# Food Security in Food Deficit Countries

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# FOOD SECURITY IN FOOD DEFICIT COUNTRIES

The central proposition of this paper is that periodic shortfalls in aggregate food consumption in the developing countries are primarily related to poor harvests in the countries and not short world supplies. Instability of food grain consumption in the 1960s and early 1970s was high in many countries while the world market was nearly stable. Consumption was highly correlated with production. Neither stocks nor imports were apparently used aggressively enough to counter fluctuations in production.

A simulation model is used to evaluate the stability of food consumption under alternative trade and stock policies. A stabilizing trade policy is shown to be by far the most effective and economically preferred instrument for achieving food security. Aside from political consideration of placing reliance on highly fluctuating levels of imports, which are not discussed in the paper, such policies are feasible only, however, if countries are able and willing to cope with highly fluctuating import bills.

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# PREFACE

Research on which this paper is based is part of a study undertaken by the World Bank (RPO 671-24) on various aspects of food stabilization in developing countries. Previous papers by Reutlinger, et al. (1976), and Bigman and Reutlinger (1979), summarize results from simulations of country scenarios for normally self-sufficient countries. A preliminary analysis of international dimensions of food security is provided by Reutlinger (1978). The authors wish to express their gratitude to D. Bigman, D. Eaton, and Y. Levy who participated in various stages of the development of the model and computer programs.

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## INTRODUCTION AND SUMMARY

Instability in food production, consumption and prices between one year and another has always been a central concern for governments. With a growing interest in preventing severe deprivation among the more disadvantaged segments of the population, food security--meaning the assurance of a minimally adequate level of food consumption--has taken on a special urgency. Yet, there are probably few areas of public policy in which popular notions, governmental behavior and economists' perceptions differ as much about the nature of the problem and the desirability of particular remedial government interventions.

In this paper we briefly review the historical record of the instability in food grain production and consumption in developing countries during the 60s and into the early 70s. This period has been characterized by relative stability in the international food grain market. Yet, while a large number of developing countries could be classified as being deficit countries in almost any year, food grain imports have been used only to a minor extent for stabilizing consumption in the countries. Without food aid, consumption would have been probably even more unstable than actually observed.

We can only speculate why consumption has been unstable and has fluctuated in close concert with production, i.e., why imports were not used more extensively to offset fluctuations in production. Unstable income may be one explanation. Furthermore, and to a limited extent, consumption instability may be inevitably tied up with instability in production. One reason is that there is usually a divergence of price among different regions within each country, depending whether a region is food deficit, surplus or self-sufficient. A decrease in production in a region may cause a former surplus region to become just self-sufficient or even deficit and an increase in production may have the opposite effect. Hence, even a perfectly elastic supply of imports (or a large national buffer stock) could not assure a stable price and consumption in all regions of a country. Moreover, in countries which derive a significant share of their income from agricultural production, the production-consumption link may be further reinforced. At the level of aggregation at which we analyzed the data, it is, of course, not possible to get a clear picture of the importance of these production-consumption links. Yet, we believe it is safe to assume that these links explain only part of the instability in consumption in food deficit countries. The other, and probably major cause of instability, is the fact that many governments of developing countries, in sharp contrast to developed countries, pursue destabilizing trade policies with respect to food imports, be it by choice or by necessity.

The second part of the paper presents a simple grain market model by which it is possible to analyze the effect of alternative trade and buffer stock policies for the stability of a country's per capita food grain consumption and prices in the face of unstable production and world market prices.

Under the hypothetical scenarios analyzed, it is shown that food security, defined as the probability of per capita consumption falling below a specified level, is highly sensitive to the choice of trade policy, while a buffer stock of any reasonable size is generally less effective and usually a relatively more costly instrument for attaining food security and stabilization of consumption. However, to achieve greater food security through stabilizing trade policies, food deficit countries must be willing and able to cope effectively with highly unstable foreign exchange requirements and fiscal resources needed to pursue stabilizing food import policies.

At the international level, establishment of a financial facility for the purpose of assisting countries to pay for higher than normal import bills would be the most effective measure to insure food security. Stabilization of the world's food supply through large buffer stocks, even if politically and financially feasible, would not preclude the need for financial measures to assist countries to cope with highly unstable import requirements arising from domestic instability in production.

## I. THE HISTORICAL RECORD

Instability of food grain consumption between one year and the next has been recorded in the statistics of many nations for a long time. For non-trading nations, the basic underlying cause of instability in consumption is of course the climatically induced instability in domestic production and the only feasible remedy is a large buffer stock operation. It is more difficult to explain unstable consumption in a normally food importing country and to suggest appropriate remedies. From economic theory we would expect instability of food consumption in a food deficit country engaging in free trade to be primarily the consequence of instability in domestic demand and the international price of food. Instability in domestic production, as well as the extent of buffer stock operations should be of consequence for the stability of consumption only to the extent that they impact on the dispersion of food prices within the country, and indirectly, on the stability of demand.

The historical record of instability in food consumption of developing countries in the 60s and into the early 70s raises interesting questions about the underlying causes of that instability. During this period, international prices for food grains have been relatively stable and most developing countries were food deficit countries.[1/] Yet, the data reveal not only high instability in consumption, but also a strong and significant correlation between consumption and production.

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1/ By a "food deficit country" we mean that the country's production is short of consumption even in a year of a good harvest and "low" demand.

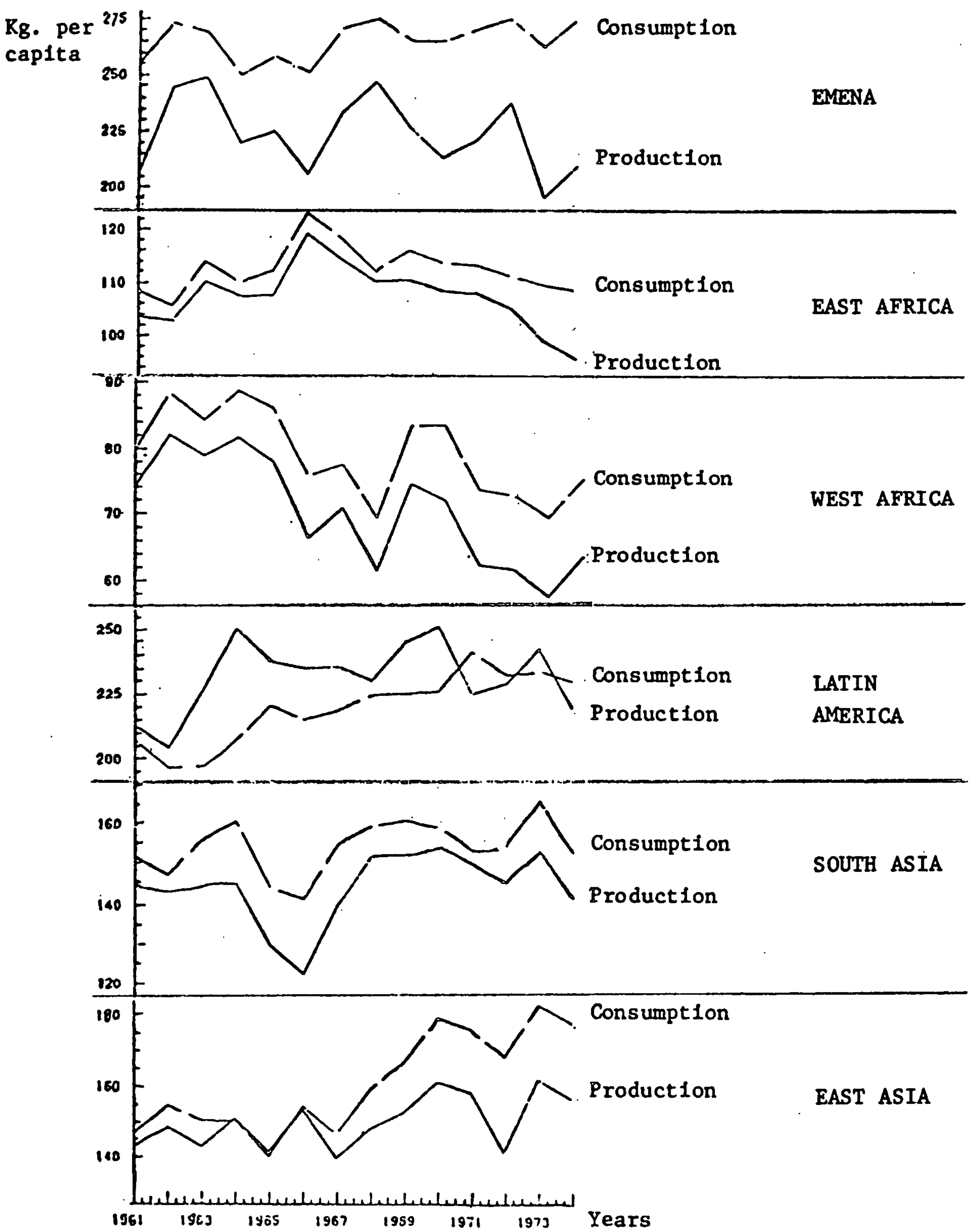
Annual per capita food grain consumption and production data for developing countries by major regions are graphically shown in Figure 1. Table 1 gives some summary statistics based on the same data. As can be seen, imports represent a small share of total consumption but are always positive (except for East Asia). For Africa and East Asia, annual consumption is as unstable as production. In the remaining regions, the coefficient of variation of annual consumption is a little over half the coefficient of variation of production. Table 2 provides similar statistics for individual countries. As expected, the coefficients of variation for individual countries are generally much higher than for regional aggregates. Table 2 also shows that deviations from underlying trends in consumption are highly correlated with deviations from production.

Table 1: MEAN LEVELS AND COEFFICIENTS OF VARIATION OF ANNUAL PER CAPITA CONSUMPTION, PRODUCTION, IMPORTS AND INCOME IN DEVELOPING COUNTRIES BY REGIONS, 1961-1972

| Region | Mean | | | | Coefficient of Variation | | | |
|---|---|---|---|---|---|---|---|---|
| | Consumption | Production | Imports | Income | Consumption | Production | Imports | Income |
| | ------ kg/cap ----- | | | $ | ---------- % -------- | | | |
| Europe, Middle East & N.Africa | 265 | 227 | 39 | 483 | 2.9 | 6.4 | 24.9 | 1.6 |
| East Africa | 113 | 109 | 5 | 125 | 3.6 | 3.9 | 27.6 | 0.8 |
| West Africa | 80 | 72 | 8 | 164 | 6.3 | 6.8 | 11.4 | 7.2 |
| South America (excl. Argentina) | 196 | 175 | 21 | 624 | 3.0 | 5.3 | 31.7 | 2.0 |
| South Asia | 154 | 144 | 10 | 111 | 3.8 | 5.9 | 40.3 | 2.3 |
| East Asia & Pacific | 158 | 148 | 9 | 189 | 4.7 | 4.1 | 257.0 | 2.7 |

For the regionally aggregated data, we also calculated regressions between per capita consumption and production. As can be observed from the results reported in Table 3, the regression coefficients are all significant,

Figure 1: TOTAL GRAINS: PRODUCTION AND CONSUMPTION PER CAPITA 1961-1974




Source: Sandra Hadler, "Developing Country Foodgrain Projections for 1985," World Bank Staff Working Paper No. 247, November 1976.

Table 2: INDICATORS OF RELATIVE VARIABILITY IN STAPLE FOOD CONSUMPTION AND PRODUCTION IN SELECTED COUNTRIES, 1961-1976 /a

| | Coefficient of Variation | | Correlation coefficient between total consumption and production |
|---|---|---|---|
| | Consumption /b (%) | Production /c (%) | |
| **Asia** | | | |
| Bangladesh | 7.6 | 6.4 | .90 |
| India | 5.3 | 6.4 | .89 |
| Indonesia | 6.1 | 5.4 | .92 |
| Korea, Rep. of | 6.5 | 7.1 | .20 |
| Philippines | 3.3 | 5.7 | .03 |
| Sri Lanka | 8.3 | 9.3 | .56 |
| **North Africa/Middle East** | | | |
| Algeria | 24.6 | 28.9 | .78 |
| Egypt | 12.6 | 4.5 | .29 |
| Jordan | 21.2 | 65.6 | .63 |
| Libya | 16.2 | 28.0 | .62 |
| Morocco | 19.3 | 27.2 | .98 |
| Syria | 18.7 | 38.8 | .92 |
| **Sub-Sahara Africa** | | | |
| Ghana | 6.1 | 5.8 | .98 |
| Nigeria | 5.6 | 5.7 | .99 |
| Senegal | 15.7 | 18.6 | .99 |
| Tanzania | 14.6 | 12.7 | .98 |
| Upper Volta | 9.5 | 9.8 | .95 |
| Zaire | 4.1 | 4.9 | .96 |
| **Latin America** | | | |
| Brazil | 5.8 | 5.2 | .92 |
| Chile | 14.4 | 11.1 | .54 |
| Colombia | 4.7 | 4.4 | .51 |
| Guatemala | 6.9 | 6.5 | .51 |
| Mexico | 5.3 | 7.7 | .53 |
| Peru | 3.9 | 9.8 | .37 |

/a Source: A. Valdes and P. Konandreas, "Assessing Food Insecurity in Developing Countries," October 1978 (unpublished).

/b Defined as the standard deviation of $\frac{C_t - \hat{C}_t}{\hat{C}_t}$.

/c Defined as the standard deviation of $\frac{Q_t - \hat{Q}_t}{\hat{Q}_t}$.

i.e., variations in productions seem to "explain" a significant portion of consumption instability. An increase in production of 1 kg. has led to an increase of 1/2 to 1 kg. of consumption and, vice versa, a decline in production has the opposite effect of the same magnitude.

Table 3: REGRESSIONS OF ANNUAL PER CAPITA CONSUMPTION ON PRODUCTION, 1961-1972

| | Regression Coefficients a/ | | | |
|---|---|---|---|---|
| Region | Constant | Production | Time | $R^2$ |
| EMENA | .154 | .45* (4.8) | .001* (2.8) | .78 |
| East Africa | .009 | .94* (11.9) | .0002* (1.96) | .95 |
| West Africa | .003 | 1.01* (15.7) | .0006* (4.04) | .98 |
| South America (excl. Argentina) | .126 | .29 (1.6) | .002* (4.4) | .80 |
| South Asia | .069 | .58* (4.7) | .00007 (.2) | .74 |
| East Asia & Pacific | .007 | .91* (3.52) | .002* (3.94) | .83 |

a/ Numbers in ( ) are t-statistics.

* Indicates significance at the 95% level.

What, then, were the sources of the unexplained variability in consumption and why did deviations in productions lead to similar deviations in consumption? To put it in another way, why were imports not used more extensively to offset deviations in production during the period in which the world price of food grains was relatively stable? 1/

1/ The coeficient of variation of wheat price was approximately 4% and of rice price 16%.

The most obvious other variable which might explain variations in consumption (and imports) is income. By comparing the results of the regressions with income and production reported in Table 4 with the results of the regressions with production alone reported in Table 3, we note that income contributes significantly to the explanation in only one region.
The change in the coefficient for production also suggests that in that region and several other regions the correlation between income and production is positive; hence the upward bias in the partial regression coefficient, if income is deleted from the regression. The absence of a very significant contribution of income toward explaining the instability in consumption is undoubtedly the consequence of income not having fluctuated very much about its trend.

For the purposes of this study, we do not intend to pursue this empirical analysis very far, nor would this likely to be very productive at such a high level of country and commodity aggregation. Yet it is interesting to speculate a little further about the reasons for the observed instability in consumption and the observed significant effect of production. Offhand, we would certainly expect that consumption (and imports) must have been also affected by (a) the amount of food aid, i.e., the extent to which food imports were obtained at below the commercial import price, (b) the shadow exchange rate, and (c) government food import restrictions. All of these variables may have been highly unstable from year to year as well as having been correlated with production.

It is well known that regression coefficients estimated by least squares are biased when the model is underspecified and if the missing

Table 4: REGRESSIONS OF ANNUAL PER CAPITA CONSUMPTION ON PRODUCTION AND INCOME, 1961-1972

| Region | Regression Coefficients 1/ | | | | |
| --- | --- | --- | --- | --- | --- |
| | Constant | Income | Production | Time | $R^2$ |
| Europe, Middle East & N.Africa | .139 | .05 (.29) | .45* (4.6) | .00008 (.02) | .78 |
| East Africa | .063 | -.51 (1.6) | .94* (12.9) | .0014 (1.8) | .96 |
| West Africa | .001 | .04 (1.92) | .99* (17.1) | .0003* (2.0) | .98 |
| South America (excl. Argentina) | -.004 | .21 (1.2) | .46* (2.1) | -.001 (.4) | .83 |
| South Asia | .017 | .75 (1.3) | .42* (2.5) | -.0009 (1.1) | .79 |
| East Asia and Pacific | -.09 | .88* (4.5) | .81* (5.5) | -.005* (3.2) | .95 |

1/ Numbers in ( ) are t-statistics.

* Indicates significance at the 95% level.

variables are correlated with the included variables. If the effect of the missing variable and the correlation of the missing variable with the included variable are both positive or negative, the estimated coefficient has an upward bias. If the effect and the correlation are in opposite directions, the result is a downward bias. We think it is reasonable to postulate the following positive (+) and negative (-) effects, correlations and consequent directions of bias included in the estimated regressions reported in Tables 3 and 4.

| Missing Variable | Effect on Consumption | Correlation with Production | Bias in Coefficient of Production |
|---|---|---|---|
| Food aid | + | - | - |
| Shadow exchange rate | - | - | + |
| Government import restrictions | - | - | + |

The food aid effect is positive on consumption, but only to the extent that the country obtains all its imports on food aid terms, or, alternatively, if food aid leads to a more ready adoption of food price subsidy schemes. Food aid, while being affected by many other determinants, is likely to have been also somewhat responsive to production shortfalls. On balance, therefore, having neglected to consider food aid might have resulted in an underestimation of the effect of production on consumption.

Obviously, the higher the exchange rate, the higher will be the cost of food and the lower consumption. We can only speculate on how variable the shadow exchange rate is from one year to the next and whether the exchange rate is significantly affected by food grain production. Yet there can be little doubt about the direction of the correlation between the exchange rate and production. The demand for food imports will diminish with increases in production and, since food grain production is likely to run in the same direction as the production of agricultural exports, there is also likely to be an increase in the supply of foreign exchange with increased production. Hence, we should expect a negative correlation between the exchange rate and production. In this case our speculations would lead us simply to a better understanding of the way in which production instability leads to instability in consumption. In turn, this might suggest that measures to stabilize the exchange rate might be more effective, more feasible, and less costly than the stabilization of supply.

It is well known that most countries do not conduct their trade on the basis of the shadow exchange rate. Particularly with respect to food imports, governments frequently take charge of all foreign trade operations or exercise strict controls through the issuance of import and export licenses. While not being entirely oblivious to market demand, the amount of food imports allowed tends to be fairly inflexible with the result that the effective exchange rate tends to be far in excess of the shadow exchange rate in years of poor harvests, while being close to the shadow rate in normal or better than normal years (for some econometric evidence, see Abbott and Sarris). Of all the variables mentioned so far, governmental controls over food imports in violation of free trade principles may well have been the most significantly determinant of the level and stability of food consumption in food deficit countries. This is not to say, however, that even without government intervention and with stable import prices, aggregate national consumption would not have been somewhat unstable as a consequence of unstable production, income, and the exchange rate, as well as the stability of the distribution of income and production among regions and consumer groups.

The empirical evidence presented so far is of course no more than suggestive of the complexity of the phenomenon called food security. Only on one point, the evidence is conclusive: a stable world food price is not a sufficient condition for stable food consumption in the developing countries. Whether countries are able to or should stabilize consumption to a greater extent than in the past through changes in their present import and internal income and food distribution policies or through expanded buffer stock operations remains an important issue. While further empirical research is needed, we believe that policy simulation models and simulation experiments of the kind presented below can also contribute to increasingly more realistic assessments of policies aimed at improving food security.

## II. THE MODEL[1/]

To study the effects of various food security policies we use a partial equilibrium model of the grain sector in a small, normally importing country. There is only a single grain commodity which is assumed to be some aggregation of the various foodgrains actually consumed. Time is discrete in this model,with the length of each period being the time between successive harvests.

Our assumptions about production and demand are quite simple. Domestic production is assumed to be a normal random variable with identical, independent distributions in each year. There is no supply response to annual price variations. However, mean production is responsive to the expected price prevailing under different trade policy scenarios. World prices are generated from a normal distribution of world production and a kinked world demand.

Policies pursued by the government are of two general types--grain reserves and trade policies. The grain reserve is of fixed capacity and is operated by the government with public knowledge of its operating rules. In particular, two kinds of rules have been used--"optimal" rules and "food-security" rules. The trade policies to be considered here are of four types:

(1) Free Trade--that is, the government imports grain so that domestic prices and border prices are equalized;

(2) Restricted Trade--a tariff is added to the border price and grain is imported so that domestic price equals the border price plus the tariff;

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1/ The model is similar to the one reported in Bigman and Reutlinger (1979). It differs in the addition of one trade policy (constrained trade) and in the buffer stock operating rules.

(3) Stabilizing Trade--the government stabilizes the domestic price (and hence, consumption) by the use of variable import taxes;

(4) Constrained Trade--grain is imported as under free or stabilizing trade, with the exception that the total import bill can be no larger than a specified amount.

Operation of the model is straightforward. By sampling procedures, a large number of supply events are generated in accordance with predetermined probabilities. For each world supply level the model determines a world price. Similarly, for each level of the country's supply and world price and given carryover levels of stocks, the model determines (a) the amount of grain imported, stored (positive or negative) and consumed in the country and (b) the country's internal grain price and the economic and financial gains (or losses) to various sectors, generally calculated on the basis of the incremental consumer and/or producer surplus from a particular policy. Summary statistics and frequency distributions of many variables are obtained on the basis of 9000 observations (300 replications of 30-year time horizons).

The particular trade and stock policies considered will now be described in some detail.

## Trade Policies

Trade policies may be viewed as different perceptions, on the part of the government, of either the marginal cost of importing additional food or the desirability of using the market demand curve to determine consumption levels. In each case, however, consumption in a particular year is fixed at the level at which the marginal cost of imports intersects the relevant "demand" function. Imports make up any difference between the consumption level so determined and production in that year.

(a) Under Free Trade, demand is the market demand (DM) and the marginal cost of imports is the import price ($p_m$), i.e., the world price plus import costs. (Consumption and imports corresponding to Free Trade are designated as c and m in Figure 2).

(b) Under Restricted Trade, demand is the same as under Free Trade, but the marginal cost of imports is the import price plus a tariff, $p_m^*$. (Consumption and Imports corresponding to Restricted Trade are designated as $c^*$ and $m^*$ in Figure 2.)

(c) Under Stabilizing Trade, the government imposes its demand schedule (DG), which implies import subsidies when the import price is high and import tariffs when the import price is low. (Consumption and Imports corresponding with stabilizing trade are designated as $c^{**}$ and $m^{**}$ in Figure 2.)

(d) Under Constrained Trade, there is an upper limit on the food import bill. This implies that the marginal import price is either the import price or the intersection of the domestic demand and the inelastic production plus the maximum allowable import level, depending on the level of production in the particular year and the import price. If production is high, consumption and imports are likely

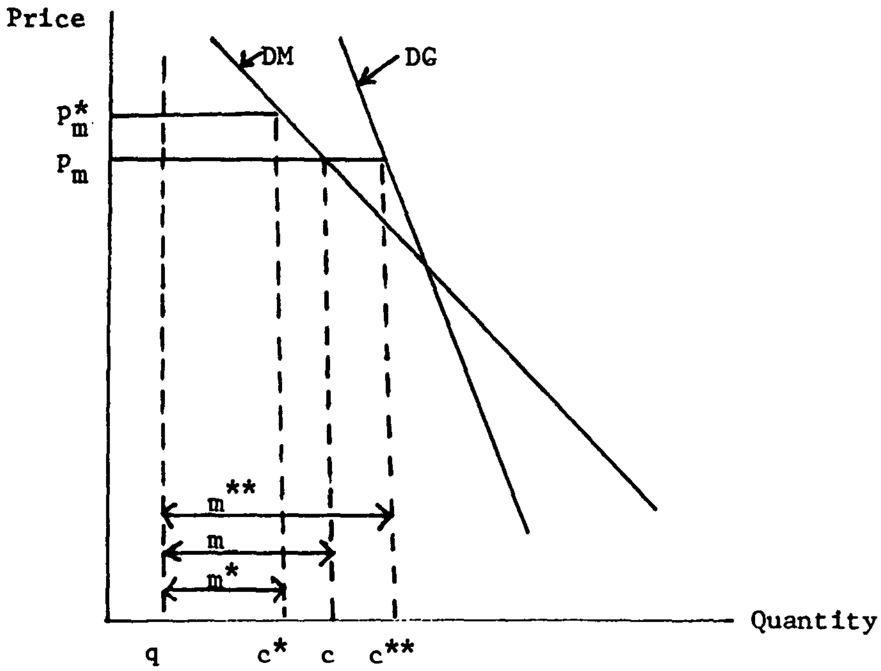


Figure 2: ILLUSTRATION OF FREE TRADE, RESTRICTED TRADE AND STABILIZING TRADE POLICIES

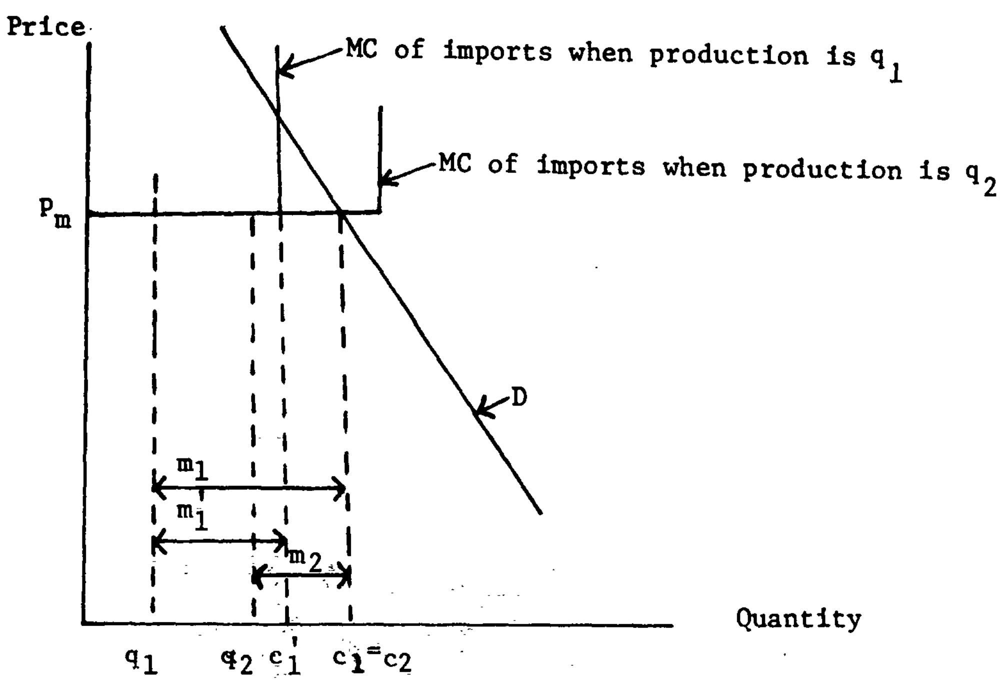


Figure 3: ILLUSTRATION OF CONSTRAINED TRADE POLICY

to be the same as under unconstrained trade; however, when production is low, consumption and imports could be less. (In Figure 3, note that when production is high ($q_2$) imports and consumption, $m_2$ and $c_2$, are the same under both unconstrained and constrained trade. However, when production is low ($q_1$) imports and consumption are $c_1$ and $m_1$, under unconstrained trade, whereas imports and consumption are $m_1'$ and $c_1'$ under constrained trade.)

## Stock Policies

The buffer stock has an upper limit determined by a fixed storage capacity. The level of annual storage activity is determined on the basis of a carryover demand function. Storage costs include the initial construction costs of the facility plus variable costs which are incurred whenever grain is put into storage or taken out of storage.

Carryover demand in the model is a linear function of the domestic price and is constrained not to exceed a prespecified maximum storage capacity. The method for specifying alternative parameters of the functions used in the simulation experiments will be described later on. Figure 4 illustrates how a carryover demand function, $D^k$, is used to determine whether grain is put into or taken out of storage. If the domestic price is above $p_t^o$ , carryovers are zero and any amount of grain held in storage from the previous year is released. If the domestic price is $p_t^1$ , for example, the carryover level is $k_t$. Whether grain is added to or taken out from storage depends on the size of the stock already held in storage; if that stock is for example, $k_o$, an amount of grain equal to $k_o - k_t$ is released from storage, but if that stock is only $k_o'$ an amount equal to $k_1 - k_o'$ is added to the stock. If the

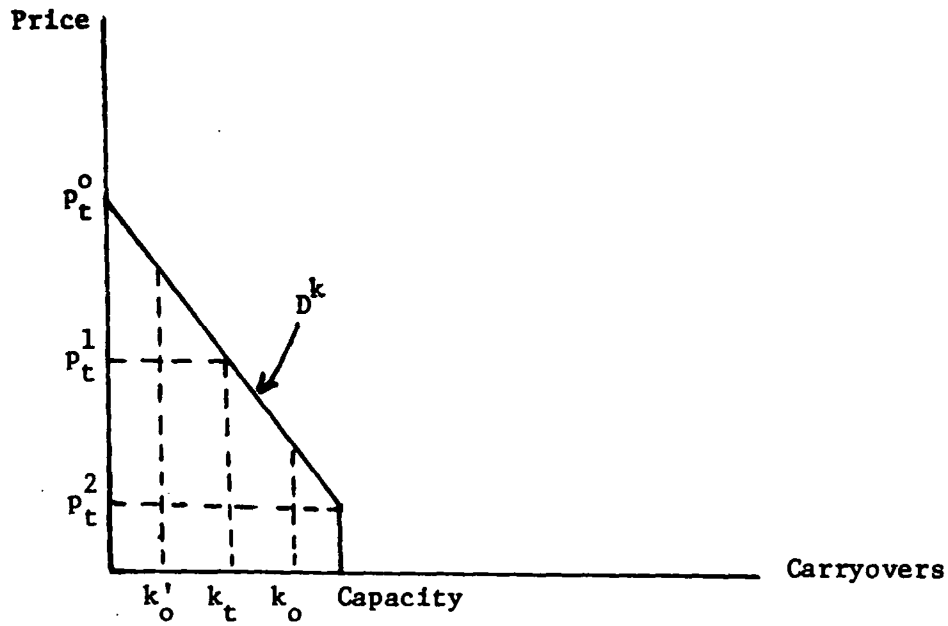


Figure 4: THE CARRYOVER DEMAND FUNCTION

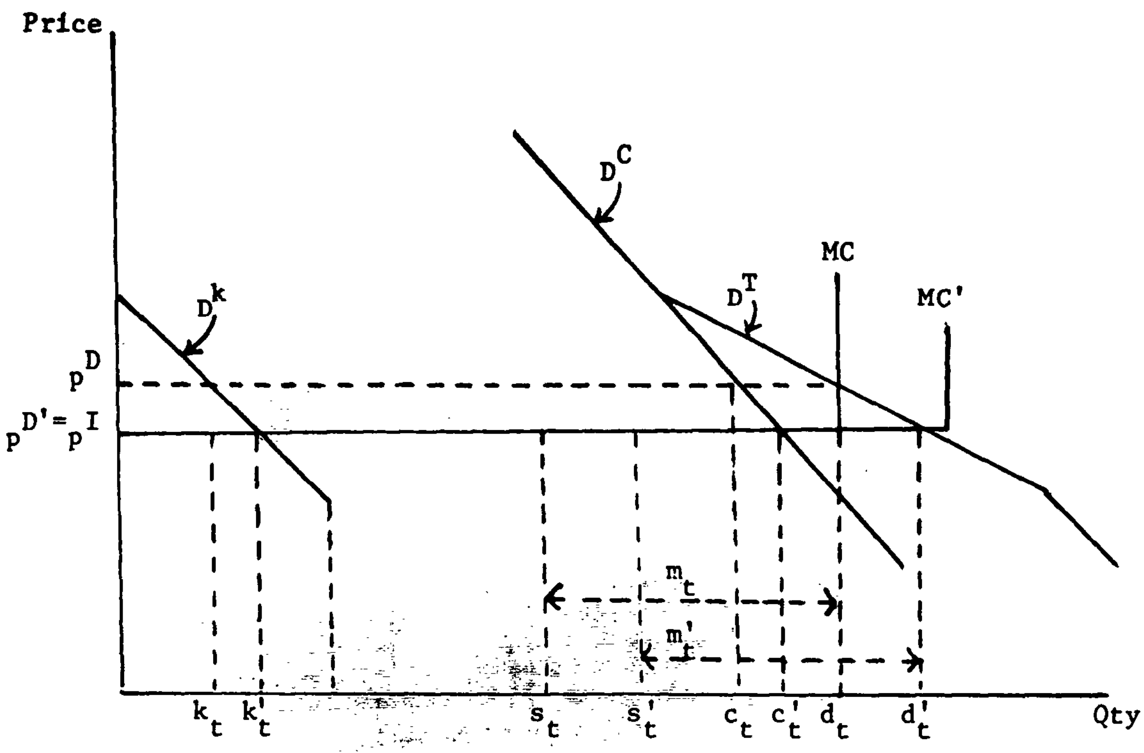


Figure 5: JOINT DETERMINATION OF DOMESTIC PRICE, CARRYOVER, CONSUMPTION AND IMPORTS

domestic price is less than $p_t^2$ and the stock in storage is any less than the maximum capacity, the existing stock is augmented to the extent of the full storage capacity.

In general, the domestic price, imports and consumption are determined simultaneously. This is illustrated in Figure 5 for the constrained trade policy. First, the carryover demand, $D^k$, is added horizontally to the domestic demand $D^C$, resulting in a total demand function, $D^T$. Given the import price, $p^I$, Figure 5 illustrates the marginal import cost function (MC) for two levels of domestic supply $s_t$ and $s_t'$. The domestic supply is the sum of the current harvest and the carryover level from the previous year. If the domestic supply is $s_t$, the domestic price is $p^D$, the carryover level is $k_t$, current consumption is $c_t$, total effective demand is $d_t$ and imports are $m_t$. If the domestic supply is larger, i.e., $s_t'$, the domestic price is $p^I$, the import price, the carryover level is $k_t'$, current consumption is $c_t'$, total effective demand is $d_t'$ and imports are $m_t'$.[1/]

We now return to discuss the specifications of the carryover demand function on the basis of two kinds of stock operating rules: rules which are optimal in some sense and rules which provide for maximum food security.

The optimal carryover demand function was derived by using a dynamic programming algorithm, which is more fully discussed in the Appendix. Optimal stock operating rules maximize the net economic benefit--or minimize

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1/ Simulation of carryovers, consumption and imports under unconstrained trade is similar. The only difference is that the marginal cost of imports (MC) is infinitely elastic. Correspondingly, the optimal carryover function is also infinitely elastic within the limits of the storage capacity.

the cost--of operating a buffer stock, constrained by a predetermining size storage capacity. Like Gustafson (1958) and later applications of his methodology (for example, Johnson and Sumner [1975]) the objective function in the optimization model uses the area under the market demand curve as a measure of consumption benefits.[1/] However, this algorithm represents an extension of those earlier works by determining optimal decision rules for both carryovers and imports when domestic production and the import price are random variables.

From the dynamic programming solution to the optimization problem we can readily calculate for any year the discounted value of expected future benefits to be received from different levels of carryovers in that year. Subsequently a linear approximation to the expected marginal value of carryovers is obtained. Subtracting the per unit storage costs gives the net expected marginal value of carryovers and this function was used as the carryover demand function.[2/]

That this procedure yields the optimal import and carryover decisions for a given domestic supply and import price can be seen intuitively. First let the domestic demand curve be interpreted as giving the marginal benefits of current consumption. Then referring back to Figure 5, it is seen that imports and carryovers are set so that the marginal benefits of current consumption equal the expected net marginal benefits of carryovers while both are

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1/ Clearly this implies optimality in a narrow sense, i.e., the rules are optimal only to the extent that consumer surplus is the correct measure of benefits and that the objective function is risk neutral, etc.

2/ Within the limits of our linear approximation to the marginal value of carryovers.

equal to the marginal cost of imports. Thus there would be no gain from decreasing current consumption by one unit and increasing carryovers by one unit or vice versa.

The second type of storage rule used in the simulations is oriented towards food security, i.e., to minimize the probability that consumption falls below some critical level. This rule, which we have called the food-security rule, is illustrated in figure 6 where $c^{critical}$ is the critical consumption level and $p^{critical}$ is the associated equilibrium price. In this case we let the carryover demand function be horizontal at $p^{critical}$ so that the total effective demand curve, $D^T$, has the shape illustrated.

The effect of this particular carryover demand specification is to ensure that in relatively good years as much grain as possible is kept in storage for use in the years in which consumption would otherwise be below $c^{critical}$. For example, with an import price of $p$ and supply of $s_t$, any imports above those necessary to maintain consumption at $c^{critical}$ are put into storage.

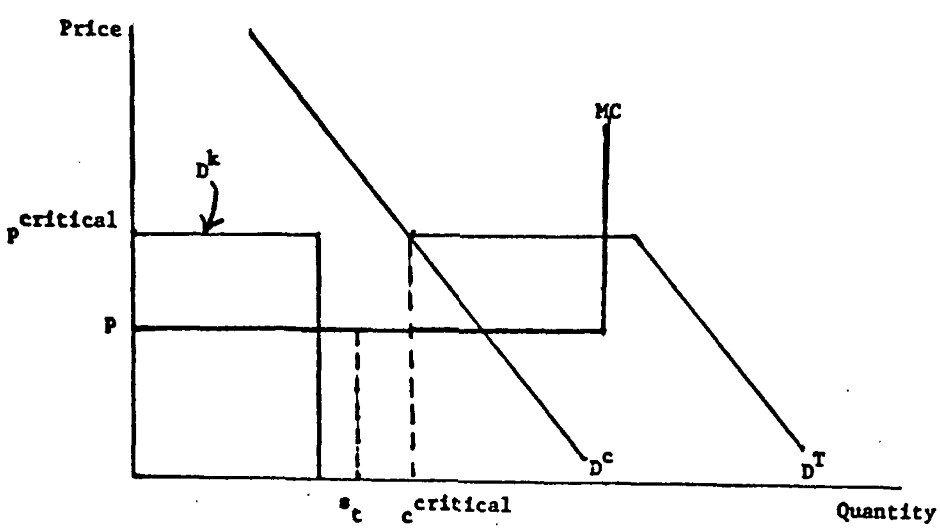


Figure 6: THE CARRYOVER DEMAND FUNCTION AND TOTAL EFFECTIVE DEMAND FOR THE FOOD-SECURITY STORAGE RULES

## III. POLICY SIMULATIONS

We now proceed to illustrate the application of the model by reference to a hypothetical country. Specifically, the purpose of the simulation experiments is to investigate the consequences of the country pursuing alternative trade and stocks policies for food security and the stability of grain consumption, prices and external food trade and, relatedly, to determine the long run expected gains or losses by consumers, producers, the government and the economy at large.

The basic parameters of the model were assumed to be as follows:

- World price is a random variable generated from transforming a normal distribution of world production with mean 350 and standard deviation of 14 with a kinked linear demand function. At the vicinity of $Q = 350$, the elasticity of demand of the segment corresponding with $Q < 350$ is -0.1 and the elasticity of the segment corresponding with $Q > 350 = -0.3$. The derived price has a skewed distribution with a mean of approximately \$140, a median of \$125 and a standard deviation of approximately \$33. 95% of all times, the world price is in the range of \$92 and \$223.
- The import price is assumed to be \$25 above the world price, hence, the average import price is approximately \$165. The country's imports are assumed not to affect the world price.
- Domestic demand is linear with an elasticity of -0.2 when the price is \$165 and consumption per capita is 130 kg.

Expected domestic per capita production $Q^*$ is a function of the expected domestic price $P^*$ under a given trade policy, as follows: $\ln Q^* = 3.0734 + 0.3 \ln P^*$

and annual domestic production is:

$$Q_t = Q^* + e_t$$

where $e_t$ is distributed normally with mean zero and standard deviation of 7 kg. Under free trade, expected per capita production is 100 kg. For restricted and constrained trade, $P^*$ and $Q^*$ were derived through successive iterations of the model.

The Restricted Trade policy is assumed to be implemented through a constant import tax of $25.

Under the Stabilizing Trade policy, the country's demand is assumed to be linear with an elasticity of -0.1 when the price is $165 and per capita consumption is 130 kg. At the mean import price no tax or subsidy is required. The marginal subsidy (tax rate) above (below) $165 is 0.5. When the import price is $30 above the mean price, for instance, the subsidy to the domestic market is $15. The total cost of the subsidy is about 8% of the import bill. Similarly, the tax collected when the import price is $30 below the mean is $15. The tax revenue is then about 12% of the food import bill.

Under the Constrained Trade policy, the maximum allowable food import bill is approximately the mean import bill, i.e., $5 per capita (30 kg. x $0.165/kg).

- The parameters of the optimal carryover demand function under constrained trade were derived by using the separate dynamic programming algorithm described in the Appendix. Letting P represent the domestic price ($/ton) and K the desired carryover level (kg/capita), the equations for different storage capacities are as follows:

| Capacity (kg/cap) | Equation |
|---|---|
| 4 | $P = 165 - 2.435K$ |
| 8 | $P = 165 - 2.083K$ |
| 12 | $P = 165 - 1.684K$ |
| 16 | $P = 165 - 1.420K$ |

For the food security oriented policy, the carryover demand function is horizontal at P=195.

- The assumed storage cost is 8% of the value of grain held in storage, a $5 per ton loading charge and a fixed amortization charge of $9.36 per ton of storage capacity (i.e., an investment of $100 per ton amortized at 8% over 30 years).

## A. Simulated Results: National Trade Policies

Table 5 shows the consequences of different trade policies for food security and the stability of related indices, given the above specified parameters. A primary concern for food security is the probability of consumption falling below a critical level and the extent of such shortfalls when they occur.

Table 5: POLICY SIMULATIONS: INDICES OF STABILITY WITH DIFFERENT TRADE POLICIES

| Policy | Food Security: Consumption below 125 kg/cap | | Import Bill: Probability of being in excess of $5/cap | Coefficient of variation of: | | | |
|---|---|---|---|---|---|---|---|
| | Probability of occurrence | Expected shortfall 1/ | | Consump-tion | Farm income | Import bill | Gov't. revenue |
| | (%) | (kg/cap) | (%) | (%) | | | |
| Free trade | 18 | 4.3 | 41 | 4.2 | 22.4 | 24.9 | 0 |
| Constrained free trade | 26 | 5.3 | 0 | 5.0 | 21.6 | 20.0 | 196 |
| Stabilizing trade | 6 | 1.9 | 41 | 2.1 | 12.7 | 26.1 | 696 |
| Constrained stabi-lizing trade | 20 | 4.8 | 0 | 3.8 | 14.9 | 19.1 | 167 |
| Restricted trade | 33 | 5.2 | 7 | 4.2 | 19.3 | 35.5 | 40 |

1/ Average amount by which consumption is below 125 kg. when shortfall occurs.

Table 6: POLICY SIMULATION: EXPECTED VALUES OF PRICE, CONSUMPTION, PRODUCTION, AND IMPORT BILL AND GAINS (LOSSES) DUE TO DEVIATING FROM FREE TRADE

| Policy 1/ | Expected Annual Value of: | | | | Expected Annual Gain (Loss) due to Deviation from Free Trade | | | |
|---|---|---|---|---|---|---|---|---|
| | Consump-tion | Produc-tion | Import bill | Gov't. revenue | Consumers surplus | Producers surplus 2/ | Gov't. Revenue | Economy |
| | (kg/cap) | (kg/cap) | ($/cap) | | (kg/cap) | | | |
| Free trade | 130 | 100 | 4.75 | - | -- | -- | -- | -- |
| Constrained free trade | 129 | 101 | 4.27 | 0.31 | (1.28) | 0.92 | 0.31 | (0.04) |
| Stabilizing trade | 130 | 100 | 4.82 | -0.07 | (0.15) | 0.06 | 0.07 | (0.02) |
| Constrained stabi-lizing trade | 128 | 102 | 4.25 | -0.38 | (1.47) | 1.03 | 0.38 | (0.06) |
| Restricted trade | 126 | 105 | 3.38 | 0.55 | (3.18) | 2.53 | 0.54 | (0.11) |

1/ The respective expected prices with the different policies are $164, $174, $164, $175 and $188.

2/ Net Farm Income divided by the total population.

Constrained trade represents most closely the actual food import policy pursued in many developing countries. The difference between constrained free trade and constrained stabilizing trade is that in the latter case, the government facilitates consumption in excess of what it would be otherwise when the world price is high and intervenes in the opposite direction when the world price is low. In both cases, financial constraints limit the maximum size of the import bill. As a consequence of the imposition of the financial constraint, food security is less than what it would be without government intervention. The constrained trade policy is seen to result also in a highly unstable fiscal budget, if as we have assumed, the government implements the constrained trade policy by the imposition of tariffs on imports or trades on its own account (i.e., when the domestic price rises above the import price, the government collects the difference between the lower import price and the higher domestic price). In turn, free trade is seen to result in a high probability of encountering a large import bill.

The consequences of restricted trade for food security are, as expected, negative. What is interesting is the magnitude of the effect on food security from a relatively low tax on imports (about 15%). Protection of agriculture is increasingly advocated in some quarters in order to provide an incentive to increase production. There can be no question, however, that for a food deficit country, protection reduces consumption and hence could be detrimental to food security.

At the other end of the spectrum, food security can be significantly enhanced by the kind of intervention subsumed under a stabilizing trade policy. This policy, which is effectively pursued by some of the wealthier food deficit and surplus countries, can be used to stabilize the food supply to any desired degree, but its implementation requires measures to cope not only with unstable foreign exchange requirements but also with unstable demands on the fiscal resources of the government. Nevertheless, given the potential effectiveness of the policy, an investigation of ways by which the financial, managerial and political constraints to its implementation could be removed deserves high priority attention among all the efforts to bring about food security.

In Table 6 we report on selected long-run consequences which might also explain why some policy is preferred to another. For instance, the Restricted Trade policy is shown to reduce the average food import bill by about 25% due to both reduced average consumption and increased production. It is also noteworthy that, in general, deviations from free trade are not extremely costly to the overall economy. For instance, a cost of $0.02 per capita (e.g., $200,000 for a country with a population of 10 million people) incurred with the stabilizing trade policy which has a large positive effect on food security, may be quite tolerable. However, some policies are seen to result in very sizeable gains for some and losses for other groups in the population or for the government account. These distributional consequences of different policies may well explain why some policies have greater political support than others. It must be emphasized, however, that the actual magnitude and even whether some group gains or loses is very sensitive to the particular specification of the demand and supply function. For instance, with a linear demand function, it is a foregone conclusion that consumers lose and producers gain from stabilization (Turnovsky). With a constant elasticity function and certainly with a demand function by which elasticity increases with the quantity supplied, the distribution of gains and loses between consumers and producers from stabilization would be reversed.

B. Simulation Results: Buffer Stocks

In contrast to the high sensitivity of food security to trade policies, as seen in the previous section, the simulation results of different stock scenarios reported in Table 7 show that stocks are relatively ineffective and/or costly.

Table 7: FOOD SECURITY AND ECONOMIC COSTS OF BUFFER STOCKS (OPERATED BY ALTERNATIVE RULES) UNDER FREE TRADE AND CONSTRAINED FREE TRADE

| | Free Trade | | Constrained Free Trade | | | |
|---|---|---|---|---|---|---|
| | "Security" Stock Policy | | "Optimal" Stock Policy | | "Security" Stock Policy | |
| Storage capacity | Food security 1/ | Cost 2/ | Food security 1/ | Cost 2/ | Food security 1/ | Cost 2/ |
| kg/cap | (%) | ($/cap) | (%) | ($/cap) | (%) | ($/cap) |
| 0 | 17.6 | - | 25.9 | - | 26.9 | - |
| 4 | " | .03 | 24.5 | .01 | 23.0 | .03 |
| 8 | " | .07 | 23.5 | .03 | 21.0 | .06 |
| 12 | 17.3 | .11 | 22.6 | .06 | 20.1 | .11 |
| 16 | 16.2 | .16 | 22.0 | .09 | 18.8 | .15 |
| 20 | 14.4 | .20 | - | - | 17.4 | .20 |
| 24 | 11.1 | .26 | - | - | - | - |
| 28 | 8.2 | .32 | - | - | - | - |
| 32 | 6.0 | .39 | - | - | - | - |
| 36 | 4.6 | .46 | - | - | - | - |
| 40 | 3.8 | .54 | - | - | - | - |

1/ Food Security is defined as the probability of per capita consumption falling below 125 kg.

2/ Cost refers to the expected annual overall economic cost (consumer plus producer surplus plus government cost)

Under Free Trade, stocks are completely ineffective with respect to the food security objective explored in the study, unless the storage capacity is very high. Following food security oriented stock rules, whereby stocks are accumulated to the full extent of the storage capacity whenever the import price is below $195 per ton and stocks are released in whatever quantity needed to prevent consumption from falling below 125 kg/cap (i.e., to prevent the price from rising above $195 per ton), the minimum storage capacity having any perceptible food security impact is seen to be on the order of 15 kg/cap, or approximately 50 % of average imports. To reduce the probability of consumption falling below 125 kg/cap to a level of 6% would require a stock which approximately equals the average level of imports. The cost of $0.35 per capita would be far in excess of the $0.02 per capita which it would cost to achieve an equal level of food security through the stabilizing trade policy described earlier. Moreover, operating such a large stock, while slightly reducing the average import bill, would imply extremely unstable imports. The coefficients of variation of both the quantity of imports and the food import bill under Free Trade plus a 30 kg/cap stock operation are nearly 0.6 whereas the coefficients of variation of imports and the food import bill under Stabilizing Trade are on the order of 0.25.

Food security can be slightly improved with a modest buffer stock and at a reasonable cost under Constrained Free Trade. Stocks are used in this case to augment consumption whenever imports are restricted for lack of foreign exchange. Large improvements in food security are not possible because the financial constraint which limits imports for consumption in the current year also prevents large accumulation of stocks irrespective of available storage capacity.

Finally, it is worth noting the consequences reported in Table 7 of operating the buffer stock by "optimal" and "security" oriented rules. The "optimal" rules clearly minimize the cost of operating a given storage capacity, whereas the "security" oriented rules provide more food security for the same storage capacity. If maximization of economic welfare were the sole objective, we note that the optimal stock would be less than 4 kg/cap, perhaps even zero. If, however, the primary objective is food security and cost-effectiveness in terms of food security, we note that a smaller stock operated along the "security" oriented rules or a larger stock operated by "optimal" rules may be equally cost-effective while "security" oriented rules make a significant improvement in food security feasible (albeit, at a considerable cost) whereas "optimal" rules prevent a significant improvement at any cost.

C. Simulation Results: Sensitivity Analysis

Finally, we should ask ourselves to what extent the observed relatively large effect of trade policies for food security holds up under different scenarios. Table 8 shows the result under three variations from the scenario described in the base case. The higher demand elasticity (at the expected price) is 0.4 instead of 0.2. Similarly, the higher supply elasticity scenario assumes that the supply elasticity is 0.6 rather than 0.3 as assumed in the Base Case. The final scenario assumes that the coefficient of variation of the world supply is half as originally assumed, i.e., about 2% rather than 4%. Some results of the sensitivity analyses are reported in Tables 8 and 9.

With a higher demand elasticity, the food security effect of engaging in a stabilizing trade policy becomes even more pronounced. While

Table 8: FOOD SECURITY: PROBABILITY OF CONSUMPTION BELOW 125 KG/CAP (%) AND (EXPECTED SHORTFALL) (KG/CAP)

| Policy | Scenario: Base Case | Higher demand elasticity | Higher supply elasticity | More stable world price |
|---|---|---|---|---|
| | % (Kg/cap) | | | |
| Free trade | 18 (4.3) | 27 (9.1) | 18 (4.3) | 3 (1.7) |
| Constrained free trade | 26 (5.3) | 46(10.2) | 25 (5.0) | 19 (2.4) |
| Stabilizing trade | 6 (1.9) | 6 (1.9) | 6 (1.9) | 0 (1.2) |
| Constrained stabilizing trade | 20 (4.8) | 24 (5.3) | 18 (4.6) | 15 (4.1) |
| Restricted trade | 33 (5.2) | 34 (8.4) | 33 (5.0) | 17 (4.0) |

Table 9: EXPECTED ANNUAL LOSS TO ECONOMY DUE TO DEVIATION FROM FREE TRADE

| Policy | Scenario: Base case | Higher demand elasticity | Higher supply elasticity | More stable world price |
|---|---|---|---|---|
| | ($/cap) | | | |
| Constrained free trade | 0.04 | 0.04 | 0.04 | 0.07 |
| Stabilizing trade | 0.02 | 0.11 | 0.12 | 0.10 |
| Constrained stabilizing trade | 0.06 | 0.11 | 0.05 | 0.07 |
| Restricted trade | 0.11 | 0.15 | 0.15 | 0.11 |

free trade can still significantly improve food security over what it would be under restricted or constrained trade, a highly elastic demand implies highly unstable consumption under free trade.

With the higher supply elasticity, the decline in food security associated with restricted or constrained trade policies is only slightly less than in the base case. This is so because in spite of the increased domestic supply, the country's consumption level essentially remains dependent on the ability or willingness to import.

With a more stable world price the decline of food security associated with restrictions on trade become substantially more pronounced. Two observations are particularly noteworthy. As expected, a relatively stable world price translates into a high level of consumption stability under free trade. But more importantly, we should take note that a more stable world food price will not significantly increase food security if trade is severely constrained by a maximum foreign exchange allotment. Thus food deficit countries would see little improvement in food security from international stabilization schemes unless they are able and willing to change their food import policies.

Table 9 shows that the expected annual cost of deviating from free trade (as measured by changes in the combined consumer and producer surplus) is generally not very sensitive to the various scenarios. The only exception is the significant increase in the cost of engaging in stabilizing trade when the demand elasticity is high, i.e., with a higher demand elasticity both the stabilizing effect and the cost of the stabilizing trade policy are more pronounced.

## APPENDIX: DERIVATION OF OPTIMAL STOCK RULES

The general procedure by which optimal stock operating rules were incorporated into the simulation model was discussed in Section II. This involved (a) solving an optimization problem using dynamic programming and then (b) using the results of that exercise to specify the carryover demand function in the simulation model so that the resulting decisions were optimal. The purpose here is to elaborate further on this procedure.

Grain production, $q_t$ , is assumed to be a random variable, identically and independently distributed for all years in the horizon. The amount of grain carried over from year $t$ to year $t+1$ , denoted as $k_t$ , and grain production in the current year, $q_t$ , are summed to get the domestic supply, $s_{t+1}$ , in year t+1. Grain carryovers are constrained not to exceed the assumed capacity, CAP, of the storage facility. A variable cost of $5 per ton is incurred for the quantity of grain carried over from one year to the next.

Grain can be imported from the world market. The world price of grain is a random variable, identically and independently distributed for all years. A $25 per ton transportation fee is added to the world price to yield the import price, $p_t$. The amount of grain imported, $m_t$ , is subject to a constraint on the maximum food import bill, i.e., $p_t m_t \leq M$. When M is small, we have the constrained trade policy, discussed in the text, while a sufficiently large M implies free trade.

In any year the total supply of grain in the country is $s_t + m_t$ . This supply is to be allocated between consumption, $c_t$ , and carryover stocks, $k_t$ , i.e., $s_t + m_t = c_t + k_t$ . With $s_t$ given, a choice of $k_t$ and $m_t$

determines $c_t$. Specifically, the government is assumed to know the domestic grain supply, $s_t$, and the import price, $p_t$. It then proceeds to determine how much grain should be carried over and how much grain should be imported. These decisions are to be made on the basis of a storage rule $f$, where:

$$k_t = f(s_t, p_t)$$

and an import rule g, where:

$$m_t = g(s_t, p_t).$$

Functions $f$ and $g$ which satisfy the constraints

$$0 \leq f(s_t, p_t) \leq CAP$$

and

$$0 \leq g(s_t, p_t) \leq M/p_t$$

are termed admissible.

The benefits from consuming $c_t$ units of grain are defined by the standard willingness-to-pay criterion and are denoted $w(c_t)$. The annual net benefit, $B_t$, arising from consumption, imports and carryovers is given by the equation:

$$B_t = w(c_t) - p_t m_t - 5\,k_t$$

and the criterion function to be maximized is:

(1) $$\underset{q_1, p_1 \ldots q_T, p_T}{E} \left[ \sum_{t=1}^{T} \alpha^t B_t \right]$$

where $\alpha = 1/(1+r)$ and $r$ is the discount rate which has been assumed to be 0.08 .

The problem to be solved is to find a sequence of admissible storage/import rules, $(f_1^*, g_1^*, \ldots f_T^*, g_T^*)$ which maximize criterion function (1) subject to:

(2) $$s_{t+1} = q_t + k_t$$

and

(3) $$c_t = s_t + m_t - k_t \quad ,$$

given the initial domestic supply and import price.

To solve the optimization problem it was necessary to discretize $q_t$ and $p_t$ . This was done by assuming 17 possible values of $q_t$ and 14 possible values of $p_t$. Probability weights were assigned on the basis of the distributions described in the text. For the purpose of the optimization problem an infinite time horizon was assumed. This assumption, in conjunction with the assumed stationarity of the benefit functions, the discount rate and the distributions of the random variables, implies that the optimal carryover/import rules are the same in every period.

The solution to the optimization problem is obtained by a dynamic programming algorithm (see, for example, Bertsekas(1976)). First define $S$ as the set of possible domestic supplies. Since domestic supply in any period is the sum of harvests and the carryovers from the previous period, and since each of these variables can take on only a finite number of values, $S$ is a finite set. Likewise define $P$ as the set of possible import prices and this is also a finite set following the discretization assumption made earlier.

The dynamic programming (DP) algorithm proceeds by solving the following recursive equation:

(4) $$J_0\,(s,p) = 0 \qquad \forall\ (s,p) \in S \times P$$

(5) $$J_n(s,p) = \max_{\substack{0 \le k \le CAP \\ 0 \le m \le M/p}} w(s + m - k) - 5\,k - p\,m + \underset{q,p}{E}\,[\,J_{n-1}(q + k,\, p)\,]$$

$$\forall\ (s,p) \in S \times P$$
$$n = 1,2,\ \ldots$$

Here the $J_n(s,p)$ are the optimal value functions.[2]

In words, the DP algorithm operates as follows. We first set $J_0 = 0$ for all values of supply s and import price p (eqn. 4). Substituting this into the right-hand side of (5) , we then calculate for a given s and p the maximum of the resulting expression. This determines the value of $J_1$ for a single point. By repeating the maximization for each of the possible (s,p) combinations the function $J_1$ is calculated.

$J_1$ may then be substituted in the right-hand side of (5) to calculate $J_2$. Proceeding in this manner, $J_2$ , $J_3$ , $J_4$ and so on are successively computed.

Now define, for each initial s and p , the value of the criterion function (1) under optimal operation as $J^*(s,p)$ (noting again that $T = \infty$ ). Then it can be shown that as $n \to \infty$ the functions $J_n$ produced by the DP algorithm (4) and (5) converge to $J^*(s,p)$[3/].

For our purposes only $J^*(s,p)$ is needed. However, the optimal carryover/import decisions are readily obtained as by-products of the DP algorithm. They are simply the values of k and m which solve the maximization problem indicated in (5) for the different combinations of s and p.

We can now show how the carryover demand function was specified. As discussed in Section II, it is necessary to specify the carryover demand

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[2] If the horizon were finite, the $J_n(s,p)$ could be interpreted as the expected discounted returns from optimal operations over the last n periods, given the initial domestic supply s and import price p. Thus $J_1(s,p)$ would be the return under optimal operation in the final period if $s_T = s$ and $p_T = p$. Likewise $J_2(s,p)$ would be the expected discounted return under optimal operation in periods T-1 and T.

[3] See Bertsekas, op.cit., Chapt. 6. To speed up this convergence process we also computed error bounds at each iteration of the algorithm. (An explanation of the error bound calculations is given in Bertsekas, Chapt. 6). With the use of error bounds, convergence was obtained in ten iterations or less in our computations.

function as the marginal value of carryovers. $J^*(s,p)$ gives the expectation of the discounted future returns under optimal operation and this is a function of the initial domestic supply $s$ and import price $p$. This function applies to every period because of the assumption that $T = \infty$. Since

$$s_{t+1} = k_t + q_t ,$$

a new function $\bar{J}(k_t)$ can be defined by

$$(6) \qquad \bar{J}(k_t) = \underset{q_t, p_{t+1}}{E} [ J^*(q_t + k_t , p_{t+1} ) ]$$

$\bar{J}(k_t)$ is the expected value of discounted future returns and this is a function of the carryovers $k_t$. If $k_t$ were a continuous variable and $\bar{J}(k_t)$ was differentiable, the marginal value of carryovers in period $t$, net of variable storage costs, would simply be $d\bar{J}(k_t) / dk_t - 5$. Since all variables in the optimization model are discrete, the calculations of the marginal value of carryovers were actually done using the difference between various computed values of $\bar{J}(k_t)$. Specifically, if $k_t^n$ and $k_t^{n+1}$ were two successive values of carryover levels, a marginal value net of variable storage costs at a carryover level of $(k_t^n + k_t^{n+1}) / 2$ was computed by $\alpha (\bar{J}(k_t^{n+1}) - \bar{J}(k_t^n) / (k_t^{n+1} - k_t^n) - 5$ and this was done for all successive pairs of possible carryover levels. A linear approximation to the resulting plot of net marginal values was used as the carryover demand function in the simulation model.

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