4.4	—	−1.8	—
Production	327.9	374.0	443.1	510.0	558.2	n.p.	—	n.p.	—	303.3	−18.9	326.6	−12.7	395.4	−10.8	446.5	−12.4	453.1	−11.1	550.7	−1.3
Demand	332.5	357.1	443.7	497.6	550.8	n.p.	—	n.p.	—	226.4	−36.6	295.1	−17.3	377.4	−15.0	441.1	−11.4	448.8	−9.8	548.9	−0.3
Production																					
Developing	96.7	125.3	157.9	205.9	233.4	n.p.	—	n.p.	—	83.6	−33.3	101.0	−19.4	133.8	−15.2	154.9	−24.8	172.8	−16.1	232.3	−0.5
Latin America	12.0	15.7	14.9	20.9	20.9	12.5	4.5	12.4	3.6	15.5	−1.3	17.1	8.7	16.3	9.6	19.6	−6.0	21.9	5.0	23.1	10.3
Africa	4.9	5.4	4.7	6.3	8.1	6.0	23.6	7.7	58.7	4.7	−13.1	5.7	3.9	6.4	34.8	6.6	5.0	7.7	22.6	6.2	−23.1
Near East	21.5	24.6	31.7	30.3	39.1	23.3	8.5	23.9	11.3	10.8	−56.2	14.0	−43.3	26.4	−16.8	29.7	−2.2	31.8	4.9	37.0	−5.4
Far East	28.3	33.6	46.7	59.8	69.5	17.8	−37.0	23.4	−17.2	22.2	−34.0	32.5	−3.5	44.4	−4.9	47.3	−20.8	53.5	−10.5	73.1	5.3
Asian CPE	30.2	45.9	59.8	88.6	95.8	n.p.	—	n.p.	—	30.4	−33.9	31.8	−30.8	40.3	−32.6	51.7	−41.7	57.9	−34.7	92.8	−3.1
Others	0.0	0.0	0.0	0.0	0.0	n.p.	—	n.p.	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0	—	0.0	–
Developed	231.2	248.6	285.2	304.1	324.8	n.p.	—	n.p.	—	219.7	−11.7	225.7	−9.2	261.6	−8.3	291.7	−4.1	280.3	−7.8	318.4	−2.0
North America	53.9	72.9	86.7	90.1	90.8	56.9	5.5	56.9	5.5	63.5	−12.9	63.5	−12.9	60.2	−30.6	72.2	−19.9	58.6	−34.9	94.8	4.4
Western Europe	51.4	57.5	65.1	85.0	92.7	49.8	−3.0	49.8	−3.0	66.4	15.4	66.9	16.3	56.9	−12.6	62.8	−26.1	63.2	−25.7	75.8	−18.3
Eastern Europe and USSR	114.4	103.8	115.9	108.6	124.8	n.p.	—	n.p.	—	76.9	−25.9	82.5	−20.6	129.5	11.8	140.2	29.0	145.1	33.6	126.0	1.0
Oceania	9.4	12.0	14.8	17.3	13.4	6.5	−30.6	6.5	−30.6	10.6	−11.5	10.6	−11.5	14.5	−2.0	14.0	−19.0	10.4	−40.1	18.5	37.3
Others	2.2	2.3	2.7	3.0	3.1	0.7	−67.9	1.1	−49.5	2.2	−6.2	2.2	−6.2	0.5	−81.4	2.5	−18.0	3.1	0.4	3.4	10.9
Demand																					
Developing	122.2	151.4	206.1	257.4	290.5	n.p.	—	n.p.	—	79.8	−47.3	114.5	−24.4	157.9	−23.4	198.9	−22.7	206.6	−19.7	289.3	−0.4
Latin America	15.9	19.7	22.8	25.0	25.5	15.7	−1.0	16.7	5.3	4.7	−76.2	17.3	−12.2	20.9	−8.6	24.2	−3.3	25.4	1.5	31.3	22.8
Africa	7.9	10.1	13.5	16.3	17.4	10.1	27.4	11.4	43.8	5.1	−49.5	7.2	−28.9	10.0	−25.9	14.1	−13.9	14.9	−9.0	20.1	15.4
Near East	27.3	32.6	42.6	49.0	56.4	23.3	−14.6	24.0	−12.1	3.1	−90.4	16.6	−49.1	30.7	−28.0	40.6	−17.0	40.4	−17.5	55.8	−1.0
Far East	35.2	43.1	55.7	67.7	82.2	31.7	−9.9	36.3	3.2	31.4	−27.0	36.6	−15.1	50.0	−10.2	61.5	−9.2	65.0	−4.0	81.4	−1.0
Asian CPE	35.8	45.9	71.3	99.3	109.0	n.p.	—	n.p.	—	35.4	−22.8	36.9	−19.7	46.3	−35.1	58.3	−41.3	60.7	−38.9	100.4	−7.9
Others	0.1	0.0	0.2	0.0	0.0	n.p.	—	n.p.	—	0.0	—	0.0	—	0.0	—	0.2	—	0.2	—	0.2	–
Developed	210.3	205.7	237.6	240.2	260.3	n.p.	—	n.p.	—	146.7	−28.7	180.6	−12.2	219.5	−7.6	242.2	0.8	242.2	0.8	259.6	−0.3
North America	25.9	24.3	26.9	36.7	38.6	23.2	−10.5	22.4	−13.6	26.0	7.0	26.1	7.5	23.1	−14.0	26.2	−28.5	25.3	−31.1	33.4	−13.5
Western Europe	55.9	55.5	58.8	67.6	68.8	51.9	−7.2	51.6	−7.7	31.9	−42.4	66.6	20.0	63.6	8.1	57.6	−14.7	56.8	−16.0	63.6	−7.4
Eastern Europe and USSR	118.2	114.8	139.9	123.3	139.9	n.p.	—	n.p.	—	77.7	−32.3	76.5	−33.4	121.7	−13.0	144.5	17.2	146.4	18.7	148.6	6.2
Oceania	3.1	3.1	3.3	3.5	3.8	2.8	−10.9	2.8	−10.9	3.0	−3.8	3.0	−4.4	3.5	5.1	4.0	14.8	3.9	10.5	4.0	4.8
Others	7.1	8.1	8.7	9.2	9.2	1.2	−79.1	1.3	−77.3	8.1	0.2	8.5	5.8	7.6	−12.7	9.8	7.0	9.9	8.1	10.0	8.3

Sources: Actual data are from the FAOSTAT database. Projections are from FAO 1962, 1967, 1971, 1979, and 1986.

Notes: n.p. = not projected; CPE = centrally planned economies. An error with a negative sign indicates an underestimate.

[a] The figures correspond to three-year averages centered in the reported year.

[b] Low- and high-income growth scenarios, respectively.

[c] The error in "Others" was computed considering only those countries projected (that is, Japan and Israel).

Table 16—Comparison among USDA wheat projections for selected regions (million metric tons)

	Actual data[a]					Projections as made in 1961				1964 projections	
Regions	1962	1966	1970	1980	1985	1962	Error (%)	1966	Error (%)	1970	Error (%)
Aggregate[d]	–16.5	–20.9	–25.5	–84.0	–89.6	–14.4		–15.4		–22.0	
Production	138.5	157.7	181.3	297.5	321.1	131.4	–5.1	142.7	–9.5	156.7	–13.6
Consumption	122.0	136.8	155.8	213.4	231.5	117.0	–4.1	127.3	–7.0	134.7	–13.5
Production											
North America	45.8	56.0	53.9	86.7	90.1	43.2	–5.5	43.7	–22.0	57.7	7.0
Canada	14.3	18.8	13.9	20.4	25.6	13.3	–6.8	13.8	–26.8	16.0	15.1
United States	31.5	37.2	40.0	66.2	64.5	29.9	–5.0	29.9	–19.6	41.7	4.2
Western Europe	39.9	46.0	48.9	63.5	83.9	38.5	–3.7	41.2	–10.5	36.3	–25.9
Africa and Middle East[e]	18.1	20.3	23.1	31.6	35.1	18.5	1.9	20.3	–0.1	22.3	–3.4
North Africa and Middle East	16.5	18.6	20.4	28.6	31.8	17.5	5.8	19.3	3.9	21.2	3.7
Central Africa	0.0	0.0	0.0	0.0	0.0	0.2	–[g]	0.2	–[g]	0.0	–[g]
East Africa	0.8	1.0	1.2	1.1	1.2	0.1	–86.0	0.1	–88.5	0.2	–85.1
South Africa	0.8	0.8	1.5	2.0	2.1	0.7	–12.1	0.8	–1.4	0.9	–35.8
India	11.3	11.3	20.9	49.6	45.5	10.4	–7.8	13.0	14.6	13.9	–33.3
Latin America and Caribbean	10.3	10.7	11.6	15.0	20.9	10.5	1.1	11.5	7.2	12.6	8.5
Upper Latin America and Caribbean	1.6	2.0	2.1	2.7	4.4	1.4	–10.0	1.7	–11.5	2.3	13.4
Lower Latin America	8.8	8.8	9.5	12.3	16.5	9.1	3.1	9.8	11.4	10.2	7.4
Consumption											
North America	20.2	22.6	26.4	27.2	36.7	20.5	1.8	22.0	–2.6	26.1	–1.2
Canada	4.0	4.3	4.7	5.3	5.8	4.6	15.9	4.9	12.8	6.0	28.5
United States	16.2	18.3	21.7	21.9	30.9	15.9	–1.6	17.1	–6.2	20.1	–7.6
Western Europe	48.7	50.8	55.5	56.3	66.5	46.8	–3.9	48.1	–5.3	44.8	–19.2
Africa and Middle East[e]	23.0	26.9	30.9	49.4	59.2	22.9	–0.6	25.5	–5.2	29.7	–3.8
North Africa and Middle East	21.0	24.4	27.9	45.4	53.6	20.6	–1.6	22.9	–6.0	26.9	–3.7
Central Africa	0.1	0.1	0.1	0.3	0.3	0.9	–[g]	1.1	–[g]	0.8	–[g]
East Africa	1.0	1.2	1.5	1.8	3.1	0.3	–69.5	0.3	–71.0	0.7	–55.0
South Africa	0.9	1.2	1.3	1.9	2.2	1.0	4.7	1.1	–9.5	1.4	3.8
India[f]	14.9	18.4	22.4	53.1	44.1	14.5	–3.2	17.6	–4.4	18.9	–15.7
Latin America and Caribbean	12.0	14.1	16.2	22.1	25.0	12.4	3.7	14.2	0.7	15.2	–6.1
Upper Latin America and Caribbean	2.5	3.2	3.8	6.0	7.5	2.5	–3.7	2.8	–12.0	3.2	–16.0
Lower Latin America	9.4	10.8	12.4	16.1	17.5	9.9	5.8	11.3	4.5	12.0	–3.1

I	Error (%)	II	Error (%)	II-A	Error (%)	II-B	Error (%)	III	Error (%)	II	Error (%)	III	Error (%)	IV	Error (%)		
Projections to 1980 as made in 1971[b]										**Projections to 1985 as made in 1978[c]**							
–59.5		–77.1		–77.9		–76.0		–46.0		–60.7		–63.9		–56.9		–70.4	
247.6	–16.7	277.6	–6.7	297.6	0.1	288.5	–3.0	223.4	–24.9	270.3	–15.8	285.6	–11.1	259.8	–19.1	292.0	–9.1
188.1	–11.9	200.5	–6.1	219.7	2.9	212.5	–0.4	177.4	–16.9	209.6	–9.4	221.6	–4.2	202.9	–12.4	221.6	–4.3
61.8	–28.7	60.4	–30.3	83.5	–3.6	75.7	–12.6	62.8	–27.5	81.9	–9.1	99.9	10.9	66.7	–26.0	89.1	–1.1
18.6	–8.9	17.6	–13.8	27.4	34.1	24.3	19.0	19.3	–5.5	21.7	–15.2	24.8	–3.1	19.7	–23.2	22.6	–11.6
43.2	–34.8	42.8	–35.4	56.1	–15.3	51.4	–22.4	43.5	–34.3	60.2	–6.7	75.1	16.5	47.1	–27.0	66.5	3.0
51.7	–18.6	51.5	–18.9	50.6	–20.3	48.2	–24.1	51.7	–18.6	54.6	–34.9	49.3	–41.3	60.6	–27.8	47.5	–43.4
25.3	–19.9	27.9	–11.6	27.3	–13.5	27.8	–12.0	23.7	–24.9	36.4	3.8	37.4	6.7	36.0	2.5	42.6	21.4
23.2	–18.8	25.7	–10.1	25.4	–11.1	25.6	–10.4	21.5	–24.8	32.8	3.2	33.6	5.7	32.5	2.0	38.9	22.1
0.0	–[g]	0.0	–[g]	0.0	–[g]	0.0	–[g]	0.0	–[g]	0.8	–[g]	0.8	–[g]	0.8	–[g]	0.8	–[g]
0.8	–24.9	0.9	–15.5	0.9	–15.5	0.9	–15.5	0.9	–15.5	0.6	–52.4	0.6	–50.5	0.5	–53.4	0.7	–44.4
1.3	–33.8	1.3	–33.8	1.0	–49.1	1.3	–33.8	1.3	–33.8	2.3	9.4	2.4	17.9	2.2	5.0	2.3	11.6
46.3	–6.6	59.9	20.9	59.9	20.9	59.9	20.9	35.4	–28.6	39.9	–12.4	40.1	–12.0	39.9	–12.4	46.7	2.6
16.2	8.2	18.0	20.3	16.4	9.6	17.0	13.6	14.4	–3.8	17.5	–16.0	18.8	–9.9	16.7	–19.9	19.3	–7.5
3.2	18.5	4.0	48.1	3.9	44.4	3.9	44.4	2.7	–0.0	2.8	–37.1	3.0	–32.6	2.7	–39.3	3.3	–24.2
13.0	6.0	14.0	14.1	12.5	1.9	13.1	6.8	11.7	–4.6	14.8	–10.3	15.8	–3.8	14.0	–14.8	16.0	–3.0
26.8	–1.4	29.6	8.9	39.7	46.1	34.3	26.2	24.8	–8.8	30.6	–16.5	30.2	–17.6	30.0	–18.0	31.5	–14.2
4.3	–18.8	4.7	–11.2	9.4	77.6	7.4	39.8	4.0	–24.4	5.9	2.9	6.0	4.3	5.8	0.2	6.1	6.3
22.5	2.8	24.9	13.8	30.3	38.4	26.9	22.9	20.8	–5.0	24.7	–20.1	24.2	–21.7	24.3	–21.4	25.3	–18.0
51.7	–8.1	53.0	–5.8	57.3	1.8	57.1	1.5	50.7	–9.9	58.8	–11.6	60.2	–9.5	56.7	–14.8	61.4	–7.7
42.0	–15.0	44.8	–9.3	45.3	–8.3	44.6	–9.7	39.8	–19.4	54.3	–8.3	57.1	–3.5	52.6	–11.1	55.4	–6.4
37.2	–18.1	39.7	–12.5	40.0	–11.9	39.9	–12.1	35.7	–21.4	48.4	–9.7	49.9	–6.9	46.9	–12.5	49.3	–7.9
1.5	–[g]	1.7	–[g]	1.7	–[g]	1.7	–[g]	1.4	–[g]	2.5	–[g]	2.7	–[g]	2.4	–[g]	2.7	–[g]
1.5	–17.6	1.6	–12.1	1.7	–6.6	1.7	–6.6	1.4	–23.1	1.3	–58.8	2.5	–19.2	1.2	–59.6	1.3	–57.7
1.8	–6.8	1.8	–6.8	1.9	–1.7	1.3	–32.7	1.3	–32.7	2.1	–4.7	2.1	–4.2	2.1	–5.8	2.1	–4.0
46.0	–13.4	52.8	–0.5	54.0	1.7	53.4	0.6	43.5	–18.1	41.3	–6.4	48.7	10.4	39.4	–10.8	48.0	8.9
21.6	–2.5	20.3	–8.4	23.4	5.6	23.1	4.3	18.6	–16.0	24.7	–1.4	25.4	1.7	24.1	–3.4	25.3	1.1
5.5	–8.8	4.0	–33.7	6.4	6.1	6.3	4.5	2.7	–55.2	5.4	–27.6	5.8	–22.8	5.2	–30.9	5.8	–22.8
16.1	–0.1	16.3	1.1	17.0	5.5	16.8	4.2	15.9	–1.4	19.2	9.9	19.6	12.2	18.9	8.4	19.5	11.4

Sources: Actual data are from the USDA PS&D database. Projections are from World GOL model (Rojko, Urban, and Na¨ive 1971; Rojko et al. 1978).

Notes: An error with a negative sign indicates an underestimate.

[a] The figures correspond to three-year averages centered in the reported year.

[b] I = Continuation of policies and moderate gain in productivity in developing countries. II = Higher productivity and economic growth than in I in developing countries. II-A = Major exporters maintain their share in the world grain market. II-B = Major developed importers adjust their domestic prices with international prices. III = Lower agricultural production and economic growth in developing countries than in scenario I.

[c] I = Continuation of the trend in terms of economic growth and policies. II = High economic growth that leads to higher level of imports. III = Low income growth that reduces import demand. IV = Moderately higher productivity in developing countries in the context of high income growth and strong world import demand.

[d] Considers only the countries presented in the table.

[e] Includes only those countries considered in the projection.

[f] Figures for 1980 (actual and projection) are for South East Asia and not only for India.

[g] Greater than 100 percent.

Table 17—USDA wheat projections for selected regions to 1990, 1995, and 2000 (million metric tons)

	Actual data[a]			Projections					
	1990	1995	2000	1990	Error (%)	1995	Error (%)	2000	Error (%)
Aggregate[b]	–62.3	–66.9	–73.7	–78.3		–85.4		–90.5	
Supply	362.5	325.3	349.2	371.3	2.4	398.5	22.5	427.0	22.3
Demand	300.2	258.4	275.5	293.0	–2.4	313.1	21.2	336.5	22.1
United States	–31.6	–28.8	–27.2	–53.3		–55.8		–56.2	
Supply	80.3	74.7	87.3	112.8	40.5	123.4	65.3	134.2	53.7
Demand	48.7	45.8	60.1	59.5	22.3	67.6	47.5	78.0	29.8
Canada	–21.0	–18.7	–18.9	–25.8		–30.6		–35.4	
Supply	36.9	33.8	34.2	41.8	13.3	47.7	41.1	54.3	58.5
Demand	15.9	15.1	15.3	15.9	0.1	17.2	13.6	18.9	23.2
Australia and New Zealand	–9.7	–12.7	–16.4	–16.3		–19.1		–22.2	
Supply	16.4	19.2	26.1	23.9	46.0	27.0	40.8	30.5	17.0
Demand	6.7	6.5	9.7	7.6	14.0	8.0	22.7	8.4	–13.6
Argentina	–5.8	–7.3	–11.8	–6.8		–8.2		–9.9	
Supply	10.8	12.2	16.2	11.6	8.1	13.3	9.3	15.2	–6.0
Demand	4.9	4.9	4.5	4.8	–2.6	5.1	3.9	5.3	19.4
EC-10	–20.4	–15.7	–15.4	–13.7		–14.7		–15.4	
Supply	94.0	93.5	105.2	68.9	–26.7	71.9	–23.0	74.5	–29.2
Demand	73.7	77.7	89.8	55.3	–24.9	57.2	–26.4	59.1	–34.2
Japan	5.2	5.7	5.3	5.8		5.8		5.7	
Supply	2.5	1.6	1.7	2.8	14.9	3.3	100.4	3.7	120.4
Demand	7.7	7.4	7.0	8.6	12.7	9.0	22.8	9.4	34.5
USSR	17.0	3.3	1.0	24.0		28.9		34.4	
Supply	113.4	83.3	71.5	101.4	–10.6	102.3	22.9	103.1	44.1
Demand	130.4	86.5	72.5	125.4	–3.8	131.2	51.6	137.4	89.6
Brazil	3.5	6.0	7.7	6.1		6.5		6.6	
Supply	4.1	3.0	3.0	4.1	0.4	5.0	64.1	6.1	101.7
Demand	7.6	9.0	10.7	10.2	34.5	11.5	27.2	12.7	18.4
Mexico	0.4	1.4	2.1	1.7		1.7		1.9	
Supply	4.3	4.1	3.9	3.9	–9.9	4.6	12.6	5.3	38.1
Demand	4.7	5.4	5.9	5.5	18.2	6.3	16.7	7.2	22.0

Sources: Actual data are from the USDA PS&D database. Projections are baseline projections from Liu and Seeley 1987).

Notes: Supply is defined as production plus beginning of year stocks and demand as consumption plus end of year stocks. An error with a negative sign indicates an underestimate.

[a] Actual data are centered averages on the reported year, except 2000, which is the average of only the 1999 and 2000 figures.

[b] Considers only the regions projected.

Table 18—Comparison among IFPRI food production projections to 1990 and 2000 (million metric tons, in cereal equivalent)

	Actual data[a]		Projections			
	1990	2000	1990	Error (%)	2000	Error (%)
Developing countries	591.0	1,433.7	591.6	0.1	1,471.0	2.6
Asia	318.9	1,028.7	298.2	–6.5	1,035.0	0.6
China[b]	2.2	509.7	3.1	41.4	501.0	–1.7
South Asia	225.0	321.9	203.9	–9.4	323.0	0.3
East and South East Asia	91.7	197.1	91.2	–0.5	211.0	7.0
North Africa/Middle East	83.2	104.5	70.5	–15.2	119.0	13.8
Northern Africa	28.4	35.8	27.9	–1.5	35.0	–2.2
Western Asia	54.8	68.8	42.6	–22.3	83.0	20.7
Sub-Saharan Africa	73.7	142.5	70.9	–3.8	114.0	–20.0
West Africa	38.3	79.6	30.6	–20.0	39.0	–51.0
Central Africa	10.4	19.3	17.4	68.0	25.0	29.8
Eastern and Southern Africa	25.0	43.7	22.8	–8.7	49.0	12.2
Latin America	115.3	158.0	151.9	31.8	204.0	29.1
Mexico, Central America, and Caribbean	29.2	37.6	40.1	37.3	57.0	51.5
Upper South America	59.0	78.8	72.4	22.9	100.0	27.0
Lower South America	27.1	41.6	39.4	45.3	47.0	13.0

Source: Actual data are from the FAOSTAT and USDA PS&D databases. Projections are from IFPRI 1977 and Paulino 1986.

Notes: An error with a negative sign indicates an underestimate.

[a] Actual data for 1990 and 2000 are not comparable since 2000 data include more countries. In addition, food is defined including not only cereals, roots and tubers, pulses and nuts but also cassava, and bananas and plantains. The actual figures for 1990 correspond to the average for the 1989–91 period and the figures for 2000 correspond to the average for the 1998–99 period.

[b] The 1990 study included only Taiwan. The 2000 projection figures include the People's Republic of China and Taiwan under the name of China.

Table 19—Comparison of cereal projections to 1985 according to FAO, USDA, and Iowa State University models (million metric tons)

Item	Actual data[a]			FAO		USDA projections[b]								Iowa State University[c]	
	FAO	FAO for ISU	USDA	Projection	Error (%)	Model I	Error (%)	Model II	Error (%)	Model III	Error (%)	Model IV	Error (%)	Projection	Error
World															
Consumption	1,617	1,138	1,594	1,725	7	1548.5	–3	1,619	2	1,502	–6	1,644	3	1046.4–1145.5	–8.0–0.7
Production	1,677	1,301	1,648	n.a.	n.a.	1550.4	–6	1,621	–2	1,504	–9	1,646	–0	1,226	–6
Balance[d]	60	–163	54	n.a.	n.a.	1.9		2		2		2		179.6–80.5	
Developed countries															
Consumption	774	785	750	796	3	857.3	14	893	19	823	10	900	20	581.5–620.8	–25.9–20.9
Production	900	857	879	n.a.	n.a.	918	4	972	11	877	–0	925	5	817	–5
Balance	126	–72	129	n.a.	n.a.	60.7		79		54		24		235.2–195.9	
Developing countries															
Consumption	843	n.a.	844	929	10	691.2	–18	726	–14	679	–20	744	–12	n.a.	n.a.
Production	777	n.a.	768	853	10	632.4	–18	649	–16	626	–19	721	–6	n.a.	n.a.
Balance	–66	n.a.	–76	–76		–58.8		–78		–52		–23		n.a.	
Developing market economies															
Consumption	516	353	538	629	22	479.4	–11	513	–5	467	–13	529	–2	465.0–524.7	31.8–48.9
Production	398	443	473	544	37	424.7	–10	441	–7	419	–11	513	9	409	–8
Balance	–118	–90	–65	–85		–54.7		–72		–48		–16		–56.0–116.0	
Asian centrally planned economies[e]															
Consumption	327	n.a.	306	300	–8	211.8	–31	214	–30	212	–31	214	–30	n.a.	n.a.
Production	379	n.a.	296	309	–18	207.7	–30	208	–30	208	–30	208	–30	n.a.	n.a.
Balance	52	n.a.	–11	9		–4.1		–6		–4		–7		n.a.	n.a.

Sources: FAO data are from the FAOSTAT database and USDA data are from the USDA PS&D database. FAO and USDA projections are from USDA 1974, ISU projections are from Blakeslee, Heady, and Framingham 1973.

Notes: n.a. = not available. An error with a negative sign indicates an underestimate.

[a] The data for FAO and USDA differ because FAO carries rice as paddy and USDA carries rice as milled. Actual data from FAO are the sum of cereals excluding beer plus other cereals. Actual data from USDA are the sum of coarse grain, rice, and wheat. In addition, actual data are an average of 1984–86.

[b] Model I assumes initial slow growth, but resumed in the late 1970s and early 1980s. Model II assumes high world demand. Model III assumes low demand and stagnation. Model IV assumes faster growth of production in developing countries (less demand for food from developing countries).

[c] Iowa State assumes high (H) and low (L) scenarios for demand, resulting in two possible balances.

[d] Imbalances for USDA are due to stock buildup, timing of shipments, and missing data on a number of small importers.

[e] For FAO, Asian CPE includes China, the Democratic People's Republic of Korea, and Vietnam; for USDA it includes only China.

Table 20—Comparison between FAPRI and FAO wheat projections to 1990 for selected countries (million metric tons)

Country	Actual data[a]	FAPRI Projection	FAPRI Error (%)	FAO Projection	FAO Error (%)
Production	237.3	232.8	–2	228.1	–4
Australia	13.3	19.1	44	18.1	36
Canada	29.6	23.8	–20	23.7	–20
EC-10	80.2	70.1	–13	60.4	–25
India	53.0	50.3	–5	54.8	3
United States	61.2	69.5	14	71.2	16
Consumption	267.1	254.8	–5	250.8	–6
Australia	3.3	3.2	–4	3.6	8
Canada	7.0	4.5	–35	5.9	–15
EC-10	56.5	54.8	–3	47.3	–16
India	53.5	50.3	–6	54.2	1
United States	31.7	27.6	–13	27.5	–13
USSR	115.2	114.4	–1	112.3	–3
Gap[b]	29.8	22.0	–26	22.7	–24

Source: Actual data are from the FAOSTAT database. FAPRI projections are from Meyers, Devadoss, and Helmar 1986, FAO projections are from FAO 1986.

Notes: An error with a negative sign indicates an underestimate.

[a] Average 1989–91.

[b] Difference between consumption and production.

Table 21—Comparison among FAO, IFPRI, USDA, and World Bank cereal projections to 2000 (million metric tons)

	Actual data[a]		Projections[b]											
					IFPRI									
							IMPACT MODEL							
	FAO	USDA	FAO	Error	IFPTSIM	Error	Intrapolation[c]	Error	Dynamic run[d]	Error	World Bank[e]	Error	USDA	Error
World[f]	n.a.	–8.0	4.5		0.0						17.7		–4.7	
Production	1,862.2	1,871.9	2,027.4	8.9%	2,027.9	8.9%	1,989.7	6.8%	1,997.6	7.3%	1,982.8	5.9%	1,924.7	2.8%
Consumption	n.a.	1,879.9	2,022.9	n.a.	2,027.9	n.a.	n.a.	n.a.	n.a.	n.a.	1,965.1	4.5%	1,929.4	2.6%
Production														
Developed countries	844.5	857.7	935.7	10.8%	1,013.5	20.0%	934.2	10.6%	928.5	9.9%	928.4	8.2%	907.9	5.9%
Eastern Europe and former USSR[g]	189.2	200.6	291.4[h]	54.0%	316.2	67.1%	278.5	47.2%	275.1	45.4%	296.1	47.6%	225.9[h]	20.7%
Developing countries	1,017.6	1,014.2	1,091.7	7.3%	1,014.4	–0.3%	1,051.0	3.3%	1,069.1	5.1%	1,054.4	4.0%	1,016.8	0.3%
Latin America	128.6	130.7	133.5	3.8%	125.4	–2.5%	119.5	–7.1%	121.3	–5.7%	124.3	–4.8%	127.5	–.4%
Sub-Saharan Africa	71.0	67.0	76.8	8.1%	68.7	–3.2%	73.3	3.2%	72.0	1.4%	94.6	41.3%	72.3	8.0%
Asia	747.3	739.8	779.2	4.3%	724.1	–3.1%	746.8	–0.1%	763.4	2.2%	733.4	–0.9%	742.0	0.3%
Middle East/North Africa	70.7	76.7	102.2	44.5%	96.2	36.1%	97.3	37.6%	102.3	44.7%	102.0	33.0%	74.9	–2.3%
Consumption														
Developed countries	n.a.	745.5	812.9	n.a.	889.3	n.a.	n.a.	n.a.	n.a.	n.a.	766.7	2.8%	757.5	1.6%
Eastern Europe and former USSR[g]	n.a.	204.5	304.0[h]	n.a.	324.5	n.a.	n.a.	n.a.	n.a.	n.a.	294.4	43.9%	230.9[h]	20.7%
Developing countries	n.a.	1,134.4	1,210.0	n.a.	1,138.6	n.a.	n.a.	n.a.	n.a.	n.a.	1,198.4	5.6%	1,171.9	3.3%
Latin America	n.a.	146.6	153.7	n.a.	138.5	n.a.	n.a.	n.a.	n.a.	n.a.	139.4	–4.9%	139.6	–4.8%
Sub-Saharan Africa	n.a.	79.4	89.2	n.a.	90.0	n.a.	n.a.	n.a.	n.a.	n.a.	99.2	25.0%	80.6	1.6%
Asia	n.a.	768.5	809.1	n.a.	762.1	n.a.	n.a.	n.a.	n.a.	n.a.	795.6	3.5%	840.3	9.3%
Middle East/North Africa	n.a.	139.9	157.9	n.a.	148.0	n.a.	n.a.	n.a.	n.a.	n.a.	164.2	17.3%	111.4	–20.4%

Sources: Actual data are from the FAOSTAT and USDA PS&D databases. Projections are from FAO (1994), IFPRI [IFPTSIM results are from Agcaoili and Rosegrant (1995); IMPACT results are from Mark Rosegrant (private communication, 2001)], World Bank (Mitchell, Ingco, and Duncan 1997), and USDA (1997). The structures of the IFPTSIM and IMPACT models are similar; the main difference is that IMPACT includes many updated elasticities.

Notes: n.a. = not available. An error with a negative sign indicates an understimate.

[a] Actual data are expressed as the average 1999–2000.

[b] FAO and IFPRI projection errors were computed using actual FAO data; for the other two agencies we used USDA actual data.

[c] Computed from Rosegrant, Agcaoili-Sombilla, and Perez (1995) by applying the growth rates in projected production, 1990–2020, to the period 1990–1999 to estimate 1999 projected values.

[d] Projection computed running the 1995 version of the IMPACT model to year 2000 in year 2001 (private communication with Mark Rosegrant).

[e] Computed by applying the projected 1990/2000 growth rates from Mitchell et al. (1997) to 1990 USDA figures.

[f] Production minus consumption.

[g] USDA actual figures include the former German Democratic Republic (GDR), estimated as 30 percent of total Germany production and 35 percent of total Germany consumption, to make make it comparable with the World Bank projection. However, USDA error was computed excluding GDR from the actual number.

[h] Eastern Europe figures were computed by applying the Eastern Europe actual share for 1999–2000 to the total projected for Europe (28.1 percent for production and 30.8 percent for consumption).

Table 22—Comparison of two forecasts to 2000 of the dynamics of water use in the world by human activity

Water uses (km³/year)[a]	1900	1940	1950	1960	1970	1980	1990	2000
Agriculture								
Withdrawal 1993	525.0	893.0	1,130.0	1,550.0	1,850.0	2,290.0	2,680.0	3,250.0
Withdrawal 1999	513.0	895.0	1,080.0	1,481.0	1,743.0	2,112.0	2,425.0	2,605.0
Difference (%)	2.3	–0.2	4.6	4.7	6.1	8.4	10.5	24.8
Consumption 1993	409.0	679.0	859.0	1,180.0	1,400.0	1,730.0	2,050.0	2,500.0
Consumption 1999	321.0	586.0	722.0	1,005.0	1,186.0	1,445.0	1,691.0	1,834.0
Difference (%)	27.4	15.9	19.0	17.4	18.0	19.7	21.2	36.3
Industry								
Withdrawal 1993	37.2	124.0	178.0	330.0	540.0	710.0	973.0	1,280.0
Withdrawal 1999	43.7	127.0	204.0	339.0	547.0	713.0	735.0	776.0
Difference (%)	–14.9	–2.4	–12.7	–2.7	–1.3	–0.4	32.4	64.9
Consumption 1993	3.5	9.7	14.5	24.9	38.0	61.9	88.5	117.0
Consumption 1999	4.8	11.9	19.1	30.6	51.0	70.9	78.8	87.9
Difference (%)	–27.2	–18.5	–24.1	–18.6	–25.5	–12.7	12.3	33.1
Municipal supply								
Withdrawal 1993	16.1	36.3	52.0	82.0	130.0	200.0	300.0	441.0
Withdrawal 1999	21.5	58.9	86.7	118.0	160.0	219.0	305.0	384.0
Difference (%)	–25.1	–38.4	–40.0	–30.5	–18.8	–8.7	–1.6	14.8
Consumption 1993	4.0	9.0	14.0	20.3	29.2	41.1	52.4	64.5
Consumption 1999	4.6	12.5	16.7	20.6	28.5	38.3	45.0	52.8
Difference (%)	–13.2	–28.0	–16.2	–1.5	2.5	7.3	16.4	22.2
Reservoirs								
Withdrawal = Consumption 1993	0.3	3.7	6.5	23.0	66.0	120.0	170.0	220.0
Withdrawal = Consumption 1999	0.3	7.0	11.1	30.2	76.1	131.0	167.0	208.0
Difference (%)	0.0	–47.1	–41.4	–23.8	–13.3	–8.4	1.8	5.8
Total[b]								
Withdrawal 1993	579.0	1,060.0	1,360.0	1,990.0	2,590.0	3,320.0	4,130.0	5,190.0
Withdrawal 1999	579.0	1,088.0	1,382.0	1,968.0	2,526.0	3,175.0	3,633.0	3,973.0
Difference (%)	0.0	–2.6	–1.6	1.1	2.5	4.6	13.7	30.6
Consumption 1993	417.0	701.0	894.0	1,250.0	1,540.0	1,950.0	1,360.0	2,900.0
Consumption 1999	331.0	617.0	768.0	1,086.0	1,341.0	1,686.0	1,982.0	2,182.0
Difference (%)	26.0	13.6	16.4	15.1	14.8	15.7	–31.4	32.9

Source: Shiklomanov 1993, SHI/UNESCO 1999.
Notes: The year next to withdrawal and consumption figures corresponds to the publication year.
[a] Withdrawal stands for total water withdrawal; consumption stands for irretrievable water loss.
[b] Total water use figures are rounded off.

Table 22—Comparison of two forecasts to 2000 of the dynamics of water use in the world by human activity

Water uses (km³/year)[a]	1900	1940	1950	1960	1970	1980	1990	2000
Agriculture								
Withdrawal 1993	525.0	893.0	1,130.0	1,550.0	1,850.0	2,290.0	2,680.0	3,250.0
Withdrawal 1999	513.0	895.0	1,080.0	1,481.0	1,743.0	2,112.0	2,425.0	2,605.0
Difference (%)	2.3	–0.2	4.6	4.7	6.1	8.4	10.5	24.8
Consumption 1993	409.0	679.0	859.0	1,180.0	1,400.0	1,730.0	2,050.0	2,500.0
Consumption 1999	321.0	586.0	722.0	1,005.0	1,186.0	1,445.0	1,691.0	1,834.0
Difference (%)	27.4	15.9	19.0	17.4	18.0	19.7	21.2	36.3
Industry								
Withdrawal 1993	37.2	124.0	178.0	330.0	540.0	710.0	973.0	1,280.0
Withdrawal 1999	43.7	127.0	204.0	339.0	547.0	713.0	735.0	776.0
Difference (%)	–14.9	–2.4	–12.7	–2.7	–1.3	–0.4	32.4	64.9
Consumption 1993	3.5	9.7	14.5	24.9	38.0	61.9	88.5	117.0
Consumption 1999	4.8	11.9	19.1	30.6	51.0	70.9	78.8	87.9
Difference (%)	–27.2	–18.5	–24.1	–18.6	–25.5	–12.7	12.3	33.1
Municipal supply								
Withdrawal 1993	16.1	36.3	52.0	82.0	130.0	200.0	300.0	441.0
Withdrawal 1999	21.5	58.9	86.7	118.0	160.0	219.0	305.0	384.0
Difference (%)	–25.1	–38.4	–40.0	–30.5	–18.8	–8.7	–1.6	14.8
Consumption 1993	4.0	9.0	14.0	20.3	29.2	41.1	52.4	64.5
Consumption 1999	4.6	12.5	16.7	20.6	28.5	38.3	45.0	52.8
Difference (%)	–13.2	–28.0	–16.2	–1.5	2.5	7.3	16.4	22.2
Reservoirs								
Withdrawal = Consumption 1993	0.3	3.7	6.5	23.0	66.0	120.0	170.0	220.0
Withdrawal = Consumption 1999	0.3	7.0	11.1	30.2	76.1	131.0	167.0	208.0
Difference (%)	0.0	–47.1	–41.4	–23.8	–13.3	–8.4	1.8	5.8
Total[b]								
Withdrawal 1993	579.0	1,060.0	1,360.0	1,990.0	2,590.0	3,320.0	4,130.0	5,190.0
Withdrawal 1999	579.0	1,088.0	1,382.0	1,968.0	2,526.0	3,175.0	3,633.0	3,973.0
Difference (%)	0.0	–2.6	–1.6	1.1	2.5	4.6	13.7	30.6
Consumption 1993	417.0	701.0	894.0	1,250.0	1,540.0	1,950.0	1,360.0	2,900.0
Consumption 1999	331.0	617.0	768.0	1,086.0	1,341.0	1,686.0	1,982.0	2,182.0
Difference (%)	26.0	13.6	16.4	15.1	14.8	15.7	–31.4	32.9

Source: Shiklomanov 1993, SHI/UNESCO 1999.
Notes: The year next to withdrawal and consumption figures corresponds to the publication year.
[a] Withdrawal stands for total water withdrawal; consumption stands for irretrievable water loss.
[b] Total water use figures are rounded off.

References

Abel, Martin E., and Rojko, Anthony S. 1967. *World food situation: Prospects for the world grain production, consumption, and trade.* USDA Economic Research Service Foreign Economic Report 35, September.

Agcaoili, Mercedita, and Rosegrant, Mark W. 1995. Global and regional food supply, demand, and trade prospects to 2010. In *Population and food in the early twenty-first century: Meeting future food demand of an increasing population,* ed. Nurul Islam, chapter 5. Washington D.C.: International Food Policy Research Institute.

Ahluwalia, M. S. 1976. Inequality, poverty and development. *Journal of Development Economics* 3: 307–342.

Ahluwalia, M. S., Carter, N. G., and Chenery, H. B. 1979. Growth and poverty in developing countries. *Journal of Development Economics* 6: 299–341.

Anand, Sudhir, and Kanbur, Ravi. 1991. *International poverty projections.* Policy, Research, and External Affairs Working Papers No. 617. Washington, D.C.: Office of the Vice President, World Bank.

Avery, Dennis T. 1995. *Saving the planet with pesticides and plastic.* Indianapolis, Ind., U.S.A.: Hudson Institute.

Barney, Gerald O. (study director). 1980–81. *The Global 2000 report to the President—Entering the twenty-first century: A report.* Council on Environmental Quality and the Department of State. Washington, D.C: U.S. Government Printing Office.

Blakeslee, Leroy L., Heady, Earls O., and Framingham, Charles. F. 1973. *World food production, demand and trade.* Ames, Ia., U.S.A.: Iowa State University Press.

Boserup, Ester. 1965. *The conditions of agricultural growth: The economics of agrarian change under population pressure.* Chicago: Aldine Press.

BP Amoco. 2001. *Statistical review of world energy,* 49th ed. Internet document: http://www.bp.com/worldenergy/oil/index.htm.

Brecke, Peter. 1993. Integrated global models that run on personal computers. *Simulation* 60 (2): 140–144.

Bross, Irwin D. J. 1959. *Design for decision.* New York: Macmillan.

Brown, Lester R. 1967. The world outlook for conventional agriculture. *Science,* November 3.

——— 1970. *Seeds of change: The green revolution and development in the 1970's.* New York: Praeger.

——— 1974. *By bread alone.* New York: Praeger.

——— 1976a. *Increasing world food output: Problems and prospects.* New York: Arno Press.

——— 1976b. *Twenty-two dimensions of the population problem.* Washington, D.C.: Worldwatch Institute.

——— 1979. *Resource trends and population policy: A time for reassessment.* Washington, D.C.: Worldwatch Institute.

——— 1988. *The changing world food prospect: The nineties and beyond.* Washington, D.C.: Worldwatch Institute.

——— 1995. *Who will feed China? Wake-up call for a small planet,* 1st ed. New York: W.W. Norton.

——— 1996. *Tough choices: Facing the challenge of food scarcity.* New York: Norton.

Brown, Lester R., and Kane, Hal. 1994. *Full house: Reassessing the earth's population carrying capacity.* London: Earthscan.

Brown, Lester R., Gardner, Gary, and Halweil, Brian. 1999. *Beyond Malthus: Nineteen dimensions of the population challenge.* New York: W. W. Norton.

Clark, Colin. 1970. *Starvation or plenty?* New York: Taplinger.

Cochrane, Willard W. 1969. *The world food problem: A guardedly optimistic view.* New York: Crowell.

Devadoss, S., Westhoff, P., Helmar, M., Grundmeier, E., Skold, K., Meyers, W. H., and Johnson, S. R. 1989. *The FAPRI modeling system at CARD: A documentation summary, 1986.* Technical Report 89–TR 13, Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, December.

Dixit, Praveen M., and Sharples, Jerry A. 1987. USDA's World Wheat Trade Model. In *The international agricultural trade consortium: Agricultural trade modeling, the state of practice and research issues,* ed. K. Liu and R. Seeley. Staff Report No. AGES861215, Washington, D.C.: U.S. Department of Agriculture.

Dyson, Tim. 1996. *Population and food: Global trends and future prospects.* London and New York: Routledge.

Ehrlich, Paul R. 1970. *The population bomb.* New York: Sierra Club.

Ehrlich, Paul R., and Ehrlich, Anne H. 1990. *The population explosion.* New York: Simon & Schuster.

Evans, L. T. 1998. *Feeding the ten billion: Plants and population growth.* Cambridge, U.K., and New York: Cambridge University Press.

FAO (Food and Agriculture Organization of the United Nations). 1946. *World food survey.* Washington, D.C.

——— 1952. *The second world food survey.* Rome.

——— 1962. *Agricultural commodities: Projections for 1970.* Special Supplement. Rome: FAO Commodity Review.

——— 1963. *The third world food survey.* Rome.

——— 1967. *Agricultural commodities: Projections for 1975 and 1985,* 2 vols. Rome.

——— 1971. *Agricultural commodity projections, 1970–1980.* Rome.

——— 1977. *The fourth FAO world food survey.* Rome.

——— 1979. *Agricultural commodity projections, 1975–1985.* Rome.

——— 1981. *Agriculture: Toward 2000.* Rome.

——— 1986. *Agricultural commodity projections to 1990.* FAO Economic and Social Development Paper 62. Rome.

——— 1987. *The fifth world food survey.* Rome.

——— 1988. *World agriculture: Toward 2000: An FAO study,* ed. Nikos Alexandratos. London: Belhaven.

——— 1993. *Agriculture: Toward 2010.* Rome.

——— 1994. *Medium-term prospects for agricultural commodities: Projections to the year 2000.* Rome.

——— 1995. *World agriculture: Toward 2010: An FAO study,* ed. Nikos Alexandratos. New York: Wiley.

——— 1996. *The sixth world food survey, 1996.* Rome.

——— 1998. World food model, technical documentation. Commodity and Trade Division. Rome, May. Unpublished manuscript.

——— 2000a. *Agriculture: Toward 2015/30.* Technical Interim Report. Rome.

——— 2000b. *State of food and agriculture.* Rome.

——— 2000c. *Medium-term prospects for agricultural commodities: Projections to the year 2005.* Rome.

——— 2001. *FAOSTAT database.* Rome. Internet document: http://apps.fao.org.

FAPRI (Food and Agricultural Policy Research Institute). 1995. *FAPRI international outlook 1995.* Iowa State University. Internet document: http://www.ag.iastate.edu/centers/fapri/summary.html.

——— 1996. *FAPRI international outlook 1996.* Iowa State University. Internet document: http://www.fapri.iastate.edu/baseline/home.html.

——— 1997. *FAPRI world agricultural outlook 1997.* Iowa State University. Internet document: http://www.fapri.iastate.edu/outlook97/outlook97—main.htm.

——— 1998. *FAPRI world agricultural outlook 1998.* Iowa State University. Internet document: http://www.fapri.iastate.edu/outlook98/outlook98—main.htm.

——— 1999. *FAPRI world agricultural outlook 1999.* Iowa State University. Internet document: http://www.fapri.iastate.edu/outlook99/outlook99—main.htm.

——— 2000. *FAPRI world agricultural outlook 2000.* Iowa State University. Internet document: http://www.fapri.iastate.edu/outlook2000/outlook2000.htm.

Fischer, G., Frohberg, K., Keyzer, M. A., and Parikh, K. S. 1988. *Linked national models: A tool for international food policy analysis.* International Institute for Applied System Analysis. London: Kluwer Academic Publishers.

Forrester, Jay Wright. 1971. *World dynamics.* Cambridge, Mass., U.S.A.: Wright-Allen Press.

Fox, Glenn, and Ruttan, Vernon W. 1984. A guide to LDC food balance projections. *Research in Domestic and International Agribusiness Management* 5: 165–200.

Herrera, Amilcar. O. 1976. *Catastrophe or new society? A Latin American world model.* Ottawa: International Development Research Centre.

IFPRI (International Food Policy Research Institute). 1977. *Food needs of developing countries: Projections of production and consumption to 1990.* Research Report 3. Washington, D.C., December.

Iowa State University. 1967. *Alternatives for balancing world food production and needs.* Ames: Iowa State University.

Johnson, D. Gale. 1975. *World food problems and prospects.* Washington, D.C.: American Enterprise Institute for Public Policy Research.

Kristensen, Thorkil. 1967. *The food problem of developing countries.* Paris: Organisation for Economic Co-operation and Development, December.

Lapp´e, Frances Moore, Collins, Joseph, and Rosset, Peter, with Luis Esparza. 1998. *World hunger: 12 myths.* New York: Grove Press.

Leontief, W., Carter, A. P., and Petri, P. A. 1977. *The future of the world economy.* New York: Oxford University Press.

Linnemann, Hans, de Hoogh, J., Keyzer, M. A., and van Heemst, H. D. J. 1979. *MOIRA: Model of International Relations in Agriculture.* Amsterdam: North Holland.

Liu, Karen, and Seeley, Ralph, 1987. *The international agricultural trade consortium: Agricultural trade modeling, the state of practice and research issues.* Staff Report No. AGES861215, Washington, D.C.: U.S. Department of Agriculture.

McCalla, Alexander F. 1994. *Agriculture and food needs to 2025: Why we should be concerned.* Sir John Crawford Memorial Lecture. Washington, D.C.: Consultative Group on International Agricultural Research.

Malthus, Thomas R. 1914 [1798]. *An essay on the principle of population,* Reprint. New York: E. P. Dutton.

Meadows, Donella H., Meadows, Dennis L., Randers, J., and Behrens, W. W. 1972. *The limits to growth: A report for the Club of Rome's project on the predicament of mankind.* New York: Universe Books.

Meadows, Donella H., Meadows, Dennis L., Randers, Jorgen. 1992. *Beyond the limits: Confronting global collapse, envisioning a sustainable future.* Post Mills, Vt., U.S.A.: Chelsea Green.

Mesarovic, M., and Pestel, E. 1974. *Mankind at the turning point: The second report of the Club of Rome.* New York: Dutton.

Meyers, William H. 1995. Global outlook. In *Population and food in the early twenty-first century: Meeting future food demand of an increasing population,* ed. Nurul Islam. Washington, D.C.: International Food Policy Research Institute.

Meyers, William H., Devadoss, S., and Helmar, Michael. 1986. *Baseline projections, yields impacts and trade liberalization: Impacts for soybeans, wheat, and feed grains: A FAPRI trade model analysis.* Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, January.

Mitchell, Donald O., and Ingco, Merlinda D. 1993. *The world food outlook.* International Economics Department. Washington, D.C.: World Bank.

Mitchell, Donald O., Ingco, Merlinda D., and Duncan, Ronald C. 1997. *The world food outlook.* New York: Cambridge University Press.

National Research Council (U.S.). 2000. *Beyond six billion: Forecasting the world's population.* Panel on Population Projections, Committee on Population, Commission on Behavioral and Social Sciences and Education. Washington, D.C.

Nordhaus, W. D. 1973. World dynamics: Measurement without data. *Economic Journal* 83 (4): 1156–1183.

Ohkawa, K. 1967. Economic growth and agriculture. *Annals of Hitotsubashi Academy* 7: 46–70.

Organisation for Economic Co-operation and Development, Secretariat. 1968. *Agricultural projections for 1975 and 1985: Country studies.* Paris.

Paddock, William, and Paddock, Paul. 1964. *Hungry nations.* Boston: Little, Brown.

——— 1967. *Famine, 1975! America's decision: Who will survive?* Boston: Little, Brown.

——— 1976. *Time of famines: America and the world food crises,* new ed. of *Famine, 1975!* Boston: Little, Brown.

Panel on the World Food Supply. 1967. *The world food problem: A report of the President's Science Advisory Committee.* Washington, D.C.: U.S. Government Printing Office.

Parikh, K., and Rabar, F. 1981. *Food for all in a sustainable world: The IIASA Food and Agriculture Program.* Laxenburg, Switzerland: International Institute for Applied System Analysis.

Paulino, Leonardo A. 1986. *Food in the third world: Past trends and projections to 2000.* Research Report 52. Washington, D.C.: International Food Policy Research Institute.

Poleman, Thomas, T. 1975. World food: A perspective. In *Food: Politics, economics, nutrition, and research,* ed. Philip H. Abelson. Washington, D.C.: American Association for the Advancement of Science.

Postel, Sandra. 1992. *Last oasis: Facing water scarcity.* New York: W. W. Norton.

Rojko, Anthony S., Urban, Francis S., and Na¨ive, James S. 1971. *World demand prospects for grain in 1980, with emphasis on trade by less developed countries.* Foreign Agricultural Economic Report No. 75. Washington, D.C.: U.S. Department of Agriculture.

Rojko, Anthony S., Fuchs, H., O'Brien P., and Regier, D. 1978. *Alternative futures for world food in 1985,* 3 vols. Foreign Agricultural Economic Report No. 151. Washington, D.C.: U.S. Department of Agriculture.

Rosegrant, Mark W., Agcaoili-Sombilla, Mercedita, and Perez, Nicostrato D. 1995.

Global food projections to 2020: Implications for investment. Food, Agriculture and the Environment Discussion Paper 5. Washington, D.C.: International Food Policy Research Institute, October.

Russell, Sir E. John. 1954. *World population and world food supplies.* London: Allen & Unwin.

Sanders, John H., and Hoyt, Richard C. 1970. The world food problem: Four recent empirical studies. *American Journal of Agricultural Economics* 52 (1): 132–135.

Sen, Amartya K. 1981. *Poverty and famines: An essay on entitlement and deprivation.* New York: Clarendon Press.

Shiklomanov, Igor A. 1993. World fresh water resources. In *Water in crisis, a guide to the world's fresh water resources,* ed. Peter H. Gleick, chapter 2. Pacific Institute for Studies in Development, Environment, and Security, Stockholm Environment Institute. Oxford, U.K.: Oxford University Press.

Simon, Julian L. 1981. *The ultimate resource.* Princeton, N.J., U.S.A.: Princeton University Press.

Simon, Julian L., and Kahn, Herman, eds. 1984. *The resourceful earth: A response to Global 2000.* Oxford, U.K., and New York: Blackwell.

State Hydrological Institute and UNESCO. 1999. *World water resources and their use,* Igor A. Shiklomanov (study director). Internet document: http://espejo.unesco.org.uy/index.html.

Takayama, Takashi, and Judge, George G. 1971. *Spatial and temporal price and allocation models.* Amsterdam: North Holland.

Theil, Henri. 1961. *Economic forecasts and policy,* 2d ed. Amsterdam: North-Holland.

Thompson, Robert L. 1981. *A survey of recent U.S. developments in international agricultural trade models.* Bibliographies and Literature of Agriculture Number 21. Washington, D.C.: U.S. Department of Agriculture.

Tyers, Rodney, and Anderson, Kym. 1992. *Disarray in world food markets: A quantitative assessment.* Cambridge, U.K., and New York: Cambridge University Press.

United Nations. 1966. *World population prospects as assessed in 1963.* New York.

——— 1973. *World population prospects as assessed in 1968.* New York.

——— 1977. *World population prospects as assessed in 1973.* New York.

——— 1979. *World population trends and prospects by country, 1950–2000: Summary report of the 1978 assessment.* Department of International Economic and Social Affairs. New York: United Nations.

——— 1981. *World population prospects as assessed in 1980.* New York.

——— 1986. *World population prospects: Estimates and projections as assessed in 1984.* New York.

——— 1989. *World population prospects, 1988.* New York.

——— 1990. *Global outlook 2000: An economic, social and environmental perspective.* New York.

——— 1991. *World population prospects, 1990.* New York.

——— 1995. *World population prospects: The 1994 revision.* New York.

——— 1998. *World population prospects: The 1996 revision.* New York.

——— 1999. *World population prospects: The 1998 revision.* New York.

University of California, Food Task Force. 1974. *A hungry world: The challenge to agriculture.* Berkeley, Calif., U.S.A.

USDA (U.S. Department of Agriculture). 1961. *The world food budget, 1962 and 1966.* Economic Research Service, Foreign Regional Analysis Division, Washington, D.C.

——— 1964. *The world food budget, 1970.* Economic Research Service, Foreign Regional Analysis Division, Washington, D.C.

——— 1974. *The world food situation and prospects to 1985.* Foreign Agricultural Economic Report No. 98. Washington, D.C.

——— 1994. *Long-term world agricultural commodity baseline projections.* Commercial Agriculture Division, Agricultural Economic Report No. 700. Washington, D.C.

——— 1997. *International agricultural baseline projections to 2005.* Commercial Agriculture Division, Agricultural Economic Report No. 750. Washington, D.C.

——— 1998. *International agricultural baseline projections to 2007.* Market and Trade Economics Division, Agricultural Economic Report No. 767. Washington, D.C.

——— 1999. *Agricultural baseline projections to 2008.* World Agricultural Outlook Board, Staff Report No. WAOB-99-1. Washington, D.C.

——— 2000. *Agricultural baseline projections to 2009.* World Agricultural Outlook Board, Staff Report No. WAOB-2000-1. Washington, D.C.

——— 2001. *PS&D database.* Washington, D.C. Internet document: http://usda.mannlib.cornell.edu/data–sets/international/93002.

Uvin, Peter. 1994. *The international organization of hunger.* New York: Kegan Paul International.

Wilson, David A. 2000. *The history of the future.* Toronto: McArthur & Company.

World Bank. 1979. *World development report 1978.* New York: Oxford University Press.

——— 1980. *World development report 1979.* New York: Oxford University Press.

——— 1981. *World development report 1980.* New York: Oxford University Press.

——— 1991. *World development report 1990.* New York: Oxford University Press.

——— 2001. *World development report 2000.* New York: Oxford University Press.

Worldwatch Institute. 1984. *State of the world, 1984: A Worldwatch Institute report on progress toward a sustainable society.* Lester R. Brown (project director). New York: W. W. Norton.

——— 1988. *State of the world, 1988: A Worldwatch Institute report on progress toward a sustainable society.* Lester R. Brown (project director). New York: Norton.

——— 1990. *State of the world, 1990: A Worldwatch Institute report on progress toward a sustainable society.* Lester R. Brown (project director). New York: Norton.

——— 1991. *State of the world, 1991: A Worldwatch Institute report on progress toward a sustainable society.* Lester R. Brown (project director). New York: Norton.

——— 1993. *State of the world, 1993: A Worldwatch Institute report on progress toward a sustainable society.* Lester R. Brown (project director). New York: Norton.

Yanagishima, Koji. 2000. World food model 97/98. Draft for discussion, version 13. Rome: Food and Agriculture Organization of the United Nations, November. Unpublished manuscript.

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