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STORAGE, TRADE, AND PRICE POLICY UNDER PRODUCTION INSTABILITY: MAIZE IN KENYA

Thomas C. Pinckney

December 1988

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CONTENTS

Foreword

1. Summary 9

2. Introduction 11

3. Methodological Approach 18

4. A Production Instability Model for Kenya 28

5. An Examination of Price Band and Optimal Policies 55

6. Trade-offs Between Government Objectives 73

7. Conclusions and Policy Implications 82

Appendix 1: Supplementary Tables 88

Appendix 2: Pseudocodes for Price Band and Optimization Programs 94

Bibliography 97

TABLES

1. Rural market maize grain prices, September 1984 — 15
2. Optimal storage versus certainty equivalence storage — 23
3. Dynamic programming example: terminal year payoffs — 25
4. Dynamic programming example: year T−1 payoff calculations — 25
5. Different series of maize production in Kenya — 29
6. Derivation of maize "consumption" series — 30
7. Expected values of world price in dynamic programming models — 41
8. Differences between price band simulation and dynamic programming models — 49
9. Costs of exporting maize — 50
10. Kitale rainfall: April and May, 1953-84 — 53
11. Price band results — 57
12. Optimal policy results — 61
13. Simulation of price band and optimal policies: one cycle — 65
14. Trade-offs between objectives: price band and optimal — 73
15. Adjusting the price band policy — 77
16. Price band results for demand elasticity equal −0.2 — 88
17. Price band results for production variability equal 12 percent — 89
18. Optimal policy results for demand elasticity equal −0.2 — 90
19. Optimal policy results for production instability equal 12 percent — 91
20. Price band results for comparison with optimal — 92
21. Trade-offs with price elasticity equal −0.2 — 93
22. Trade-offs with production variability equal 12 percent — 93

ILLUSTRATIONS

1. Net purchases function implied by price band policy 20
2. Maize production and trends, 1970/71-1983/84 32
3. Maize production frequency diagram, 1970/71-1984/85 35
4. Price band trade-off curves 56
5. Optimal policy trade-off curves 60
6. Price band trade-off curves for comparison with optimal 62
7. Price band versus optimal policies for price variability of 12.1 63
8. Price frequencies: price band policy 66
9. Price frequencies: optimal policy 67
10. Net purchases: price band versus optimal for opening stock = 0 68
11. Net purchases: price band versus optimal for opening stock = 400 69
12. Optimal net purchases for different objective function weights 70
13. Optimal closing stocks and exports 71
14. Stocks: optimal versus price band policy at different world prices 72
15. Moving toward the optimal: price band policy modifications 78

FOREWORD

Instability in the production of a staple food causes severe hardship for many countries. For a country that is self-sufficient in its staple food in a normal production year, the large swings in price and consumption that result from an exclusive and uninhibited reliance on trade to stabilize prices are unacceptable. Most countries, therefore, intervene in their domestic cereal markets and move supplies from surplus to deficit years through storage or by subsidizing international trade. The appropriate method of intervention and the most efficient way to achieve supply stability thus become topics of study. For the most part, economists have encouraged governments to rely more on trade than on stocks to make up deficits in years of production shortfalls.

Trade becomes less appealing as an option the larger the difference between import and export parity prices, and the greater the deviation in physical characteristics between the domestically consumed commodity and the imported commodity. Storage is more likely to be appropriate for African countries, since many of them have high transport costs and consume a commodity—white maize—that is often in short supply on world markets.

The International Food Policy Research Institute has examined these issues previously in books and research reports. *Food Security for Developing Countries,* edited by Alberto Valdés, discusses these issues in some detail. *International Finance for Food Security,* edited by Barbara Huddleston et al., is a study of ways that the international community can remove some of the risks of relying on trade rather than stocks. In IFPRI Research Report 26, *Food Security in the Sahel: Variable Import Levy, Grain Reserves, and Foreign Exchange Assistance,* John McIntire examines various policy options for dealing with instability in the Sahelian region.

In this report, Thomas Pinckney develops a general framework for studying these issues and applies it to the case of Kenya. The framework builds both on the optimal storage literature and on simulation studies. Trade-offs between the government objectives of minimizing price fluctuations, imports, and fiscal costs are measured explicitly. The techniques that make the optimal policies superior to simpler price band/buffer stock policies are studied in order to provide clues for efficient policy design. In terms of the storage/trade debate, this report finds that Kenya does indeed have a strong rationale for a significant amount of storage when world maize prices are at their present low levels.

Techniques developed in this research report have been modified and applied to Pakistan and will be applied to several southern African countries in the future. This will provide the coherent set of studies required to make generalizations about these important questions.

John W. Mellor

Washington, D.C.
December 1988

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This study was undertaken in several different stages through the support of a number of different persons and organizations. Consequently, my debts are even greater than those usually incurred by authors.

The study began in 1983 as one part of an interministerial report on grain marketing. John Cohen of the Harvard Institute for International Development had been responsible for hiring a raw graduate student 18 months earlier, and Dick Goldman named me to the study team for the report. Dick has been a good friend and stimulating colleague ever since; many thanks are due him.

Following my departure from Kenya, the report took on a semblance of its present shape when it was transformed into my doctoral dissertation at Stanford's Food Research Institute. HIID provided funding for part of my support during the writing period. My dissertation committee was helpful throughout, particularly Carl Gotsch, the chairman. Carl also was primarily responsible for producing an article based on the dissertation, "Simulation and Optimization of Price Stabilization Policies: Maize in Kenya," which appeared in *Food Research Institute Studies* 20:3.

After I came to the International Food Policy Research Institute to work on a similar study of Pakistan, Alberto Valdés encouraged me to revise my thesis for submission as an IFPRI Research Report. Chris Delgado, Marc Nerlove, Uma Lele, and an anonymous reviewer provided helpful comments.

1

SUMMARY

Kenya has been faced with the problem of production instability for as long as records have been kept. Over the last 10-year period, the country has produced about the same amount of its staple food, white maize, as it has consumed. During normal weather years, private markets have cleared at prices that are between import parity and export parity. Yet the country faced severe shortages in 1980 and 1984, and in early 1987 was faced with the opposite problem of a large excess supply. The strategy the government pursues in managing these fluctuations in supply has important ramifications for the government budget and the government's political support.

For most of the period since independence, Kenya's stated policy in this regard has been simple: all maize that is not sold directly from a producer to a consumer is to be sold to a parastatal marketing board, the National Cereals and Produce Board (NCPB). The NCPB is instructed to buy all the maize that it is offered at a price set by the government, and to sell all the maize that is demanded at a higher price, also set by the government. Since the government purchase price is set before planting, there is no sensitivity to the size of the crop. By law, therefore, there is to be no fluctuation in producer prices.

In reality, both consumers and producers have faced large fluctuations in prices. The government has not given the NCPB the fiscal resources necessary to fulfill its mandate. The NCPB has responded in surplus years by delaying payments to farmers, forcing prospective sellers to wait in long lines, and rejecting many lots in the name of quality control. In deficit years, millers have not been able to buy as much as they desire at the set price. The result has been the dependence of a large percentage of farmers and consumers on the parallel informal market and large fluctuations in price on that market.

This policy has been increasingly difficult for the government to pursue, as fiscal austerity has been recognized as vital to Kenya's long-term development. Thus a systematic analysis of policies for countering production instability is in order; in particular, it is important that the analysis be conducted from the government's perspective by measuring trade-offs between different government objectives.

The three objectives considered here are minimizing price fluctuations, minimizing fiscal cost, and minimizing imports. Minimizing imports is a separate goal over and above the cost involved for two reasons: first, imported maize is yellow, while locally grown maize is white; second, most Kenyans believe that their country should be self-sufficient in its staple food.

A common policy prescription from earlier studies is for the NCPB to defend floor and ceiling prices for maize rather than to engage in primary marketing. This policy option, with foreign trade triggered by the stock level, is termed a "price band policy" here. Price band policies with different band widths and stock triggers are simulated in this study in order to examine their effects on the three government objectives. This allows for the measurement of trade-offs between objectives.

These estimates of trade-offs will be accurate if the price band policies are efficient. There are theoretical reasons, however, for believing that such policies are inefficient. To obtain accurate estimates of the trade-offs, Kenya's storage and trade problems are solved using a model that produces the best values for domestic purchases and sales, foreign trade, and domestic stocks, given any particular system of government preferences for the three objectives. The optimization method used, stochastic dynamic programming, guarantees that the estimates of trade-offs between objectives are accurate, since the most efficient policy has been chosen.

A simple model is developed with random production fluctuations and random movements in the world price of maize. The government responds by purchasing and selling maize both domestically and internationally and storing the result of those transactions. Because the most efficient policy will depend on how much the government values, say, price stability vis-à-vis fiscal cost, the optimization exercise is carried out with several different weightings of the three government objectives. Price band policies with different-width price bands and different stock triggers for international trade are tested also.

For the same level of imports and price stability, the policies that come out of the optimization procedure cost about US$1.5 million less annually than the price band policies. These cost savings result primarily from increased flexibility. In the optimal policies, the domestic price is sensitive to the world price, domestic production, and the government's opening stock, while the maximum stock level (which triggers exports) is sensitive to the world price.

Trade-offs between fiscal cost and price stability as measured by the price band policies are found to be lower than the true trade-offs. As measured by the optimal policies, the average annual cost of decreasing the standard deviation of price by $1.00 per metric ton is $400,000-$600,000 annually, with the larger values occurring as the standard deviation moves towards zero. On the other hand, the price band policies overestimate the cost of decreasing imports. The correct trade-off is $60,000-$130,000 annually per 1,000-ton decrease in average annual imports, with the higher values occurring as average annual imports decline.

Despite the advantages of the policies that are produced by the optimization procedure, it would be incorrect to recommend that the government adopt such rules for several reasons. Most important, the optimal policies are much more complex than the price band policies. The government has an objective of designing relatively simple policies, but this objective is not easily built into an optimizing model. There is thus a trade-off between the cost of a policy and its complexity.

The lessons learned about optimal policy design are introduced into the price band policy one by one in order to design a policy that is efficient, yet retains the desirable simplicity of the price band policy. About two-thirds of the difference between the optimal and price band policies can be made up by allowing the domestic price to be sensitive to the world price and opening stocks and by making the maximum stock level sensitive to the world price. Further efficiency gains can only be made by allowing the crop size to influence the official domestic price.

Three major policy conclusions are made. First, there is no one optimal stock level, but the most appropriate closing stock level in any one year is a function of the opening stock level, production, and the world price. Second, by adding some flexibility to official prices, significant cost savings could be incurred, which would make it more likely that the NCPB would be given sufficient fiscal resources to defend the official price. Thus, price instability faced by Kenyan producers and consumers could actually decrease even though official prices would not be totally stable. Third, the degree of price flexibility required to achieve significant cost savings is not large, as shown by the trade-off between fiscal cost and price stability.

2

INTRODUCTION

In the 1981/82 crop year, Kenya produced approximately 2.5 million metric tons[1] of its staple crop, white maize. This bumper crop, which was 20 percent higher than the previous record, caused serious financial problems for the country's grain-marketing parastatal, the National Cereals and Produce Board (NCPB). The board was unable to pay farmers for their crop on delivery. In some cases depot managers simply refused to buy more maize; in others, farmers were forced to wait as long as nine months for payment. NCPB stores were full of maize and beans, with substantial quantities stored outside under tarpaulins. For a country that had experienced a fairly severe food crisis only two years before and had been labeled a chronic maize importer by many "experts," the experience was both relieving and terribly costly. With memories of queues for maize in Nairobi still fresh in everyone's mind, the government was reluctant to approve exports when imports might be required in the near future. Yet the country was in the middle of a financial crisis, with foreign reserves at their lowest point ever.

Rather belatedly, the cabinet decided to allow the NCPB to export maize during 1983 and 1984 after two reasonably good crop years. Over 100,000 tons were exported in January and February 1984. During April and May of that year, however, the government's worst fears were realized: not only were the rains in semiarid Eastern Province low for the third year in a row, but the normally reliable rains in parts of the Rift Valley were only 50 percent of normal. Failure of the rains in this breadbasket of the country led to a severe national shortage in addition to the anticipated purchasing-power problem in the east.

From the very beginning of the crisis, debate raged in the press about the maize that had been exported in January and February 1984. Unnamed officials were accused of corruption while the populace waited in queues for any white maize that became available. For about two weeks in August 1984 there was no maize meal to buy in Nairobi shops, despite assurances from the government about the adequacy of maize supplies in the country. The supply situation for maize in the rural areas was even more erratic. The failure of the bean and potato crops took away two of the most important alternative sources of calories in Central and Eastern provinces.

The government was reluctant to take the logical step of importing maize. Imports present Kenya with a threefold problem. First, the NCPB selling price of maize is determined in advance and in 1984/85 was between the import and export parity prices. As Kenya was exporting maize at planting time, this price was reasonable. But if the country was to maintain its tradition of holding official prices constant, the government would suffer large losses on every ton of imported maize sold domestically, even without correcting for Kenya's marginally overvalued exchange rate. Second, there is a strong feeling in the country that Kenya can and should be self-sufficient in maize. Imports are normally interpreted as a policy failure, and this would be especially true in 1984, since the country had exported in the first two months of the year. Indeed, a December 1984 review of the year's events in the local press was entitled

[1] All tons referred to in this report are metric tons.

"Disturbing Year: Drought, Inefficiency, and Lack of Foresight Lead to Hunger."[2] Third, Kenyans produce and consume white maize, and virtually all of the maize on the international market is yellow. When there is sufficient rain in southern Africa, South Africa exports a significant amount of white maize, but there are obvious problems for a black African country in buying that maize. Thus Kenya imports yellow maize, which looks and tastes different from the local product. The country's citizens are reminded every time they sit down to eat that their government has failed to meet one of its most important goals. Obviously, government decisionmakers want to avoid all three of these problems.

Throughout the first half of 1984 the official price remained constant. Local markets, on the other hand, began to react earlier to the low rainfall. With local market prices higher than the NCPB selling price, demand for NCPB maize increased dramatically. In May the NCPB had net sales of almost 90,000 tons, breaking the previous one-month record (of July 1980) by almost 40 percent. From May to July, NCPB net sales were about 306,000 tons, breaking the previous three-month record by an extraordinary 80 percent. The government's stockpile was being depleted rapidly.

By early July the government had realized that its stock position was untenable and reluctantly arranged for imports. Several development projects were delayed or curtailed because of the expected cost of the import program, which would eventually bring in almost 1 million tons during 1984/85. The administrative costs were also high, as key decisionmakers in the government spent large blocks of time trying to manage the problem.

The problems presented above are not new. Indeed, one of the most interesting descriptions of the issues still facing the Kenyan government was written by a Maize Commission of Inquiry more than 20 years ago (Kenya 1966):

> The dominant feature in the price structure for maize is the wide differential between the import parity and export parity prices. . . . The sharp fluctuations in the annual supply, and the inflexible total consumer demand mean . . . that it is virtually impossible to plan production exactly to meet domestic demand, even allowing for the holding of an unduly large and costly domestic reserve stock, without incurring the need to export or import at a loss from time to time. . . . It is against this cost and price background that the Government has to determine the appropriate organization for handling maize, and to fix prices to the producer, the miller, the distributor, and the consumer.

The report recognizes the fundamental problem of production variability and the costs associated with depending on storage or trade alone to deal with the problem, while accepting without comment the government's desire to mandate prices at each stage of the marketing chain. Twenty years later the government is trying to manage the same problem in an ad hoc way as each crisis comes along. Considering the Maize Commission of Inquiry report and other studies conducted during the last 60 years, Maratim (1982) laments:

> Since the first documented maize crisis of 1918, periodic maize shortages have provoked thirteen commissions of inquiry, working parties or select committees to investigate and make recommendations on the pricing and marketing of maize in the country. Most of these investigations have conducted expert analysis and made responsible recommendations only to see maize policy continue to be made on an ad hoc basis, with the authorities acting too late to avert the immediate crisis and then taking little remedial action until the next crisis.

[2] *Weekly Review* (Nairobi), December 21, 1984.

There is hope that this situation is changing. Until the 1980s, maize marketing was not a major component of government cost. The studies and commissions of inquiry were conducted after each crisis, but as the situation returned to normal the politicians felt less inclined to make the sort of difficult decisions necessary for a major change in maize marketing. During this decade, however, the situation has never returned to "normal." Between 1979 and 1984 the NCPB consumed from 10 to 20 percent of the total amount spent by the Ministry of Agriculture and Livestock Development.[3] This is in contrast to the early 1970s, when the board was virtually breaking even. With NCPB costs continuing to consume a larger and larger proportion of the country's agricultural sector investment, there is a much broader constituency for reforming maize marketing than at any time in the past.

NCPB losses began to increase at the same time that the difference between government expenditures and revenues began to grow to disturbing proportions. High coffee prices in the late 1970s had increased government revenues substantially, and as a consequence fiscal discipline in the government became lax (Pinckney, Cohen, and Leonard 1982; Leonard, Cohen, and Pinckney 1983). The size of the budget deficit prompted the president to appoint a Working Party on Government Expenditures in 1982 to study the problem. The report of the working party (Kenya 1982) states that

> Not to reduce the gap between revenue and expenditure would entail expansionary fiscal and monetary policies and creation of excessive domestic credit. This path would aggravate rather than ameliorate the economic circumstances facing the nation. . . It is not enough, however, merely to curtail Government expenditure, that is, 'to cut our coat according to the size of our cloth.' While Government expenditure must be contained within feasible limits, the development of the nation must continue. . . . As a consequence, Government must in the years ahead . . . allocate its expenditures according to orderly priorities.

The budget deficit has led to an emphasis on sorting out government priorities in different areas of public policy. The growing importance of the subvention to the NCPB as a proportion of total funds spent on the agricultural sector highlights maize marketing as one important area where priorities need to be examined. Add to these internal pressures the interest of major donors in reform, and it would appear likely that within the next few years some changes will be made in maize-marketing policy. Given this possible "window of opportunity," a systematic analysis of methods to deal with the problem is in order; in particular, it is important that an analysis be conducted from the government's perspective, measuring trade-offs between different government priorities.

This study, then, examines trade, stockholding, and pricing strategies that can be used to deal with production instability in Kenya. The primary goal of the analysis is to measure the trade-offs between three government objectives: minimizing price fluctuations, minimizing fiscal costs, and minimizing imports. The last two goals are clear and have been described above; the first requires further elaboration.

Price stability as it is used here measures average annual deviations from a target real price. The government wants farmers to be assured of a reasonable price and wants consumers to be satisfied with the price and quantity available. The history of price control dates back to the Second World War and is deeply ingrained in the political preferences of the government. This is more clearly seen by what the government has

[3] Richard Goldman, personal communication, October 1985.

not done than by any action or statement. Despite large losses on every ton of maize that was imported and sold domestically in 1980/81 and 1984/85, the government official price remained firm. Similarly, in 1981/82 when buying the bumper crop caused the NCPB to run out of cash, official prices did not decrease. Reports such as the one by the 1966 Maize Commission of Inquiry that was quoted above accept this government goal without comment.[4]

This study will attempt to measure the trade-offs between this price stability goal and the fiscal and self-sufficiency goals in order to measure the cost of stabilizing prices. At the outset, however, it is important to note that the study is dealing with questions of annual, national supply, and not with regional or seasonal shortages. This choice of objective does not imply that fluctuations in food supply by season or within provinces, districts, villages, or households are less important.[5] Nor does the choice of objective imply that food crises can be averted simply by ensuring adequate levels of national supply. As Sen (1981) has pointed out, famines often are associated more closely with the loss of purchasing power by large segments of the population than with supply fluctuations alone. Nevertheless, ensuring adequate national supply is a necessary, albeit not sufficient, condition for averting famine, and questions related to this issue are to a large extent separable from regional and seasonal factors. In addition, as the brief history above illustrates, a country like Kenya needs to examine maize pricing, stockholding, and trading strategies that will provide guidelines for action in exceptionally good years and normal years, not only in years of shortfall. The following brief review of the policy context points out that the government has not in fact been meeting its price stability goal despite high fiscal expenditures.

By law, the government has complete control of the marketing system in the country, with the NCPB acting as its agent.[6] Before planting each year, the government announces the price at which it will buy maize at harvest time.[7] The government also calculates corresponding selling prices at each level of the marketing chain, including the retail price of a 2-kilogram packet of sifted meal, but these selling prices usually are not made final until a later date. They are announced and take immediate effect close to the beginning of the first harvest. The NCPB is supposed to purchase all of the maize that it is offered at its buying price and to supply all that millers and agents want to purchase at its selling price. All foreign trade is handled by the board, but trade decisions are made by the cabinet, not the NCPB.

Most transactions other than those involving the board at the chosen price are illegal. Farmers may legally sell maize to persons whose families will consume it directly, but may not sell to traders or to institutions. All other sales are supposed to be handled by the NCPB. In fact, the government allows trade in rural markets within districts, although in most years large millers are required to buy from the board.

Restrictions on the movement of maize are enforced much more rigorously than restrictions on sales. Moving more than two bags of maize requires a permit, and the

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[4] This study argues that price stability *is* a goal of the Kenyan government, and consequently it is included in the government objective function. There has been considerable discussion in the welfare economics literature concerning whether or not price stability *should be* a goal of the government. The seminal articles in this literature are Waugh 1945; Oi 1961; Massell 1969; Samuelson 1972; and Turnovsky 1978.

[5] For a recent paper on seasonal and regional shortages, see Kleist 1985.

[6] Kenya's agricultural sector is neither described nor analyzed here. The best study is still Heyer, Maitha, and Senga 1976. For a much more complete review of the maize marketing system than the one presented here, see Booker International 1983.

[7] See Jabara 1984 for a description of the price review process.

police are likely to interfere with persons carrying even one bag (Booker International 1983, 9). Carrying any maize across district boundaries requires a permit, and permits for large amounts are issued only rarely. Unquestionably, some illegal private movement of maize takes place in the country, but recent market price data indicate that the amounts being shipped long distances are not sufficient to arbitrage price differentials. As shown in Table 1, in September of 1984, during a good harvest in Western and Nyanza provinces and a period of very short supply in Eastern and Central provinces, local market prices for maize in Eastern and Central were two to three times as high as they were in the west. In some cases, the differences were over $200 per ton,[8] which is much higher than the transportation costs.

If the board actually functioned in the way the law is written, these private market prices would not vary much more than the difference between NCPB buying and selling prices, even in times such as September 1984. The market would have a competitor in the NCPB, but the government has not given the board the fiscal resources necessary to accomplish this task. The NCPB has responded by not buying all the maize available in bumper crop years and by selling less than market demand in scarce years. Goldman (1983) has shown econometrically that the NCPB's buying and selling behavior is influenced by its available stocks. Private market prices such as those in Table 1 confirm this analysis.

These conclusions are reinforced by several studies of the marketing system in Kenya. Schmidt (1979, 65) found that in times of plenty the board forced prospective sellers to line up for days before taking delivery and sometimes would pay less than the official price. On the other hand, in deficit areas in times of scarcity very little would be sold. Hesselmark and Lorenzl (1976, 176-177) conclude their study of maize marketing by lamenting that the board "seems not to be able to reach producer price stabilization in surplus areas. . . [and] does not reach its objective of consumer price stabilization in rural deficit areas."

Such problems have led some observers to condemn the NCPB for inefficiency and corruption. While the studies mentioned above and a recent study commissioned by

Table 1—Rural market maize grain prices, September 1984

Market	Province	Price	Ratio to Bondo Price	Difference	Transport Cost from Bondo[a]
		(KSh/kilogram)		(US$/metric ton)	
Embu	Eastern	5.00	3.0	221	38
Kiambu	Central	4.22	2.5	169	27
Luanda	Western	2.13	1.3	29	4
Mumias	Western	1.94	1.1	17	6
Bondo	Nyanza	1.69	1.0	0	. . .

Sources: Based on data from Kenya, Ministry of Agriculture, Development Planning Division, "A Summary Report of the Food Situation as of 31 October 1984," Ministry of Agriculture, Nairobi, November 1984 (mimeographed); data for transport costs from Bondo derived from Michael Schluter, *Constraints on Kenya's Food and Beverage Exports*, Research Report 44 (Washington, D.C.: International Food Policy Research Institute, 1984), p. 63.

Note: An exchange rate of KSh 15.00 = US$1.00 is used here.

[a] Schluter's estimates of operating costs for a 7-ton truck in 1982 are increased by 40 percent to account for inflation (the CPI increased 31 percent during this period) and an additional 20 percent to allow for normal profit.

[8] The $ symbol refers to U.S. dollars throughout this report.

the World Bank have shown that the board is not the most efficient of organizations, it is important to understand that it has been assigned an impossible task (Booker International 1983). The board is supposed to buy whatever is offered at a price over which it has no control; to sell whatever is demanded at a second price over which it has no control; to export and import only when given approval by the cabinet, not when it seems profitable to do so; and to store whatever the result of all these other decisions requires. Even an exceptionally efficient organization could be forced to lose money when operating under such constraints. The board's bending of the law by allowing stock levels to influence its buying and selling operations is understandable.

Government policy, then, must be distinguished from government pronouncements. In Kenya, as elsewhere, "most farmers have learned by painful experience that simple statements of government intentions to stabilize prices—or even to require them by law—are ineffective" (Timmer, Falcon, and Pearson 1983). The government claims to provide complete price stability to its consumers and producers, but the evidence presented above clearly shows that this is not the case. Because the pronouncements about price stability are unworkable, given the fiscal constraints of the NCPB, and since the foreign-trade decisions are out of its hands, the board is forced to buy and sell in ways that produce considerable price variability for consumers in rural deficit areas and producers in rural surplus areas. Thus maize prices in many rural areas are determined more by parastatal officials trying to keep their corporation solvent than by senior decisionmakers weighing one goal against another.

The government's official policy is to set the price at which maize will be sold long before the size of the crop can be estimated, with real prices being almost constant from year to year. Yet simple accounting identities show that if prices are to remain constant in real terms while production is variable, either the stock level or the foreign-trade account or both must absorb the instability. Another option that may appear to work is to limit NCPB sales or purchases by quantitative restrictions. All of these methods have been used in recent years. In 1979/80, government stocks decreased almost to zero, maize was imported, and the NCPB did not sell all that was demanded from it at the official price.[9] The situation in 1984/85 was similar, although government stocks had opened the market year at a much higher level and consequently were above 100,000 tons when the imports began to arrive. Conversely, in 1981/82 stocks were increased substantially, exports were approved (after a lag), and the NCPB did not buy all the maize that it was offered.

The quantitative restrictions, however, do not truly limit price instability because of the large percentage of maize that is bought and sold in private markets. While such restrictions allow the government to continue to buy or sell maize at the controlled price, they lead to large increases in local market prices (or decreases in years of abundant maize), thus causing price instability for rural consumers and producers.[10] So the only tools that successfully control price stability for all market participants are trade and storage policies. Historically, then, the goal of real price stability has been met only through the facade of stable official prices, while fluctuations in local market prices have been large.

The logical recommendation under such conditions is to add some flexibility to the official policy. For many years, a number of analysts have recommended freeing the

[9] "Where the Maize Really Went," *The Standard* (Nairobi), July 2, 1980.

[10] Bates (1981) argues that food policies in Africa have tended to favor the urban market for political reasons. This is less true in Kenya than elsewhere (see Jabara 1986; Meilink 1985).

marketing system in one way or another, most often arguing for a buffer stock scheme that would allow prices to fluctuate within a band. The Maize Commission of Inquiry discussed the issue in 1966 (Kenya 1966, 22). More recently, Gsaenger and Schmidt (1977) and Schmidt (1979) have argued that the NCPB should not play a primary marketing role but should hold buffer stocks and a strategic reserve.

It was in this context that the government appointed an Inter-Ministerial Working Group to study proposals for reforming the maize marketing system in 1983. This working group, of which the author was a member, developed a simulation model of the price band/buffer stock schemes that were being proposed at the time (Kenya 1983a). The policies under consideration would have caused the marketing system to be more flexible by making three changes: (1) decision rules for foreign trade would be approved ahead of time by the cabinet, so that each specific trade would not be delayed by cabinet deliberations; (2) movement controls would be relaxed to allow the private sector to accomplish what the NCPB has been unable to do historically—integrate the maize market across regions; and (3) prices would be allowed to fluctuate within a band, so that producers and consumers would bear some of the consequences of unstable production.

The working group was concerned with rationalizing the present system (changes 1 and 2) and investigating the benefits of allowing prices to fluctuate (change 3). The simulation models conducted by the working group assume that the first two changes are made and then attempt to measure the trade-off between cost and price flexibility in a dynamic, stochastic framework. The report clearly shows that much lower fiscal costs are possible when prices are allowed to fluctuate.

The analysis in the present study will begin in the next chapter by discussing the appropriate methodological approach, starting with the simulation methods used by the working group. Readers whose primary interest is in the policy conclusions may wish to skim this chapter. The model is developed in Chapter 4, with results presented in Chapter 5.

3

METHODOLOGICAL APPROACH

The Analytical Context: Simulation and Optimization

The Inter-Ministerial Working Group appointed in 1983 to study marketing reform proposals used a simulation approach to measure the costs of different policy options. The two parameters that determine this type of price band/buffer stock scheme (these are defined explicitly in the following section) are varied and tested in a large number of possible 10-year production cycles. It is necessary to make annual production stochastic, since the underlying nature of the problem is instability in production. Including 10 years in each cycle allows the model the opportunity to test for performance of the policies in sequences of good and bad years. This dynamic component is necessary to test different strategies for stock carry-outs.

Each of the three objectives—price stability, fiscal cost, and imports—is measured over the 10-year cycles for every variation of the policy parameters, thus defining a set of feasible combinations of the objectives. Trade-offs between pairs of objectives are then calculated by holding the third objective constant. These trade-offs will be accurate reflections of the cost of increasing the level of each objective, provided the underlying model is sufficiently realistic and *the price band/buffer stock schemes are the most efficient policies for meeting the three government objectives.*

There are reasons for suspecting that such schemes are inefficient. In a closed economy with a somewhat different objective function, Newbery and Stiglitz (1981) have shown that price band policies are quite inefficient. Since the government tools in the price band scheme do not respond to changes in the world price, it would seem that these policies may be even less efficient in an open economy. This consideration alone suggests that there are alternative policies that are more efficient and might yield a different measure of trade-offs because they flexibly adjust to states of the world.

There are two alternatives for measuring trade-offs accurately: modify the price band policies to make them more flexible to state parameters such as the world price; or set up an optimizing model that chooses the best level of the government control variables for each possible state of the world, and then simulate the chosen policy.

Although optimizing is bound to be more difficult, there are four reasons for using an optimization method rather than simply simulating additional chosen policies. First, since there is a potentially infinite number of possible policies, the choice of which ones to simulate will be to some extent ad hoc. As Eaton (1980) points out, when simulating different types of administrative rules "we cannot know whether an untested solution exists which better achieves the stated goals. Optimization is the preferred mode of analysis for screening many alternatives."

Second, optimization ensures that the trade-offs between objectives are measured accurately. When optimizing a multidimensional objective function, trade-offs between objectives are measured by varying the weights on the different objectives (Blandford and Lee 1979). Different weights on the three government objectives will force the optimizing algorithm to choose different policies. If the weight on minimizing imports is increased, for example, optimization ensures that the policy is adjusted in such a way that the cheapest method of reducing imports has been chosen.

Parts of this chapter appeared in Pinckney 1986b, 451-466.

Third, finding the optimal policy allows for measurement of the degree of suboptimality of alternative policies. Once the optimal policy for a given set of weights is found, it can be simulated in the same way as a price band/buffer stock scheme, thus allowing a direct comparison between the two types of policies. This is especially important for policy recommendations, since administrative rules generally are easier to understand and implement than the policies that come out of optimization routines. Yet ease of communication and implementation is an objective of the government that is difficult, if not impossible, to build into the optimizing process. Once the optimal values of the objectives are known, the values of the objectives produced by the administrative rules can be compared, and a trade-off between complexity and cost can be computed.

Fourth, differences between the way the optimal policies and the administrative rules respond to the state of the world can be studied, and the administrative rules can be adjusted in ways suggested by the optimal policies. This should make possible both reductions in the complexity/cost trade-off and the formulation of an administrative rule that is much more efficient than one that would have been tested without considering the optimal policies.

Thus there are several potential benefits of using optimization techniques. The costs, however, in terms of program development and analysis are considerably larger for optimization routines than for simulation of administrative rules. This study will use optimization methods and consider in conclusion whether or not the benefits gained from their use outweigh the costs.

Defining the Price Band/Buffer Stock Policies

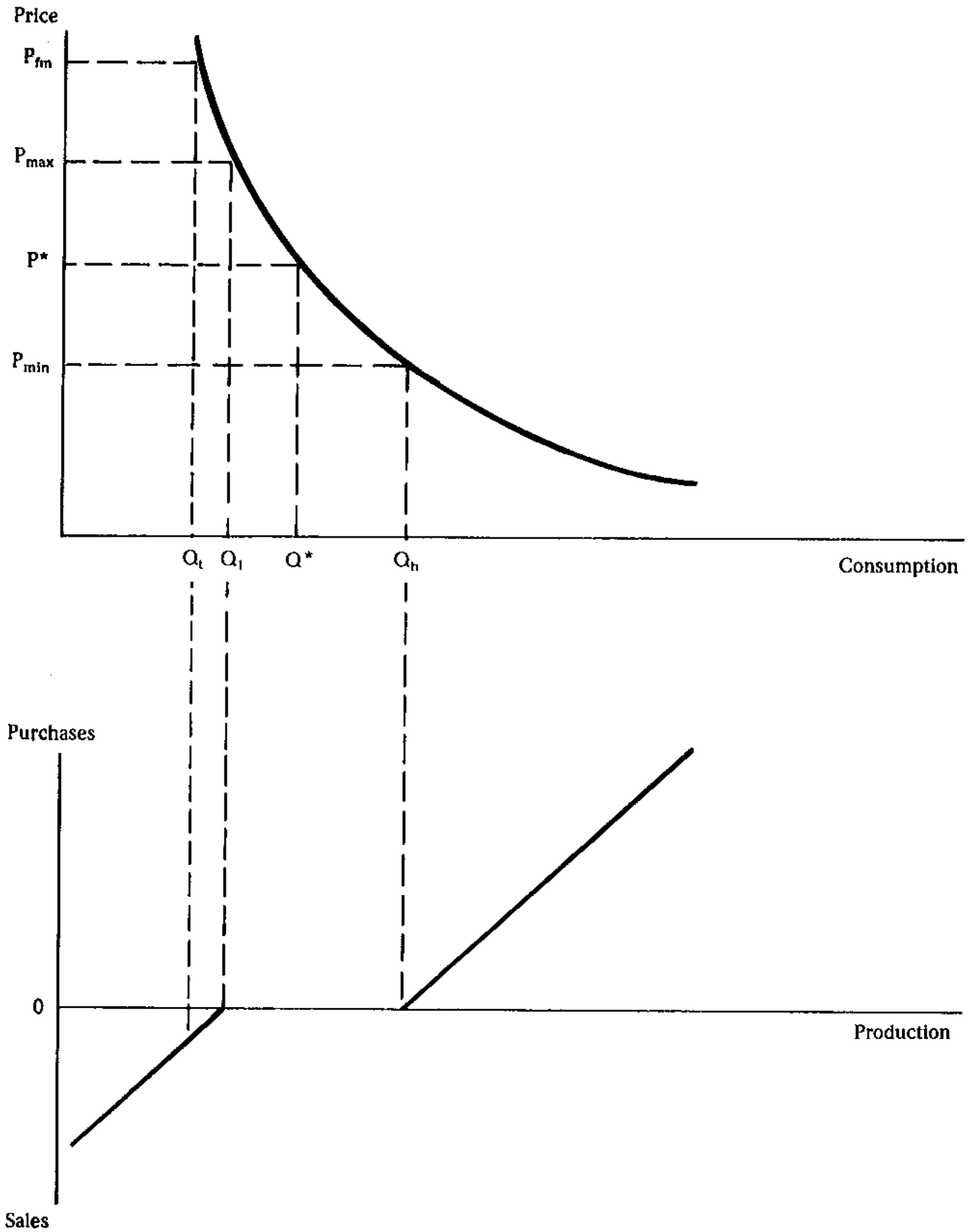
The basic price band/buffer stock policies studied by the Inter-Ministerial Working Group are described in this section. For brevity, these policies will be termed "price band policies" in what follows. It is assumed that the government has a target price, P^*. A maximum price is set, P_{max}, at which the government promises to sell sufficient quantities of maize to meet demand. Similarly, a price, P_{min}, is set, at which the government will buy all the maize which it is offered. Between P_{min} and P_{max}, prices are allowed to fluctuate freely. Two graphs (Figure 1) can help explain the basic policy. In the top graph, P_{max}, P^*, and P_{min} are drawn on the Y-axis. Each of these prices corresponds to a quantity consumed on the X-axis. Now suppose that actual production in year t is Q_t which corresponds to a free market price, P_{fm}, greater than P_{max}. The government would have to sell $Q_l - Q_t$ in order to keep the price at or below P_{max}.

The lower graph shows the relation between production and government purchases under such a system. The board buys all that is produced above Q_h, and makes up the total difference between Q_l and actual production. This graph will be particularly helpful later on when comparing price band policies with those that result from optimizations.

How should these three prices (P^*, P_{min}, and P_{max}) be chosen? The government does not want stocks to grow year after year or to be depleted continually. Price band/buffer stock schemes may be useful for stabilizing prices from year to year but are unlikely to be successful if the government is trying to raise or lower long-run market prices. So the working group takes P^* to be the free market price during a normal weather production year, and chooses the logarithms of P_{min} and P_{max} to be symmetrically distributed around the logarithm of P^*. This is approximately equal to holding the price within equal percentage bands.

The rules for exporting and importing are more difficult to choose. In the past, Kenya has allowed its own stock position to determine whether or not trade should

Figure 1—Net purchases function implied by price band policy



take place. Another alternative would be to allow imports and exports at other times if prices warrant it, or to adjust the stock triggers, depending on the prevailing world price. The working group simulations follow past government practice and allow stocks alone to trigger trade. The price band schemes therefore have minimum and maximum stock figures, S_{min} and S_{max}, which serve as trigger points for foreign trade. Since imports will not arrive in Kenya until three or four months after orders are placed, the S_{min} should be greater than zero. For the purpose of dealing with production instability, however, the important parameter of the model is not S_{min} or S_{max} but $(S_{max} - S_{min})$, the difference between maximum and minimum stock levels. This difference will be termed "stock variability." The purpose of stocks in a dynamic, stochastic world is to absorb shocks in present production and move grain from a surplus time period to a deficit time period. The degree to which stocks are able to accomplish this task is determined by the stock variability, not by S_{min} or S_{max} in isolation from each other.

This is seen most clearly by considering an example. Policies with larger stock variabilities will have higher average stock levels, lower imports, and lower exports. But the difference between two policies with the same figure for stock variability is only a constant. Suppose that policy A imports at a stock level of 100,000 tons and exports at 400,000 tons, and policy B imports at a stock level of 200,000 tons and exports at 500,000 tons. Both policies, then, have a stock variability figure of 300,000 tons. But the only difference between these policies when simulated will be the net present value of storing 100,000 tons for the entire time period, assuming that policy B begins with 100,000 tons more in store than policy A. This figure is a constant. Imports and exports will be identical, and average stock levels will only differ by 100,000 tons. Thus the single parameter of stock variability is required to determine the policy rather than two separate stock triggers.

So, given that P^* is constant across policies and that the price bands are symmetric, the price band policies studied by the working group differ only in two parameters: the allowable price variability and the stock variability.

The simulation model of the price band schemes is similar to the country models developed by Reutlinger and Bigman and Abbott's proposed methodology (Reutlinger 1983; Reutlinger and Bigman 1981; Reutlinger, Eaton, and Bigman 1976; Bigman 1982a, 1982b, 1985; Bigman and Reutlinger 1979a, 1979b; Abbott 1985). There are significant differences, however, between their models and the ones used here and by the working group. The Bigman and Reutlinger models are used primarily to measure the efficacy of implementing one type of policy versus another type, such as relying on trade to stabilize supplies versus relying on buffer stocks. Also, while they attempt to build their models for a generic country, it is obvious that any results will be particularly dependent on the specific parameters and policy structure chosen. Many of the published results use parameters relevant to India, including modeling a ration shop system similar to the one in use in that country. Kenya's status as a marginal importer and exporter with large differences between import and export parity prices makes its situation considerably different from the countries modeled in their publications. Finally, the goal of measuring the trade-offs between government goals leads to a different type of analysis than one focusing on choosing one type of policy over another.

Choice of Optimization Technique

There are at least three optimization techniques that have been used to analyze storage problems in the literature. These are Bigman's method, Eaton's programming method (Eaton 1980), and stochastic control methods (Rausser and Hochman 1979;

Kim, Goreux, and Kendrick 1975; Kendrick 1981; Arzac and Wilkinson 1980) or dynamic programming.[11] They will be considered in order.

Bigman has developed a technique that finds the optimal price band/buffer stock policy (Bigman 1985; Bigman and Yitzhaki 1983). If the government has already decided that a policy of this type is to be implemented, this is a useful technique. Otherwise, there could be a more efficient policy that does not fit into this category. Thus, in the absence of government direction in the matter, this technique cannot yield the four benefits outlined above.

Eaton's method requires that the problem be formulated with a quadratic or linear objective function and linear constraints (Eaton 1980). Production must be characterized as a random variable that is not influenced by the endogenous government decision variables. Thirty or more sequences of, say, 10 years each of possible future production are then produced by a random number generator. A series of multiperiod quadratic programming problems are then formulated, one for each 10-year production sequence, with the level of production for each year entering as a constraint. The quadratic programming results give optimal levels of the control variables for each particular future production sequence. The control variables clearly will be different for each production sequence and are chosen by the model with full knowledge of future production. It is as if Eaton acknowledges that this is unrealistic, since the model is making use of facts that would be unknown at the time decisions are made. However, he suggests that more general optimal policies can be gleaned from these particular implementations by regressing the levels of the control variables on values of other control and state variables that are known at the time decisions would have been made.

The problem with this technique is that the best specification of the regression equations is unknown. Given the results of the quadratic programming problems, it is difficult to move ahead. Should only linear decision rules be considered? Will the relationship between, say, carry-out stocks (the amount of stock held at the end of a market year—in this report, total stocks minus the import cushion) and production be the same for high levels of production as for low? That is unlikely, but it is unclear what levels of production should be included in the regression. So Eaton's method is not a true optimization method, since there is no way to guarantee that the optimal specification for policy structure has been tested in the regression analysis. Thus, it cannot yield the four benefits listed above.

Stochastic control methods leave no question about optimality if prior conditions are satisfied. Solving the continuous optimization problem by calculus techniques, however, is notoriously difficult. Kim, Goreux, and Kendrick (1975) are unenthusiastic about recommending this technique to other researchers dealing with storage problems, as they conclude their article by admitting that they cannot be certain their computations are correct. So if control methods are to be useful, they will have to be simplified in some way.

There are at least two ways of simplifying the problem: using certainty equivalence methods or using dynamic programming. Theil (1957) has shown that a stochastic control problem with a quadratic objective function and linear state transition equations

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[11] Bellman 1957 is the classic presentation. Howard 1960 concentrates on the Markov chain methodology, which is employed for world prices in this study. In the area of optimal stockholding, Gustafson (1958) was the pioneer. Gardner (1979) and Burt, Koo, and Dudley (1980) use dynamic programming in more complex models. Gardner 1979 and Plato and Gordon 1983 are particularly useful for the practitioner. Johnson (1981) and Johnson and Sumner (1976) attempt to apply dynamic programming to stockholding problems of LDCs. The manual for the Microsolve program (Jensen 1983) is especially helpful for composing a computer program to solve such a problem; it is also an excellent teaching tool.

has a certainty equivalence solution; that is, the variability of the stochastic variable makes no difference in the choice of the optimal policy. If the problem can be stated in those terms, the solution can be found simply by filling in the values of some variables in an equation.

The Kenya model that will be used here has a quadratic objective function and could have been constructed with a linear demand curve, allowing for this solution technique. But consider the following implications of certainty equivalence: Suppose there are two countries, each with an average production of 10 million tons. In one, the standard deviation of production is 5 million tons, while in the other the standard deviation is only half a million tons. If certainty equivalence is correct, provided both countries have the same opening stock and the same production, and face the same world price, then they should carry out the same stock despite the large difference in the standard deviations. This is counterintuitive.

It is also incorrect. The problem is that the derivation of the certainty equivalence theorem assumes that there are no inequality constraints. But stocks, imports, and exports are all strictly non-negative variables (because of the difference between import and export parity, imports and exports must be costed differently and thus must remain distinct rather than being added together as trade). Such non-negativity conditions make the certainty equivalence formulation unworkable.

In spite of these problems, Arzac and Wilkinson (1980) have developed a storage model for grains that uses certainty equivalence methods and compared their results to those from the pioneering dynamic programming work of Gustafson (1958). They comment that "the numerical [dynamic programming] solution and the linear rules [from the certainty equivalence formulation] give very similar results for stocks greater than or equal to 35." This statement is correct (except that 35 should refer to total supply rather than stocks). But Gustafson goes on to compute his model for different levels of production variability, and he gets considerably different results with a higher level of variability. The certainty equivalence formulation gives the same result for every level of variability, since it ignores the standard deviation of production. Table 2 shows the level of total supply (production plus opening stocks), Gustafson's results with a low variability of yield, his results with a high variability of yield, and the Arzac and Wilkinson certainty equivalence results.

Most striking are the negative stock levels with a total supply of 25 and 30 in the certainty equivalence results. The authors claim that the "negative stocks produced by

Table 2—Optimal storage versus certainty equivalence storage

Total Supply	Optimal Storage: Low Variability	Optimal Storage: High Variability	Certainty Equivalence Storage
25	0.0	0.0	–4.5
30	0.0	0.0	–1.1
35	2.4	2.9	2.3
40	5.9	6.4	5.6
45	9.7	10.2	9.0

Sources: Based on data from Enrique R. Arzac and Maurice Wilkinson, "Dynamic Analysis and Optimal Control of Agricultural Commodity Markets," in *Applied Stochastic Control in Econometrics and Management Science*, ed. Alain Bensoussan, Paul Kleindorfer, and Charles Tapiero (Amsterdam: North Holland Publishing Company, 1980), pp. 41-77; and Robert L. Gustafson, *Carryover Levels for Grains: A Method for Determining Amounts That Are Optional Under Specified Conditions*, Technical Bulletin 1178, U.S. Department of Agriculture, October 1958.

the linear rules can be interpreted as a reduction in the working stocks of the economy (which are implicit in this analysis)" (Arzac and Wilkinson 1980, 46). But this is surely not a proper interpretation, since there is no mechanism for the buildup of working stocks in the model.

They also suggest that the certainty equivalence solution with stocks truncated at zero "seem[s] to produce a very good approximation to the numerical solution" (Arzac and Wilkinson 1980). While not far off for Gustafson's original case, it is considerably off for Gustafson's case with a larger variance, and Gardner (1979) cites an example in which the certainty equivalence stock level is only about 50 percent of the dynamic programming stock level. Clearly, it is fortuitous that the particular case Arzac and Wilkinson cite turns out to be close. It is thus wrong for an analyst to assume a priori that the certainty equivalence solution will be close to the dynamic programming solution. In fact, Gardner (1979, 17) makes the point that the

> use of optimal control methods which substitute the expected value of future production for the probability distribution of production can lead to recommended carryover stock levels substantially lower than the optimal carryover. Indeed, in almost every practical application, optimal storage increases significantly as the variance of future production increases.

It is clear, then, that certainty equivalence methods are not appropriate for the analysis at hand.[12]

The second possible simplification of the stochastic control problem is dynamic programming. This involves making the problems discrete rather than continuous and solving by means of a backward recursion. The algorithm is best understood by a simple example.[13] Suppose there is a country where production is either 8 or 12 units every year, with the two outcomes being equally likely. Storage capacity is 3 units and everything that is not stored is consumed. The cost function to be minimized is

$$\Sigma (C_t - 10)^2 + 0.1 \cdot S_t$$

for all years t in the time horizon, where C_t represents consumption in year t and S_t represents closing stocks. Say there are T years in the time horizon. Dynamic programming generally uses a backward recursion technique to solve the problem. Beginning with the terminal year T, all possible opening states of the world are enumerated, each one being evaluated for all of the possible stock carry-outs. This is shown in Table 3.

Consider the first row of the table: if production is 8 and there are no carry-in stocks, then carrying out no stocks implies consumption of 8 and thus a cost of

$$(10 - 8)^2 + 0.1 \cdot 1 = 4.0.$$

Storing 1 unit implies consumption of 7, leading to a cost of

$$(10 - 7)^2 + 0.1 \cdot 1 = 9.1.$$

[12] Control methods are most useful and interesting when the systematic variations from period to period are significant, making the nonstochastic case nontrivial. Then certainty equivalence methods can be used to approximate a solution, and the stochastic case can be solved by minimizing deviations from the certainty equivalence case. This is the technique used by Kim, Goreux, and Kendrick (1975).

[13] Gardner (1979, 5-14) gives a more detailed example of a similar problem.

Table 3—Dynamic programming example: terminal year payoffs

Production	Opening Stocks	Cost if Closing Stock Is 0	1	2	3	Minimum Cost
8	0	4.0	9.1	16.2	25.3	4.0
8	1	1.0	4.1	9.2	16.3	1.0
8	2	0.0	1.1	4.2	9.3	0.0
8	3	1.0	0.1	1.2	4.3	0.1
12	0	4.0	1.1	0.2	1.3	0.2
12	1	9.0	4.1	1.2	0.3	0.3
12	2	16.0	9.1	4.2	1.3	1.3
12	3	25.0	16.1	9.2	4.3	4.3

The rest of the table is computed in a similar fashion, with the cost of the best stock option shown in the right-hand column.

That completes the analysis for the terminal year T. Now, consider the situation in year T–1. Since the objective function is the same, the cost in year T–1 alone of storing a particular quantity, given opening stocks and production, will be identical to the values computed for year T. However, the total cost in year T–1 is the sum of the cost in year T–1 plus the expected future cost in year T. These total costs are computed in Table 4 for the state in which production is 8 and carry-in stocks equal 2 in year T–1.

Consider the first row of the table. Table 3 shows that the cost in year T–1 of carrying out zero stocks when production equals 8 and opening stocks are 2 is zero. But if no stocks are carried out in year T–1, then there are two possibilities for year T shown in Table 4: either production will be 8, with a cost of 4.0, or production will be 12, with a cost of 0.2. Since those outcomes are equally likely, the expected cost in year T of carrying out zero stocks in year T–1 is 2.1. The best choice, then, is to consume 9 units and store 1, with a total expected cost of 1.75. Note that when only one year is considered, it is optimal to consume all of production and stores when production is 8 and stores are 2, but when the subsequent year is considered, it is best to consume less in the present year and store 1 unit.

To complete the dynamic programming recursion, similar tables would have to be computed for the other seven possible states of the world in year T–1. Each table would yield the cost of being in that state of the world in year T–1. Then the recursion would move back to year T–2 and proceed in a similar fashion until year 1 is reached.

It is clear from this example that dynamic programming can solve dynamic, stochastic problems similar to Kenya's maize-marketing problem. Dynamic programming has the additional advantage of allowing inequality constraints on the variables. The constraints

Table 4—Dynamic programming example: year T–1 payoff calculations

Carry-out	Cost in Year T–1	Cost in Year T If Production = 8	Cost in Year T If Production = 12	Expected Cost in Year T	Total (T–1 + T)
0	0.0	4.0	0.2	2.10	2.10
1	1.1	1.0	0.3	0.65	1.75
2	4.2	0.0	1.3	0.65	4.85
3	9.3	0.1	4.3	2.20	11.50

Note: Production = 8; carry-in stocks = 2.

do not have to be linear, so unlike Eaton's method or certainty equivalence techniques, a nonlinear demand curve can be used. In fact, a limitation of this approach is that as a discrete system, inequality constraints are required on every variable. Thus it is difficult at times to ensure that the results are not constrained by inequalities that are a function of the particular specification of the solution algorithm rather than of the theoretical model.

Before accepting dynamic programming as the proper technique for this study, it is necessary to consider the two charges that other analysts have brought against it. These are the need for a simplistic objective function, and the "curse of dimensionality."

Although the example considered above is very simple, the criterion for optimality in most applications of dynamic programming to storage problems has not been much more complex than the one used there. As Bigman and Yitzhaki (1983, 2) point out, these functions have generally been "a single valued social welfare function (generally, the sum of the present and the expected future consumers' and producers' surplus)." Indeed, Eaton (1980, 20) points out that maximizing producer/consumer surplus after subtracting costs of storage "has been the sole objective of dynamic programming analyses of grain reserves." Cochrane's (1980) critique of such an objective function is only the best known of many others.

The use of simplistic objective functions, however, has been the result of researchers' choice, not a requirement of the solution technique. The solution algorithm used in the present study is simply a brute-force search; this is slow computationally, but it is effective in dealing with the three objectives, with nonlinear costings, and with a nonlinear objective function. Importantly, all the programs can run on microcomputers, so the costs are not excessive.[14] Consequently, there is no need to avoid dynamic programming because of the need for a complex objective function.

The second problem with dynamic programming is the curse of dimensionality (Bellman 1957). This problem multiplies in difficulty with the number of possible states of the world in the model. As an example of the effects of the curse, consider the model to be developed below. The state of the world will be determined by three variables: world price, production, and opening stocks. Nine discrete levels of production and 30 discrete stock levels are allowed. If these were the only two state variables, there would be $9 \times 30 = 270$ possible states of the world. By adding one more variable, world price, with 7 discrete levels, there are now $7 \times 9 \times 30 = 1{,}890$ possible states of the world. The problem has increased more than sevenfold in terms of computing time. The curse consequently constrains the size of the model that can be developed. To some extent, this constraint can be relaxed by using larger computers or more efficient solution techniques.[15]

The curse is not a major problem for this study. As discussed in the next chapter, data problems and the desire to keep the model understandable would have led to a fairly simple model even if a different solution technique had been used.

Thus dynamic programming is clearly the best choice of optimization technique for the problem at hand. Each of the four benefits of optimization mentioned above—

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[14] Programs are listed in Pinckney (1986a). Recent versions of both programs are available from the author in Microsoft Fortran 4.0.

[15] Burt, Koo, and Dudley (1980) use a solution technique that is not a backward recursion. Their method allows other variables from a more complex econometric model to influence the expected value of future costs. The disadvantage is that expected values are no longer exact, as they are when a backward recursion algorithm is used. Nevertheless, this technique is interesting and warrants further research in countries where data limitations do not rule it out.

making selections across many types of policies, measuring trade-offs accurately, maximizing the value of the objective function for comparison with suboptimal policies, and providing suggestions for modifications of administrative rules—is gained through the use of dynamic programming.

In order to take advantage of the last three benefits, however, it is necessary to take the analysis one step beyond the optimization algorithm itself. As mentioned above, the optimal policies must be simulated in the same framework as the price band schemes in order to compare measurements of trade-offs, to judge the suboptimality of the price band schemes, and to learn from the optimal policies in order to adjust the price band schemes. Before the optimal policies can be simulated, however, they need to be made "continuous" rather than discrete. This is accomplished by linearly interpolating the discrete optimal policies across state variables. While it is unlikely that the resulting policy will be the optimal continuous policy, it will not be substantially different if the discrete optimization includes a large enough number of levels of each state variable. This is discussed more fully in the following chapter.

4

A PRODUCTION INSTABILITY MODEL FOR KENYA

Food Production and Consumption Data in Kenya

In a review of the problems associated with formal analyses of food security issues in East Africa, Lele and Candler (1981, 105) warn against "planning without facts," and go on to say

> We do not believe that the exercises of economists in the international agencies are inherently futile; but we do warn that such analyses should not start with the facile assumptions that all the required data are readily available and that the system is totally commercial.

The quality of data on both food crop production and consumption in Kenya is poor. The only hard data available are on purchases and sales of grains by the NCPB, but these series are inappropriate for use as proxies for total production. The presence of the parallel, informal market as a competitor to the board causes the NCPB to take a larger proportion of the crop during good production years than in poor production years, since the ratio of the local market price to the official price varies. Consequently, NCPB purchases and sales fluctuate much more dramatically than production.

Yet if the NCPB numbers are inaccurate indicators of production, which production series should be used? The Kenyan government publishes several conflicting series, and others are available from international organizations. Table 5 presents the series used by the Development Planning Division of the Ministry of Agriculture (DPD/MOA) along with the series from the Food and Agriculture Organization of the United Nations (FAO) and the U.S. Department of Agriculture (USDA). For comparison, the NCPB sales and purchases data are listed also.

There are large differences between the series, most obviously in 1976/77 when the FAO series shows an increase of over 60 percent, the USDA shows an increase of over 15 percent, and the DPD/MOA series increases less than 1 percent. The figures show smaller differences between these series in recent years.

The DPD/MOA series is built up from district and provincial estimates of maize production made by Ministry of Agriculture officers in the districts. Goldman (1983) uses the provincial estimates to test for links between NCPB sales and purchases series and the production series. He estimates the following equations:

$$\text{BUY} = 205 + 0.53\ \text{RIFT} - 0.85\ \text{OPENSTOCK}$$

Years: 72-82;
Adjusted $R^2 = 0.93$,

$$\text{SALES} = 0.15\ \text{INVENT} - 0.75\ \text{WEST} - 1.45\ \text{EAST}$$

Years: 71-73, 75-81;
Adjusted $R^2 = 0.61$,

where

BUY	=	NCPB purchases,
SALES	=	NCPB sales,
RIFT, EAST	=	production in those provinces,
WEST	=	production in Western and Nyanza provinces,
OPENSTOCK	=	NCPB opening stocks, and
INVENT	=	opening stocks plus current year's purchases.

All t-statistics are significant at the 2.5 percent level.

These equations give strong support to the DPD/MOA production series, since they relate the building blocks of that series to the only hard data available. Unfortunately, it is impossible to compare the competing series by comparable tests, as those data are not reported by province. Nevertheless, because the DPD/MOA series is supported it will be used in the analysis at hand.

On the consumption side there is no series that exhibits any links with hard data. The DPD/MOA production series is at least a direct estimate of the desired quantities, albeit by people of varying levels of skill and interest. The best consumption series, on the other hand, is a derived series that leaves out a critical variable: changes in private stocks. Table 6 shows the derivation of an apparent consumption series for the last 15 years.

The series is nonsensical when considered as "consumption." It can more appropriately be called "disappearance." The problems are most obvious for 1975/76, 1981/82, and 1984/85; the first two were good crop years after relatively poor ones had

Table 5—Different series of maize production in Kenya

Year	DPD/ MOA	USDA	FAO	NCPB Purchases	NCPB Sales
			(1,000 metric tons)		
1970/71	1,181	1,500	1,400	240	278
1971/72	1,473	1,300	1,500	379	191
1972/73	1,384	1,700	1,660	455	358
1973/74	1,297	1,600	1,600	335	490
1974/75	1,387	1,600	1,400	448	343
1975/76	1,688	1,900	1,600	552	604
1976/77	1,748	2,195	2,600	536	397
1977/78	2,080	2,205	2,553	244	146
1978/79	1,740	1,895	2,169	235	513
1979/80	1,604	1,450	1,800	131	491
1980/81	1,768	1,750	1,620	393	685
1981/82	2,502	2,200	1,980	696	532
1982/83	2,348	2,340	2,349	621	473
1983/84	2,030	2,000	2,178	504	768
1984/85	1,423	1,275	1,275	366	803

Sources: Based on data from Food and Agriculture Organization of the United Nations, *FAO Production Yearbook*, various issues (Rome: FAO, various years); U.S. Department of Agriculture, Economic Research Service, *World Indices of Agriculture and Food Production*, Statistical Bulletins 669 and 710 (Washington, D.C.: USDA, July 1981 and July 1984); U.S. Department of Agriculture, Foreign Agriculture Service, *Foreign Agriculture Circular, Grains: World Grain Situation and Outlook* (FG-2-85) (Washington, D.C.: USDA, 1985); and unpublished data from the Development Planning Division, Ministry of Agriculture, Nairobi.

Notes: Figures are for crop years, July to June. DPD/MOA = Development Planning Division/Ministry of Agriculture; USDA = U.S. Department of Agriculture; FAO = Food and Agriculture Organization of the United Nations; and NCPB = National Cereals and Produce Board.

Table 6—Derivation of maize "consumption" series

Year	Production	NCPB Net Sales	"Consumption"
		(1,000 metric tons)	
1970/71	1,181	38	1,219
1971/72	1,473	−188	1,285
1972/73	1,384	−97	1,287
1973/74	1,297	155	1,452
1974/75	1,387	−105	1,282
1975/76	1,688	52	1,740
1976/77	1,748	−139	1,609
1977/78	2,080	−98	1,982
1978/79	1,740	278	2,018
1979/80	1,604	360	1,964
1980/81	1,768	292	2,060
1981/82	2,502	−164	2,338
1982/83	2,348	−148	2,200
1983/84	2,030	264	2,294
1984/85	1,423	437	1,860

Source: Unpublished data from the National Cereals and Produce Board, Kenya.

depleted private stocks. Consumption shows a big jump, which is at least partially an increase in private stocks. For 1984/85, it is clear that private stocks were drawn down to make up for the production shortfall.

There is virtually no evidence about the magnitude of private stocks in the country. The Integrated Rural Surveys of the 1970s report figures for private stocks held by smallholders, but even these numbers are derived from numbers for production and consumption, since the survey questionnaire did not ask about stocks. As an example of the magnitudes involved (which should only be considered indicative), Integrated Rural Survey 3 estimates that in July 1977, private stocks held by small farmers were 132,000 tons; this figure increased to 203,000 tons by July 1978, implying that the consumption figure in Table 6 for 1977/78 should be decreased by 71,000 tons.[16] Since 1977/78 was the second good year in a row, this figure is unlikely to be abnormally high. In addition, since large farmers and traders are not included, it is clear that changes in private stocks might be quite large relative to the variation in the consumption series.

Given the problems caused by a lack of information on the demand side, it will be necessary to forgo any direct estimate of price elasticity of demand if this study is to avoid being lumped with the "mechanistic analyses of meaningless numbers" that Lele and Candler (1981, 107) criticize. In such a situation it is more reasonable to make judgments about the magnitude of some important parameters than to use data series that are known to be far from correct. The absence of hard data also affects the type of model that can be employed, as is made clear in the following section.

The Model

The purpose of a model is not to mirror the real world. The rationale for modeling is that the real world is too difficult to understand in its entirety, and the analyst can

[16] Figures are from Booker International 1983, Annex 8, Appendix 1, Tables 8 and 9. In July of 1977 and 1978, government stocks were 400,000 and 490,000 tons, respectively, or more than double the IRS estimate of smallholder stocks. The IRS estimates, however, are suspect.

gain a better understanding of the forces at work by selecting certain aspects of the world to study in depth. There are two opposing motives for the analyst: first, the desire to include all the interactions that will affect significantly the goals of the model; second, the need to keep the model simple and understandable. A model that leaves out key relationships can cause the analyst to give incorrect advice; a model that tries to include too much can leave the analyst foundering "in a limbo of unending data requirements, impossible 'debugging' problems, and general ineffectiveness" (Clark, Jones, and Holling 1979, 7). The result of these problems can be a black box model that no one, including its builder, can understand or interpret (see Johnston and Clark 1982, 231-234).

Clearly, balancing the two goals is an art and not a science. The point of balance will depend heavily on the goals of the analysis at hand. But as Holling (1978, 57) laments, "all too often, it is the technique that grabs the lead, and the problem is then bent and redefined to suit." Since one of the goals of this analysis is to have an effect on decisionmakers, it is even more important than usual to have a model that is clear and straightforward (Labys 1975, 372). This study, then, avoids the Charybdis of a black-box model by navigating rather close to the Scylla of a simplistic model.

Therefore, a simple model underlies both the simulation and the optimization procedures. For each equation the degree of simplicity is defended below. In some cases, a slightly different model is used in the simulation analysis than in the dynamic programming. These differences will be described also. Discussion proceeds by examining first the unified market assumption. This is followed, in order, by a discussion of supply, demand, the trade and stock equations, the world price equation, and the objective function. Then other types of objective functions are considered, followed by a description of the price band/buffer stock decision rules. Finally, the parameters of the model are selected in the final section of the chapter.

Unified Market

The maize market in Kenya is treated as one unified market in the simulation and optimization exercises. Since this assumption is made for simulations of future policy rather than estimation of parameters from past experience, the assumption does not imply that the Kenyan maize market has been fully integrated in the past. Table 1, which presents maize prices in different parts of Kenya in September 1984, clearly shows that markets have not been fully integrated. To a large extent, this lack of integration has resulted from an official government policy of totally stabilizing prices that the government cannot implement, given fiscal constraints. For example, in September 1984 the NCPB was not selling all that was being demanded at the official price. There has thus been a government-induced lack of integration.

This study is examining the cost savings to the government that result from providing the NCPB with sufficient fiscal resources to defend successfully floor and ceiling prices after building some official price flexibility into the system. Therefore the changes in policy being modeled here would lead to a higher degree of integration of the maize market, with prices in different markets differing by less than the width of the price band. It is thus appropriate to make the single market assumption for the purpose of designing a national supply stabilization strategy.

Nevertheless, prices will vary across the country and across seasons within the limits allowed by the policy. Consequently, an analysis that includes regions and seasons is important when deciding on the tactics of implementation of the supply stabilization strategy. This analysis, however, can be introduced into a 12- to 18-month model after the major decisions on strategy are made. Attempting to include regions and seasons in the multiyear model that is necessary for designing stabilization strategy would lead to unnecessary complications, obscuring the important lessons on policy design.

Supply

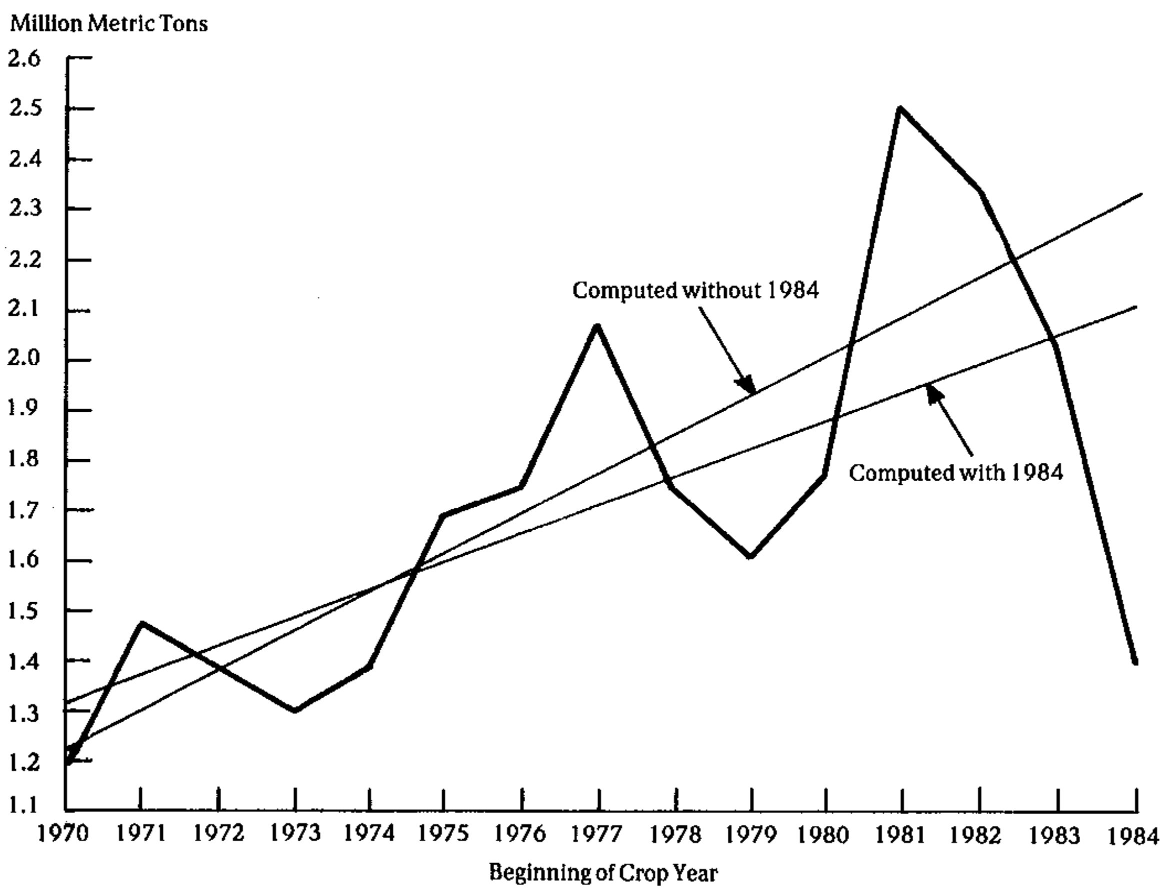
Production is modeled here as a stationary, normally distributed, uncorrelated time series:

$$Q_t = Q_0 + u_t, \qquad (1)$$

where Q_t is production in year t, Q_0 is the mean, and u_t is the random element in year t. The random term u_t is normally distributed with an expected value of zero. Critics of this specification might focus on the following areas: maize production in Kenya has increased at a rapid rate over the last several years, so a series without a trend is inappropriate; an autocorrelation term should be included; the model ignores supply response to price; and although production can be modeled as a random variable, it is not normally distributed. These objections will be discussed in order.

Absence of a supply trend. It is undoubtedly the case that maize production in Kenya has grown rapidly in the last 15 years. Figure 2 shows the DPD/MOA production series for maize from 1970/71 to 1983/84. The less steeply rising line is the linear trend computed by regressing production on time for the entire period. This corresponds

Figure 2—Maize production and trends, 1970/71-1983/84



to a trend of about 3.3 percent at the mean production level for the period. The more steeply rising line is the trend computed from a regression that leaves out the 1984/85 drought year; it corresponds to growth of about 4.5 percent per year. Thus, although there is considerable area for disagreement about the magnitude of the trend, there can be no doubt that it is large and positive. A large component of this increase, however, has been area expansion, which is unlikely to increase as fast in the future. At the same time, there is considerable potential within the country to raise maize yields through better husbandry practices and development of improved varieties. So increases in production on the order of 3.5 percent per year over the next 10 years are not unreasonable to expect.

The expected growth in demand, however, is quite close to expected growth in production. Demand growth is affected primarily by three factors: population growth, growth in per capita income, and urbanization. Present population growth is 3.8-4.0 percent per year. Urban population is expected to grow at a rate of 7.8 percent per year. If per capita income remains approximately constant, maize demand will grow at about 3.5 percent per year, since the per capita consumption of maize in urban areas is only about 75.0 percent of the rural per capita consumption. Thus, given the rate of maize production increase and assumed rates of growth in demand, the real price of maize in a normal weather year should remain fairly constant. Since there is much uncertainty about the trend in maize production, and since the estimates of maize consumption are even worse, it is best to make a straightforward assumption about ignoring trends and consider any policy recommendations that come out of the analysis about stocks, for example, as relating to the percentage of a normal crop rather than an absolute number. This has the advantage of allowing the dynamic programming model to have the same structure every year, and thus come to a stable solution after several iterations. Although the absence of trends will make estimates of cost too low, it should not affect the measure of trade-offs between the goals, which is the primary purpose of the analysis.

Autocorrelation. Autocorrelation may enter production series in four ways: if farmers have naive expectations that next year's price will equal this year's price (the cobweb effect); if farmers have a target level of on-farm stocks; if other government policies are constant for a period of years, then change to a different mix for a few years, then change again; and if rainfall is autocorrelated. In this analysis it is assumed that the government's goals are well known to and believed by the populace. The government's desired price does not change from year to year, since the absence of trends implies that the equilibrium price in a normal weather year is constant. Given these assumptions, in the simple price band models the expected price is the same every year, regardless of the previous year's price. It is more difficult to characterize the rather complex policies that result from dynamic programming, although it can be said with certainty that the expected price will vary inversely with government stocks. The regression analysis of some of the optimal policies carried out in Chapter 6 indicates that a policy with a fairly large standard deviation of price ($12.10) produces an expected price 7.2 percent below normal when stocks are at their maximum and world price is at its minimum. The expected price is 6.4 percent above normal in the opposite situation. It should be understood that these are the extremes, and most years would be considerably closer to the mean. So if farmers are rational and the government is straightforward, the autocorrelation resulting from expectations will be negligible.

The second possible source would result if the farmers' target level of on-farm storage influences their production decisions. In this case, a bad year that depletes on-farm stocks would induce increased plantings in the subsequent year; similarly, a good year that increases stocks would lead to decreased area planted to maize in the next year. This, then, is an argument for negative autocorrelation, for which there is no empirical evidence. The autocorrelation parameter measured over the years 1970 to 1983 is + 0.12.[17] Although there may be some supply response to on-farm stock levels after exceptionally bad years, this positive (although insignificant) autocorrelation parameter indicates that the effect does not occur often enough to have a large average effect.

The third source of autocorrelation, fairly consistent government policies that change periodically, is assumed away in this analysis. Any attempt to measure trade-offs between government objectives must choose which possible instruments the government will use to affect the area under analysis and hold all other government policies constant. Agricultural credit policies, for example, have been left out and are assumed to be constant throughout the time horizon. Similar assumptions must be made when doing any analysis of this type.

The final possible source of autocorrelation, rainfall, is the subject of some debate in Kenya. Many persons in the country believe in rainfall cycles, with the most often heard number being 10 years. Although Kenya has reasonably good rainfall data, going back 30 or 40 years in some cases, these series are too short to check for cycles of this length. Although there is some evidence in the rainfall data for shorter periods of autocorrelation in single agroecological zones, Kenya's ecological diversity lessens the effect of any autocorrelation that might be present in individual zones.

Supply Response. Supply response to price occurs only when expectations about relative prices in one year differ from expectations about relative prices in another year. As explained above, expected prices will be constant for the price band policies and close to constant for the optimal policies. Long-term expected prices are the same in both cases. Therefore, the appropriate supply elasticity would be a short-term elasticity, which would be smaller than a long-term elasticity. The recent study by Booker International surveys other studies of supply response of maize production in Kenya, in which estimates range from 0.15 to 0.95. Their own estimating equations in conjunction with comparisons from other studies leads them to a best guess of around 0.40.[18] Even this number seems somewhat large for a staple food in a poor country. Timmer, Falcon, and Pearson (1983) point out that from comparative experience one would expect the supply elasticity for a basic cereal grain to be between 0.20 and 0.30. Nevertheless, if the short-term supply elasticity is taken to be the higher value of 0.40, even assuming a large deviation of expected price from normal of 7 percent, the maximum expected change in maize production is less than 3 percent. In most years it will be much smaller.

There are at least two possible nonprice factors that could induce a supply response. The first, unequal changes in expected yields for competing crops, is assumed to be unimportant. This is equivalent to assuming that trends in yields for competing crops are approximately equal to trends in maize yields. The second factor, a target for on-farm maize stocks, has been discussed above under autocorrelation.

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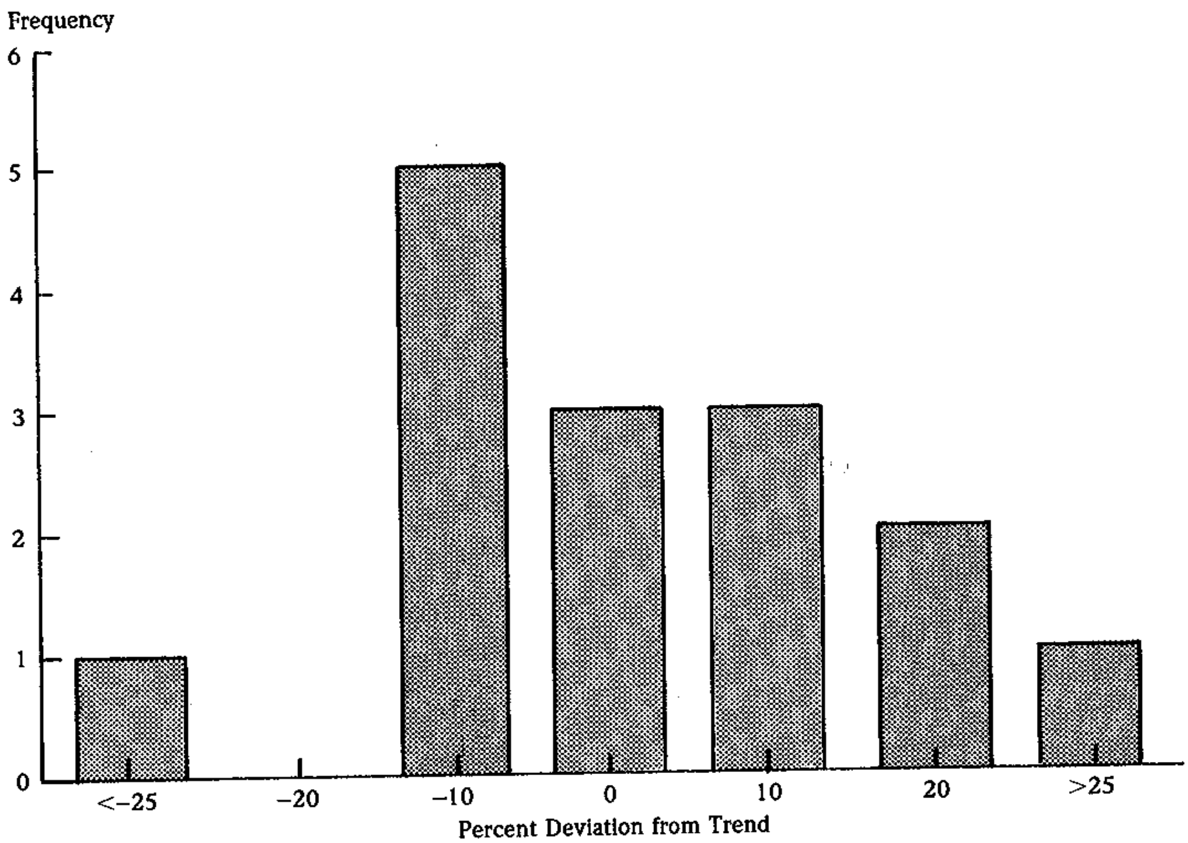
[17] As measured from 1970 to 1984 the parameter is + 0.39. This is considered inaccurate because the probability of a shortfall in production of the degree that occurred in 1984 is less likely than 1 in 15 (the implicit assumption of the regression analysis). See the discussion on the standard deviation of production below.

[18] Booker estimates supply response for different regions of the country. A weighted average of their different numbers is about 0.4. See Booker International 1983, Annex 5, Appendix 2, Table 1, and Annex 5, Appendix 4, Table 1.

Thus, nonprice supply response factors are unimportant, while supply response to changes in expected price could be as large as 3 percent in rare years for the optimal policies. Ignoring this price response will not lead to a large bias, since it is dwarfed by the standard deviation of production, which will be 10 percent (discussed below). The direction of the small bias will be toward overestimation of costs and stock requirements, since the expected price in the optimal policies will be higher in years of high world price and low stocks. Thus positive supply response will occur in exactly those situations when the country has the most to lose from a production shortfall.[19] Sensitivity analysis of the standard deviation of production will capture the effects of supply response to some extent.

Normality. Some analysts believe that production should not be considered to be normally distributed, arguing that since both exceptionally heavy rainfall and exceptionally poor rainfall lead to poor crops, production will be skewed downward. Indeed, U.S. aggregate production data for feedgrains tend to be skewed in this direction (Gustafson 1958). Data from Kenya, however, tend to show the opposite. Figure 3 shows a frequency diagram of percentage deviations from trend using data from 1970/71 to 1984/85. While the series is too short to warrant any conclusions, the apparent

Figure 3—Maize production frequency diagram, 1970/71-1984/85



[19] However, rational expectations that include knowledge of other farmers' supply response will dampen this effect. See Gardner 1977 and Plato and Gordon 1983 for a discussion of solution techniques for the difficult problem of including supply response in a dynamic programming model.

skewness is to the right.[20] Leaving out 1984/85, the series is dramatically skewed upward. Some a priori reasoning supports upward skewness. A significant percentage of maize area in Kenya is planted in semiarid areas. In these areas, the standard deviation of production is often larger than the mean. Thus, production in these areas is never more than one standard deviation below the mean, while it may occasionally be two or three standard deviations above the mean. In about 10-20 percent of all years, production is almost nil. In effect, the bottom tail of the distribution is chopped off, leading to a distribution that is skewed upward. Positive skewness that decreases with application of nitrogen was also found by Day (1965) for maize in the Mississippi Delta. Thus there are a priori arguments for skewness in both directions, conflicting evidence from the United States to support skewness in either direction, and some evidence from Kenya to support skewness upward. Amid these mixed signals it is both prudent and convenient to depend on the Central Limit Theorem and assume a normal distribution.

Demand

As stated in the data section, demand is even more of a problem than production and therefore is modeled even more simply, as a nonstochastic, constant elasticity curve that depends only on the price of maize:

$$\ln(D_t) = C + e_m \cdot \ln(P_t), \tag{2}$$

where

$\ln(\cdot)$ = natural logarithm function,
D_t = demand for maize in year t,
C = constant,
e_m = own-price demand elasticity for maize (a negative number), and
P_t = price of maize in year t.

Such a specification is in line with Bigman's (1985) suggestion. As pointed out above, there is no trend in demand. In addition, demand is not stochastic. While it would be easy to make demand stochastic in the simulation models, the dynamic programming models would become more difficult to compute because of the aforementioned curse of dimensionality.

Stochastic demand is not, however, important relative to stochastic supply. The main source of stochastic demand would be fluctuations in real per capita income. The coefficient of variation of real GDP per capita from 1972 to 1985 (during which time GDP per capita shows no trend) is 3.3 percent. The average income elasticity for maize in Kenya used in the Booker study is + 0.60.[21] Thus the appropriate coefficient of variation of demand would be 2.0 percent, which is negligible compared with the importance of supply variations.

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[20] Measuring skewness in this way assumes that the trend line represents normal weather years. Clearly, this may not be the case.

[21] Calculated from Booker International 1983, Annex 5, p. 33, and Annex 5, Appendix 3, Table 3.

Maize, however, is an important income-producing crop for a large segment of the population, and fluctuations in maize production are included in the model. Thus it would be possible to include demand fluctuations that result from changes in income associated with maize production fluctuations. This factor, however, turns out to be negligible. The gross value of maize production accounts for approximately 5.0 percent of Kenya's GDP. With a coefficient of variation of production of 10.0 percent and income elasticity of 0.6, the coefficient of variation of demand resulting from this source is only 0.3 percent. It is consequently not worth including.[22]

After the nonstochastic nature of demand, the second point to note is that the demand curve is constant elasticity. A constant elasticity curve is more appropriate than a linear curve and less ad hoc than a kinked curve. A linear demand curve implies that as price increases, demand responds more flexibly to price. This is an unlikely occurrence for the most important source of calories in a poor country.

A third assumption is the absence of other prices in the model. As mentioned above, this analysis assumes that all other government policies are held constant, so to the extent that government controls prices, the terms should all be absorbed in the constant. There is, however, a problem in that weather affects production of all crops, not maize alone. FAO (1984) estimates that from 1979 to 1981, maize accounted for 40 percent of total calorie consumption. The next seven most important sources of calories are sugar (10 percent), wheat (6 percent), oils and fats (6 percent), cassava (6 percent), sorghum and millet (5 percent), pulses (5 percent), and potatoes and sweet potatoes (3 percent). Total calorie consumption from all seven of these alternative sources, however, is no greater than the calories consumed from maize alone. Prices of sugar, wheat, and oils and fats are effectively controlled by the government.

Although the remaining crops are grown to a large extent in different agroecological zones with different weather patterns, there are nevertheless significant correlations in the production of some of the different calorie sources. A shortfall of rain that leads to a poor maize crop will raise prices of maize and thus decrease consumption; however, if the low rainfall also diminishes the bean crop, the rise in the price of beans will increase demand for maize, thus dampening the own-price effect. Since bean calorie consumption is only about 12 percent of maize calorie consumption on average, the effect from beans alone will not be large. But in a year like 1984/85, when the maize, bean, and potato crops all failed, the cross-price effects may have been significant, leading to a smaller decrease in maize demand than would have been forecast by looking at maize prices alone. It is difficult to know the magnitude of these effects, however, due to the absence of any data on potatoes and beans and on how much maize was distributed as food aid.

Although this is a problem for a simple model of demand, there seems little alternative to the formulation above. Adding additional crops would increase the costs of the study significantly (primarily by complicating the dynamic programming analysis) while clouding the interpretation of results. If reasonably good time series data were available for other crops, these costs might be offset by the benefits of increased realism. But when the absence of data would require heroic assumptions about even the most basic facts, the costs of including the additional crops are higher than any potential benefits. Clearly, the situation would be quite different in a country with a more complete data base.

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[22] This factor could be important in a regional model for major maize-producing regions.

Trade and Stock Equation

The clearing equation used is as follows:

$$D_t = Q_t + M_t - X_t - (S_t - S_{t-1}), \tag{3}$$

where

D_t = demand for maize in year t,
Q_t = production in year t,
M_t = imports in year t,
X_t = exports in year t, and
S_t = government stocks in year t.

Since the government controls imports, exports, and stocks, this can be simplified by defining a variable NP to be government net purchases (NP_t):

$$NP_t = -M_t + X_t + (S_t - S_{t-1}). \tag{4}$$

Substituting equation (4) into equation (3) yields

$$D_t = Q_t - NP_t. \tag{5}$$

There is some debate in Kenya about the importance of private stocks, which are not included here. While there is no question that such stocks are large during certain seasons of the year, some observers believe that the levels change little from one year to the next because real official prices are fairly constant. The only evidence available, mentioned above, shows stocks of small holdings changing by 73,000 tons in one year.

There are two distinct reasons for holding private stocks in Kenya: security and speculation. It is likely that small farm households have a desired level of carry-out stocks for family security that is not particularly price sensitive. After poor harvests these stores are depleted, and then are replenished after the next good crop. Casual observation in different parts of rural Kenya confirms this belief, and the maize disappearance (consumption) figures in Table 6 are consistent with it.

The amount of grain stored from year to year for speculative purposes in Kenya probably has been small. This is to be distinguished from seasonal speculation on local markets and short-term speculation on changes in official government prices. Annual price speculation has rarely been profitable in the urban areas, where the NCPB has been relatively successful in holding real prices constant. In rural areas, it is more difficult to arbitrage large quantities across years, particularly since the practice is illegal. While illegality is obviously not a complete deterrent, the cost of the activity is high because of the need for bribes and secrecy.

Unfortunately, other than the two data points from Integrated Rural Survey 3, there are no time series data whatsoever on private stocks in Kenya, and nothing but hearsay and anecdotal evidence to go on. For this type of analysis, the private stock buildup and run-downs will correspond to some extent with similar activity in government stocks. Thus, leaving out this type of security, private stocks may overestimate the level of government stocks necessary to gain a certain level of price stability. As for speculation, some of the policies modeled below would lead to significantly greater changes in price from year to year than Kenya has experienced officially in the past. But if the private market's storage charges and discount rate are greater than or equal to the figures used here for the government—approximately $25 per ton and 7 percent—full storage costs would never be covered for any of the policies modeled. So it is unlikely that the increase in speculation would be large.[23]

For the simulation, it is necessary to relate price to the exogenous variable, production, and the government decision variables. This can be done by substituting equation (5) for D_t in equation (2):

$$\ln(Q_t - NP_t) = C + e_m \cdot \ln(P_t), \tag{6}$$

and solving for the logarithm of price:

$$\ln(P_t) = [\ln(Q_t - NP_t) - C]/e_m. \tag{7}$$

World Price Equation

The world price is modeled as a percentage random walk in the simulation models. This is equivalent to a random walk in logarithms. It is desirable for the optimization model to model world price so that the expected value of world price next year equals this year's world price. Some studies, such as the one by Knapp (1982), assume that world price behaves as a random variable with known mean and variance. If this is done, the expected value in the following year at times will be much higher or lower than the present price. The optimizing algorithm will then "borrow foreign exchange, increase imports, and put the additional grain in storage" (Knapp 1982, 201-202). This builds world price speculation into the model. But, surely, increasing imports of maize is an inappropriate way for a normally self-sufficient country like Kenya to speculate. If the government of Kenya knows that the world price behaves as a random variable with a particular mean and variance and knows that the present price is low, it should enter the futures market, not import more maize. In addition, if enough actors have this knowledge about world price, a large number of them will enter the futures market, and world price will no longer behave as a random variable with known mean and variance. So this assumption is inconsistent with the existence of futures markets. Modeling world price as a random walk, on the other hand, makes the expected value of the world price equal to the present price, so that there is never an incentive to speculate.

Three variants of the Dickey-Fuller test were run to see if the series of the logarithms of real maize prices from 1957 to 1986 behaves as a random walk with a unit root.[24] In the three model specifications below, the coefficient "B" is tested by two different parameters for difference from 1:

[23] Peck (1977/78) has shown that private storage in the United States increases with increasing changes in expected price, even though the difference is less than full carrying costs. If such a relation exists in Kenya, it will lessen the need for the government to hold stocks.

[24] The time series used is for U.S. gulf port no. 2 yellow maize prices, deflated by the U.S. wholesale price index. The tests are described in Dickey and Fuller (1979), using significance tables found in Fuller (1976). Simple t-statistics for the lagged variable are not appropriate tests. The article shows that the Dickey-Fuller test is more powerful than the Q-statistic (Portmanteau test) described in Harvey (1981, 48).

$$WP_t = BWP_{t-1} + e_t,$$

$$WP_t = A + BWP_{t-1} + e_t, \text{ and}$$

$$WP_t = A + BWP_{t-1} + Ct + e_t,$$

where

WP_t	= world price in year t,
A, B, and C	= estimated parameters,
t	= time, and
e_t	= error term.

All six tests are insignificant at the 10 percent level.

The third specification is of interest because time is included in the model. The estimated equation is as follows:

$$WP_t = 0.378 + \underset{(0.16)}{0.76}WP_{t-1} - \underset{(0.0033)}{0.0049}t; \qquad (8)$$

$$R^2 = 0.59,$$

where the numbers in parentheses are standard errors. The negative trend is significant at the 10 percent level. The estimated trend is for world prices to decline by 0.5 percent per year. Nevertheless, a negative trend is not included in this model for three reasons. First, it is desirable for the optimization model to have the same structure in each of the model years so that a stable policy will be found. Including a negative trend would make this impossible. This added complication would not be a factor if the trend was certain to continue in the future and if it would imply quite different policies. This, however, is not the case. In mid-1987 it is not at all clear that world maize prices will continue their downward trend; in addition, the size of the historical trend is such that the effect of including it in the model would be small.

Thus, for the simulation, world price behaves as follows:

$$WP_t = WP_{t-1} \cdot (1 + u), \qquad (9)$$

that is, the world price in year t equals the world price in the previous year times 1 plus a random variable u, which is distributed normally with 0 mean and a standard deviation of WSD. The number WSD is an estimate of the average percent change in world price from one year to the next.

In the discrete world of the dynamic programming models, it is impossible to allow the world price to behave as a random walk without including an unacceptably large number of possible world prices. With a smaller number of levels, either the expected price will not always equal the present price or, at the extreme price levels, there will be no possibility of a change in prices. To take a simple example, suppose that the model allows only three possible price levels: \$90, \$120, and \$150 per ton. If the price is \$120 in one year, it is easy to make the expected price in the next year also equal to \$120 by assigning equal probabilities to \$90 and \$150. But if the price is presently \$150, there is no higher price to which it can climb, so either the probability of the price dropping to \$120 or \$90 must be zero, or the expected price in the next year must be less than \$150.

The dynamic programming models use seven levels of world price and choose the latter option. Table 7 lists the expected price at each level of world price. The differences are rather small except at the extremes, where they are about US$7 per ton. The discrete levels of world price also make a percentage random walk difficult to implement, so the optimizing model approximates a normal random walk.

Government Objective Function

As presented in Chapter 2, the three government objectives included in the dynamic programming models are stabilizing prices around a normal-weather-year price, minimizing imports, and minimizing government expenditures. This objective function affects only the solution algorithm of the optimizing model. For the simulation models, the value of the objective function does not affect the decision variables, since the simulation models do not maximize or minimize an objective function. The average value of each of the three components of the objective function, however, is still computed for comparison with the optimal values.

In equation form, the goals can be stated as follows:

$$\text{Minimize:} \quad GC = \Sigma\,[COST_t + a(P_t - P^*)^2 + bM_t]/(1 + r)^{t-1}, \qquad (10)$$

that is, minimize GC, which equals the sum over all years of the government's fiscal cost, plus a parameter "a" times the square of the deviation of the present year's price from the target price $(P_t - P^*)^2$, plus a parameter "b" times imports (M_t), the quantity being discounted for time preference at discount rates. The parameters are weights that measure the importance of each of the objectives relative to the other two. These weights, which were referred to in Chapter 3, are varied in order to find policies that efficiently produce more of one objective and less of the other two. This allows for the measurement of trade-offs.[25] By not putting a weight on COST, the monetary unit becomes the numeraire of the system.

The nature of the objective function will be addressed by discussing, first, the price component and discounting; second, the components of government cost; and finally, other possible objective functions.

Table 7—Expected values of world price in dynamic programming models

Price in Year t	Probability of Price in Year t + 1							Expected Price
	$60	$80	$100	$120	$140	$160	$180	
(US$/metric ton)								(US$/metric ton)
60	0.725	0.239	0.035	0.001	...	...	...	66.24
80	0.239	0.486	0.239	0.035	0.001	...	...	81.46
100	0.035	0.239	0.451	0.239	0.035	0.001	...	100.06
120	0.001	0.035	0.239	0.450	0.239	0.035	0.001	120.00
140	...	0.001	0.035	0.239	0.451	0.239	0.035	139.94
160	...	...	0.001	0.035	0.239	0.486	0.239	158.54
180	...	...	...	0.001	0.035	0.239	0.725	173.76

[25] In a linear programming environment, an equivalent formulation would be to include two of the three objectives as constraints, and vary the right-hand side in order to trace out trade-offs between objectives (see Eaton 1980). In dynamic programming, this is not a feasible alternative, and the different objectives must be included and weighted in the objective function.

Deviations of price from the goal enter as a squared term (Blandford and Lee 1979). In a country like Kenya, where prices have been controlled for so long, penalizing the absolute value of the deviation would not be correct; a 50 percent increase in price is much more than five times worse than a 10 percent increase. The penalty should be symmetric, since farmers make up such a large percentage of the population. The simplest functional form that satisfies these two criteria is the one that is used.

All three terms are discounted in future years. Clearly, a government would trade a 10 percent increase in price this year for a 10 percent increase in price five years in the future were such a deal possible, at least in part because the official making the decision might leave the government before then.

The COST term has three annual components and a fourth cyclic component. These are within-country operations, foreign trade costs, storage costs, and stock replacement costs. They will be described in turn.

Within-Country Operations. Net proceeds of within-country sales are $P_t \cdot NP_t$, where NP_t is government net purchases (so that NP_t is negative when the government sells maize).

Foreign Trade Costs. Foreign trade costs and benefits are difficult to compute in Kenya. Import parity prices usually are computed by adding local and foreign shipping costs to the world price, while export parity prices subtract local costs. The situation in Kenya is somewhat more complex for two reasons: first, in any one year, relatively small quantities of maize can be exported at a white maize premium, and second, food aid is available. An optimal maize policy should take advantage of both of these facts, so they must be built into the model.

Export premiums are available because white maize is usually a preferred commodity on the world market. The market is thin, however, and most countries that want to import white maize are short of foreign exchange. In 1983 and 1984, Kenya was able to make arrangements for the World Food Programme (WFP) to buy about 100,000 tons of Kenyan maize and ship it to third countries, mainly Somalia. The WFP saved money on transport and passed all those savings, plus a white maize premium, on to Kenya. The total premium for Kenya was about \$50 per ton. Such deals are somewhat difficult to negotiate and probably could not be arranged for large quantities of maize. To some extent, these arrangements are more like WFP aid for Kenya rather than business deals; therefore, if Kenya were to export 300,000-400,000 tons of maize in one year, it might be reasonable to expect the WFP to buy the first 100,000 tons at a high price even if considerable amounts of additional maize were being exported with no premium. So in the model, Kenya exports its first 80,000 tons in any one year at a price that is \$40 above the prevailing world price, with the premium decreasing linearly and disappearing for exports other than the first 120,000 tons. Thus the gains from exports are as follows:

$$\text{If } X_t \leq 80{,}000, \text{ then} \qquad (11)$$

$$XP_t = X_t \cdot (WP_t + 40 - XCOST).$$

$$\text{If } 80{,}000 < X_t < 120{,}000 \text{ then}$$

$$XP_t = X_t \cdot (WP_t - XCOST) + [3200 + (160 - X_t)/2 \cdot (X_t - 80)].$$

$$\text{If } X_t \geq 120{,}000 \text{ then}$$

$$XP_t = X_t \cdot (WP_t - XCOST) + 4000,$$

where

XP_t = export proceeds in year t,
X_t = exports in year t,
WP_t = world price in year t, and
XCOST = cost of exporting.

On the import side, food aid complicates the picture in two ways. First, it is clear from 1979/80 and 1984/85 that Kenya can arrange for food aid in crisis years. While the amounts received in those years may have been larger than they would have been in a tighter world maize market, there is no doubt that the United States and other donor countries will support Kenya to a significant extent in times of trouble. But food aid will not be available in years of minor shortfalls, and in serious drought years the first batch of imports would have to be ordered commercially in order to receive the maize quickly. A second problem is that a considerable proportion of food aid is not available for the government to sell. Since this study deals only with marketed and own-produced maize, not with relief, aid that is freely distributed should not be included in the models. (To the extent that free food aid substitutes for food that would be purchased in the market, it should be included in total supply.) Finally, although it is difficult to predict the response of donors to a shortfall in production, they are likely to base aid decisions on estimates of total supply (production plus government stocks, since private stock figures are unavailable) rather than production alone or planned government imports. There is no obvious model to use here, but past actions indicate that donors will make up about 40 percent of the difference between total supply and a figure that is 100,000 tons below normal-year production. For instance, if normal-year production is 2.0 million tons, government stocks are 50,000 tons, and production is 1.8 million tons, donors would be expected to provide 20,000 tons in food aid to the marketing board. Since Kenya has to pay transport costs on food aid, the accounting is as follows:

$$\text{If } Q_t + S_{t-1} > Q_0 - 100{,}000, \text{ then} \qquad (12)$$
$$AID_t = 0.$$

Otherwise,

$$AID_t = 0.4 \cdot [Q_0 - 100{,}000 - (Q_t + S_{t-1})], \text{ and}$$
$$MC_t = M_t \cdot (WP_t + MCOST) - AID_t \cdot WP_t,$$

where

Q_t = production in year t,
S_t = opening sales in year t,
Q_0 = normal-year production,
AID_t = food aid in tons in year t.
MC_t = total cost of all imports in year t,
M_t = commercial imports and aid in year t,
WP_t = world price of maize in year t, and
MCOST = cost of importing.

These models of food aid and export premiums are admittedly ad hoc. Given a situation in which both food aid and export premiums have significant effects on Kenya's maize strategy, however, it would be clearly wrong to leave them out of the model.[26] The only solution is to make the kind of reasoned judgments used here and include these components in the model.

Storage Costs. Storage charges include losses, railage to and from the stores, and any costs associated with turning over the stocks to keep them fresh. These costs are considered to be constant per unit of stock. As the maximum stock level chosen by the optimizing program is less than the presently available storage in Kenya, there is no need for increasing marginal costs of storage to reflect increasing costs of the space.

$$SC_t = S_t \cdot STCOST, \quad (13)$$

where

SC_t = total storage cost in year t,
S_t = closing stocks in year t, and
STCOST = cost per ton of holding stocks.

Note that the storage facilities themselves are neither costed nor amortized. This is for two reasons: storage is already in place, has virtually no rental value, and is not considered a cost in the country; and donor funds probably would be made available for construction of storage if more were desired.

Interest charges are not included in the costs of storage. This causes some problem in explaining the model to policymakers, who see large interest costs in the financial report of the NCPB each year. But as Gardner (1979, 18) points out, it would be incorrect to include such costs. This is best seen by considering a risk-neutral private trader, who will store grain until his expected costs equal his expected benefits. That is, until

$$P_{t+1} = (P_t + STCOST)(1 + r), \quad (14)$$

which is equivalent to

$$P_{t+1}/(1 + r) = P_t + STCOST,$$

where STCOST is storage cost and r is the interest rate. If the interest rate equals the time value of money, the discounted objective function used in the model will consider two policies to be of equal cost in exactly these circumstances. An objective function that charged interest on stocks and also discounted future benefits would include a second $(1 + r)$ term in the denominator on the left-hand side, incorrectly adding another cost to the storage operation.

If the market interest rate differs from the perceived time value of money—which it may, since there could be constraints on Kenya's ability to borrow foreign exchange—then those policies that increase borrowing should add the differential interest charges

[26] A similar model for wheat in Pakistan has been run with no export premiums. The optimal net purchases function has the same shape and the same sensitivity to parameters. The only significant difference is the shape of the closing stock curve; in the Pakistan case no exports take place until the maximum stock level is reached.

to the other costs, and those policies that decrease borrowing should subtract the same. In this model, that would mean adding an interest charge to imports and subtracting interest charges from exports. This has not been done here, although such adjustments could easily be added to the model. Note that even if these charges were included, there would not be a direct interest charge on maize in storage, but policies that resulted in more exports (and thus lower levels of storage) would cost less.

Stock Replacement Costs. Charges for replacement of stock are included in the simulation models to facilitate the comparison of policies that end with different amounts in store. All models begin with 100,000 tons in year 0. The models end each cycle with anywhere from zero to 250,000 tons in store on average, with individual cycles varying more widely. Unless some allowance is made for these changes in stock level, the policies that end with low levels will appear to be more profitable, since they include the proceeds of selling the stock. There are two alternatives: (1) value the excess or deficit stock at a constant price and add the charge to the total for that policy, or (2) force the models to export or import in the final year in order to end up with exactly 100,000 tons. The latter option penalizes the optimal policies more than the price band policies, since the optimal policies on average hold more stock in years of low world prices. Since the price band policies will be compared with the optimal policies in chapters 3 and 4, option 1 is used here. The value chosen is the base year world price (which is equal to the average world price across all simulations because of the nature of the stochastic process).

$$RS = (S_0 - S_{10}) \cdot WP_0, \qquad (15)$$

where

RS = replacement stock charges,
S_0 = closing stocks in base year,
S_{10} = closing stocks in year 10, and
WP_0 = world price in base year.

Note that the optimizing algorithm does not consider this charge in its choice of the optimal policy. Since the desired optimal policy is one that ignores the terminal conditions in the model, including these charges would not affect the stabilized policy.

Other Types of Objective Functions

Most optimizing studies of stabilization policy have not used a multiple-attribute, weighted utility function as the objective function but have used consumer/producer surplus, considering it a proxy for national welfare. As Gustafson (1958, 48-49) has shown, the result of using consumer/producer surplus is the free market solution, provided the private discount rate and storage costs equal those of the government. A model with this objective function is used as a reference. It is inappropriate for the bulk of the analysis, however, for the following reasons.

First, one supposed advantage of using consumer/producer surplus is that benefits and losses of various policies can be ascribed to different groups in the economy. Indeed, a substantial amount of the price stabilization literature deals with this issue. But as Sarris and Taylor (1978, 149-159) have shown, the shape of the demand curve is of central importance in determining such gains and losses. Given the paucity of information about demand in Kenya, it would be at best pointless and at worst misleading to measure triangles around a curve of unknown shape.

A second objection is pointed out by Cochrane (1980). For a staple food in a poor country, income effects of price changes will be large but totally ignored by the welfare measure. In addition, consumer surplus from resulting price changes in other commodities could be large but unmeasured.

Finally, regardless of whether or not such an objective function is appropriate in other contexts, it is inappropriate here because the purpose of this study is to affect government policy by measuring trade-offs between government objectives. The Kenyan government *wants* to stabilize prices; in fact, ever since independence (and before) the government has claimed to control prices directly. In such a situation, it is important to try to discover how much this sort of total price stability costs the government *in terms of its own objectives,* and how much of its other objectives it can "buy" by "selling" some price stability. For this study to be effective, the objective function of the analysis must be one relevant to the government that allows for the measurement of trade-offs, and not "an illusion created by an alternate purchasing power procedure which is non-operational" (Cochrane 1980, 508). A multiple-attribute, weighted utility function is the appropriate tool for measuring trade-offs, since the weights on the parameters can be varied directly to come up with points in the noninferior set (Blandford and Lee 1979).

A different approach would be to transform the government objective function used here into a utility function that would include a risk-aversion coefficient, as Buccola and Sukume (1987) have done for Zimbabwe.[27] Alternatively, the utility function of a government official can be measured directly, as Parton (1979) has done for wool in Australia. The latter is an interesting approach and might be particularly useful for deciding on the form of the function. But given the complex nature of the decisionmaking process for changing public policy, it is unclear whose utility function should be measured (Cohon and Marks 1975, 213). In addition, given the political sensitivity of the issue, it seems likely that the responses to counterfactual questions could be quite different from the decisionmaker's actual response in a crisis.

In sum, the objective function used here, like the rest of the model, is a simple tool formulated to address the specific substantive issue at hand, which allows for the measurement of trade-offs between three important government objectives with adjustments in a minimum number of parameters.

Price Band Decision Rules

This completes the description of the model for the dynamic programming runs. Government reponse to any particular production outcome is not specified ahead of time, but results from the maximization of the objective function. The policy rules, therefore, are endogenous. For the price band simulations, it is necessary to specify government policy toward different levels of production, stocks, and world prices. So a simple set of administrative rules is added to the previously defined market structure, as outlined in Chapter 2. The government chooses a price P* as its target, which is the normal production year equilibrium price with no government intervention:

$$\ln(P^*) = [\ln(Q_0) - C]/e_m, \qquad (16)$$

where Q_0 is normal-weather-year production, C is the constant in the demand equation, and e_m is maize demand elasticity. The government then chooses a range in which to

[27] It is debatable, however, whether or not governments should be considered risk averse. See Valdés and Siamwalla 1988, especially p. 118.

allow prices to vary without government intervention. The maximum percent price variation, W, is both added and subtracted from ln(P*) to produce the maximum and minimum allowed price:

$$\ln(P_{max}) = [\ln(Q_0) - C]/e_m + W, \text{ and} \tag{17}$$

$$\ln(P_{min}) = [\ln(Q_0) - C]/e_m - W. \tag{18}$$

Substituting equation (7) into equation (17) for $\ln(P_{max})$,

$$[\ln(Q_{min} - NP_t) - C]/e_m = [\ln(Q_0) - C]/e_m + W, \tag{19}$$

where Q_{min} is the production level that corresponds to the maximum price, P_{max}, and NP_t is net government purchases. Since all government decision variables are zero within these limits by definition, NP_t can be set to zero. Making that substitution and solving for Q_{min} yields

$$Q_{min} = \mathrm{EXP}[\ln(Q_0) + e_m \cdot W], \tag{20}$$

where EXP is the exponential function. Since e_m is a negative number, Q_{min} is less than Q_0 if W is greater than zero.

A similar derivation yields the figure Q_{max}:

$$Q_{max} = \mathrm{EXP}[\ln(Q_0) - e_m \cdot W]. \tag{21}$$

So if production is between Q_{max} and Q_{min}, the government does not intervene; if production is outside those limits, the government buys or sells maize:

$$\begin{aligned} &\text{If } Q_t > Q_{max}, \text{ then} \\ &\quad NP_t = Q_t - Q_{max}. \\ &\text{If } Q_t < Q_{min}, \text{ then} \\ &\quad NP_t = Q_t - Q_{min}. \\ &\text{If } Q_{min} \leq Q_t \leq Q_{max}, \text{ then} \\ &\quad NP_t = 0. \end{aligned} \tag{22}$$

Exports and imports are determined by the opening stock level, net purchases, and the level of stock variability, S_{max}. For computational purposes, the minimum stock level will be considered to be zero, but as pointed out in the previous chapter, in the actual case a minimum stock level equal to two or three months maximum net sales should trigger imports, since there is a delay between ordering and receiving foreign maize (a positive minimum stock level would have to be specified in a model that includes seasons).

$$\text{If } S_{t-1} + NP_t > S_{max}, \text{ then} \qquad (23)$$
$$X_t = S_{t-1} + NP_t - S_{max}, \text{ and}$$
$$S_t = S_{max}.$$

Otherwise,

$$X_t = 0, \text{ and}$$
$$S_t = S_{t-1} + NP_t,$$

where

S_{t-1} = opening stocks in year t,
NP_t = government net purchases in year t,
X_t = exports in year t, and
S_t = government stocks in year t.

$$\text{If } S_{t-1} + NP_t < 0, \text{ then} \qquad (24)$$
$$M_t = -(S_{t-1} + NP_t), \text{ and}$$
$$S_t = 0.$$

Otherwise,

$$M_t = 0, \text{ and}$$
$$S_t = S_{t-1} + NP_t,$$

where M_t is imports in year t.

At this point, the model has been developed and the price band administrative rules defined explicitly. Appendix 2 includes outlines of the computer programs used for the simulation and optimization processes. In the next section, the price band simulations are compared and contrasted with the optimizing process.

Comparison of Price Band Simulation with Optimizing Algorithm

In order to take full advantage of the four reasons for conducting an optimization outlined in Chapter 3, it is necessary that the computation of the three components of the objective function for the optimal policies and the price band schemes be directly comparable. After running the price band simulation and the dynamic programming optimization, the results are not comparable because of several differences between the two models. These differences are enumerated in Table 8.

As indicated in Chapter 3, the differences between the models are reconciled by taking the dynamic programming solution and simulating it in the same way that the administrative rules are simulated. This requires that the following adjustments be made for the differences noted in Table 8 (numbers 1-7 below correspond to the numbers in the table).

1. As shown in the example in Chapter 3, the result of running a dynamic programming algorithm is a set of tables listing each possible state of the world and the optimal values of the control variables for each state in each year. Thus, for each possible combination of domestic production, world price, and opening stocks, the appropriate net domestic purchases and net foreign trade are listed. These optimal policies may vary in each year of the optimization run. Fortunately, models such as this one in which the system parameters do not vary from year to year will usually stabilize after

Table 8—Differences between price band simulation and dynamic programming models

Price Band Simulation	Dynamic Programming
1. Policy is identical in each year.	Terminal conditions affect policy in last several years.
2. State and control variables are "continuous."	State and control variables are discrete.
3. World price is modeled as a percent random walk.	World price approximates a normal random walk.
4. Ten-year cycles are run.	Program runs for an eight-year cycle, or until the policy stabilizes.
5. Replacement-of-stock charges are included.	Replacement-of-stock charges are not included.
6. Policy is determined by an administrative rule.	Policy is determined by minimization of present and expected future value of a cost function.
7. Feasible combinations of objectives are found by changing allowed price deviation and stock variability.	Feasible combinations of objectives are found by varying weights in the cost function.

several years, and these stabilized values ignore the terminal conditions. The model used here usually stabilizes after five or six years. The stabilized values are used in the simulation, so the optimal policy is constant across years.

2. The discrete values of the dynamic programming solution are linearly interpolated in order to approximate a continuous optimal policy.

3. The simulations of the optimal policy treat the world price as a percent random walk just as in the price band simulations. This leads to some slight suboptimality of the simulated policies, since the conditions under which optimization took place are different from the conditions of the simulation.

4. Ten-year cycles are used in the simulation of the optimal policies just as in the simulation of the price band schemes. Since the chosen optimal policy is a stabilized policy, and since the object is to test the stabilized policy rather than to reach certain terminal conditions, this is the appropriate method to use. There is no loss of optimality.

5. The addition of replacement of stock charges does not affect optimality for the same reason as given in number 4. The purpose is to test a stabilized policy; the replacement of stock adjustment is used to allow for comparison between policies that consistently end with different stock levels. If such charges had been included in the optimization process itself, the final few years of the optimization would change, but the stabilized policy would be no different.

There is no need to reconcile the last two differences between the models. Indeed, numbers 6 and 7 lead to the first two benefits of optimization: screening all possible policy alternatives and accurately measuring trade-offs between government objectives. These last two are the essential differences between using an optimizing algorithm to select the policy and choosing an ad hoc rule. It is because of the differences that the optimizing process can help the analyst learn how to adjust the administrative rules to be more efficient.

The next and final section in this chapter selects the parameter values that are used in the model.

Parameters for the Model

The key parameters in the model are as follows:

- Cost of importing: $40 per ton, of which $35 is foreign exchange.
- Cost of exporting: $70 per ton, all local costs.
- Shadow price premium on foreign exchange: 15 percent.
- Maximum stock level: 580,000 tons.
- Discount rate: 7 percent.
- Opening world price: $120 per ton.
- Standard deviation of the world price: 14 percent.
- Standard deviation of production in Kenya: 10 percent.
- Own-price demand elasticity of maize: −0.3.
- Normal production year equilibrium price: $140 per ton.
- Cost of storage: $25 per ton.

Costs of Importing and Exporting

The official estimate of the costs to the NCPB of preparing maize for export was $80 per ton as of 1985.[28] Schluter (1984) gives a detailed breakdown of these costs as of 1981/82. Table 9 lists the costs as of that date, projects them to the 1985 total, and then makes two reasonable adjustments. First, the type of change in marketing policy envisaged by this study would decrease the purchase and transport charges incurred by the NCPB. It is assumed rather conservatively that this decrease would be 20 percent. Second, one large component of the export cost is the charge for bags. There are three ways these costs could be lessened: constructing bulk handling facilities both up-country and at the port, making use of some second-hand bags rather than all new bags, and using sisal bags rather than the present sisal/jute combination. Assuming that some combination of these measures is taken, the bag component of cost is decreased, first by the 10 percent duty on jute that Schluter includes, and then cut in half, for an overall decrease of 55 percent of the original estimate. The end result is a cost of exporting maize of about $70 per ton.

Table 9—Costs of exporting maize

Component	Schluter's Costs 1981/82	DPD/MOA 1985 Total	Assumed Savings	Final Estimate
	(US$/metric ton)		(percent)	(US$/metric ton)
Primary marketing	17.0	19.3	20	15.5
Bags	10.1	11.4	55	5.1
Drying	10.5	11.9	0	11.9
Railage	28.6	32.4	0	32.4
Wharf charges	1.7	1.9	0	1.9
Insurance	1.2	1.4	0	1.4
Interest	1.4	1.6	0	1.6
Total	70.6	80.0		69.8

Source: Based on data from Michael Schluter, *Constraints on Kenya's Food and Beverage Exports*, Research Report 44 (Washington, D.C.: International Food Policy Research Institute, 1984).
Notes: DPD/MOA is Development Planning Division/Ministry of Agriculture. Parts may not add to totals because of rounding.

[28] Richard Goldman, personal communication, June 1985.

The costs for importing are similar to the costs for exporting. Throughout this study, the difference between the domestic selling and buying price of the NCPB is assumed to cover the board's costs. Imported maize is sold at the domestic selling price, which is the producer price plus the margin. The correct import parity price is thus the foreign transport cost—estimated at $35 per ton[29]—plus the difference between the domestic marketing margin and the costs of handling imported maize. The difference is about $5 per ton, and would not be affected by the adjustments made in Table 9, since those adjustments would affect both local and imported maize.

Shadow Price of Foreign Exchange

It is widely perceived that the Kenya shilling is officially aligned close to its shadow rate, with the demand for foreign exchange somewhat higher than supply at official rates. A figure of 15 percent overvaluation is a reasonably good estimate. It is consistent with black market rates (Cowitt 1985).

Maximum Stock Level

In the price band models, the maximum stock level is part of the policy and never reaches levels where Kenya's present storage capacity would be exceeded. In the optimizing models, however, a maximum stock level has to be chosen, since all the variables are discrete. In the early stages of formulating the model some tests were done, and a stock level of 580,000 tons was selected, since the model did not choose to store more than 560,000 tons under any of the circumstances reported in this study.

Discount Rate

A value of 7 percent was chosen as the discount rate. This is high when compared with real interest rates, but low compared with studies that attempt to elicit discount rates from individuals. For example, Clark, Jones, and Holling (1979) did not find a single decisionmaker with a discount rate of less than 10 percent in their attempts to elicit such values in Canada.

Opening Value and Standard Deviation of the World Price

The opening value of the world price is $120 per ton, close to the average world price for 1981-85. Choosing an appropriate value for the variability of world price is somewhat more complicated.

Recall that the world price is modeled as a random walk. The series of annual percentage changes in the International Monetary Fund series of U.S. gulf port yellow no. 2 maize prices from 1957 to 1986, deflated by the U.S. wholesale price index, has a standard deviation of 13.7 percent. There are two problems, however. First, variability has been increasing over time. The standard deviation of the series up to 1969 is only 7.3 percent, while the figure since that date is 16.1 percent. This consideration argues for a value higher than the average. The post-1970 figure of 16.1, however, is influenced heavily by the extremely large price increase of 43.0 percent in 1973. The 1973 value is almost twice as large as the next largest price change, and is almost 3.5 standard deviations from the mean. The standard deviation of the price changes from 1970 to 1986, excluding 1973, is only 12.5 percent.

This analysis uses a standard deviation of world price of 14.0 percent. It is inappropriate to give full weight to 1973, since it is such an aberration, but some consideration should be given to the recent increase in variability. The data clearly indicate that the

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[29] Richard Goldman, personal communication, June 1985.

best figure is between 12 and 16 percent. Fortunately, results of the model are not sensitive to changes in this parameter within that range. Early model runs with constant rather than variable world prices produced optimal policies quite close to those produced with variable world prices. The standard deviation of the fiscal cost is the only result that varies significantly with this parameter.

For the dynamic programming models, as described above, the world price does not behave in a random walk. The seven possible levels of world price are taken to be $60, $80, $100, $120, $140, $160, and $180 per ton, with the transition probabilities chosen so that the expected values of next year's price are as shown in Table 7. These probabilities correspond roughly with a percentage change standard deviation of 14 percent at the base year world price of $120 per ton.

Standard Deviation of Production

The standard deviation used in the analysis should be a totally random phenomenon, neither the result of systematic factors in the world nor the result of changing government policies. This makes it difficult to come to an estimate of the number from past history. Since changes in government policy have exacerbated production fluctuations at times, the desired number will be less than the estimate of historical variation.[30] The difficulty is compounded by the large differences that result from including or not including the estimate of the 1984/85 crop in the analysis.

Running a linear trend through the maize production figures from 1970/71 to 1983/84 yields a standard error of the estimate of 225,000 tons. At mean production for the time period, this yields a standard deviation of 13.0 percent. On the other hand, if 1984/85 is included, the standard error increases to 306 and the mean is somewhat lower, giving a standard deviation of 17.9 percent.

Some degree of insight into the variability of maize production in Kenya can be gained by examining rainfall data in Kitale district. Kitale is a major exporter of maize to other regions of Kenya and normally has reliable rainfall. Production in 1984/85, however, was only about 50 percent of production the previous year; this shortfall was a significant percentage of the total shortfall of Kenyan production below trend for the year. Since a fairly consistent series of rainfall statistics is available for about twice as many years as the production series used in this study, the rainfall statistics can provide some additional insights into the degree of the rainfall abnormality Kenya experienced in 1984/85.

Table 10 lists rainfall data from Kitale for 1953-84 for the months of April and May, excluding 1956 for which no data are available. April and May are key months for Kitale maize production, as planting cannot be delayed much longer than early April. For 1965-84, the series is the average rainfall at all of the meteorological stations in the district. Data from the Kitale Agricultural Research Station are used for earlier years, as the average series is not available. None of the conclusions reached below are altered significantly by restricting the analysis to 1965-84 data.

Note three points about the series before considering the statistics. First, cumulative rainfall for March and April in 1984 is the lowest on record. While only slightly lower than the figure for 1958, it is almost 20 percent lower than the third lowest figure. In addition, the second, third, and fourth lowest figures are for 1958, 1955, and 1959,

[30] For example, most analysts believe that the government was at least partially responsible for the production shortfall in 1979/80 (Kleist, 1985).

Table 10—Kitale rainfall: April and May, 1953-84

Year	Rainfall		
	April	May	April and May[a]
	(millimeters)		
1953	222	172	393
1954	125	160	285
1955	157	88	244
1956	n.a.	n.a.	n.a.
1957	149	137	287
1958	104	97	201
1959	127	125	251
1960	124	182	306
1961	166	145	310
1962	163	142	305
1963	163	144	308
1964	174	148	321
1965	126	133	258
1966	280	80	359
1967	224	260	484
1968	201	95	295
1969	54	229	283
1970	144	136	281
1971	148	118	266
1972	115	168	283
1973	45	210	255
1974	108	147	255
1975	104	210	314
1976	162	246	408
1977	257	153	410
1978	183	160	343
1979	191	165	355
1980	130	244	374
1981	210	152	362
1982	335	270	605
1983	101	326	426
1984	100	97	197
	Series Statistics		
Mean (millimeters)	158	166	323
Median (millimeters)	149	152	306
Minimum (millimeters)	45	80	197
Maximum (millimeters)	335	326	605
Standard deviation	62	59	84
Coefficient of skewness	0.79	0.84	1.33

Source: Unpublished data from the Meteorological Department, Kenya.
Note: n.a. means not available.
[a] Parts may not add to totals because of rounding.

respectively. The figure for 1984 is 57 millimeters less than the next lowest figure in the last 25 years. Second, there are three sets of years during which rainfall has been virtually constant: 1960-64, 1968-74, and 1978-81. Third, the minimum cumulative rainfall in the period 1975-83 is greater than the maximum cumulative rainfall for 1968-74.

Clearly, more is going on here than random sampling from a stable population, but it is difficult to say more than that. At least, it is hoped that the unusual runs in the series are the result of natural phenomena and not the result of human error.

Considering the statistics, it should be noted that all three series are skewed upward with the mean greater than the median, confirming the generally accepted fact that Kitale rainfall is rarely poor.

These rainfall data tend to support the view that a shortfall as severe as the one in 1984/85 is less likely than 1 in 15, which is the implicit assumption in using the standard error of the estimate from the trend analysis. Thus, a variability around the trend line of about 15 percent seems reasonable, with the component of variation attributable to totally random phenomenon equal to 10-12 percent. As mentioned in the supply response section above, the small amount of supply response will dampen the production instability slightly. Consequently, a figure of 0.10 will be used here.

Own-Price Demand Elasticity

Reference has already been made to the difficulty of doing demand analysis in Kenya. Previous studies (Williamson and Shah 1981; Gerrard 1981) have produced estimates of the own-price demand elasticity for maize ranging from +2.13 to −0.443. It seems best to take a number that is reasonable, given the importance of maize in the Kenyan diet, and use that rather than a number estimated from data that are known to be far from correct. A figure of −0.3 will be used here.

It is important to note that the appropriate number for this analysis is a short-term elasticity and not a long-term number. These two numbers are likely to differ significantly for a staple food in a poor country. The short-run elasticity measures the sensitivity of consumption to immediate price changes. The long-run elasticity measures the sensitivity of consumption to changes in price that remain in effect for a long period of time, allowing consumers to adjust their taste preferences to the price differential.

Equilibrium Price in a Normal Production Year

In the absence of reliable statistics for consumption, the equilibrium price in a normal production year is difficult to estimate. Recent local market prices have been both above and below NCPB official prices (sometimes at the same time in different parts of the country). This indicates that the normal-production-year equilibrium is not far off from the official price. A producer price of $140 per ton is used here, which translates into a producer price of KSh 189 per 90-kilogram bag at an exchange rate of KSh 15 = US$1.

Cost of Storage

Storage costs estimated by the government in 1983 were KSh 27.50 per bag per year, exclusive of interest charges (Kenya 1983b). Assuming a 10 percent rate of inflation for two years and a 1985 exchange rate of KSh 15 = US$1 yields a storage cost of $2.22 per bag in 1985, or $24.65 per ton. A figure of $25.00 per ton is used here.

At this point, then, the problem has been defined, the model set up, and parameters selected. The following chapter presents the results of running the models, including the measurement of trade-offs. Chapter 6 investigates how the price band schemes can be adjusted, given what has been learned from the optimizing model, while Chapter 7 presents conclusions and recommendations.

5

AN EXAMINATION OF PRICE BAND AND OPTIMAL POLICIES

Results of the Price Band Simulation: Overview

Price band policies were simulated with 5, 10, 15, and 20 percent allowable price variation. Stocks were allowed to vary at 10 different levels between zero and 400,000 tons for each price band. A stock variability of zero implies that year-end stocks do not change; consequently, production variability is buffered only by consumption changes and foreign trade. Results reported in this chapter use an own-price demand elasticity of −0.3 and production variability of 10 percent. Tables 16 and 17 in Appendix 1 present results for a demand elasticity of −0.2 and production variability of 12 percent. Three hundred 10-year cycles were run, with the average values of all the cycles appearing in the graphs and tables.

Figure 4 presents the results graphically. The solid lines are termed "trade-off curves." Price variability is held constant on each curve, with the maximum allowable percent price deviation appearing at the bottom of each line. The marked points on each solid line represent, from top to bottom, increasing levels of stock variability. Each curve individually, then, displays the trade-off between fiscal cost and imports for one particular level of price variability.

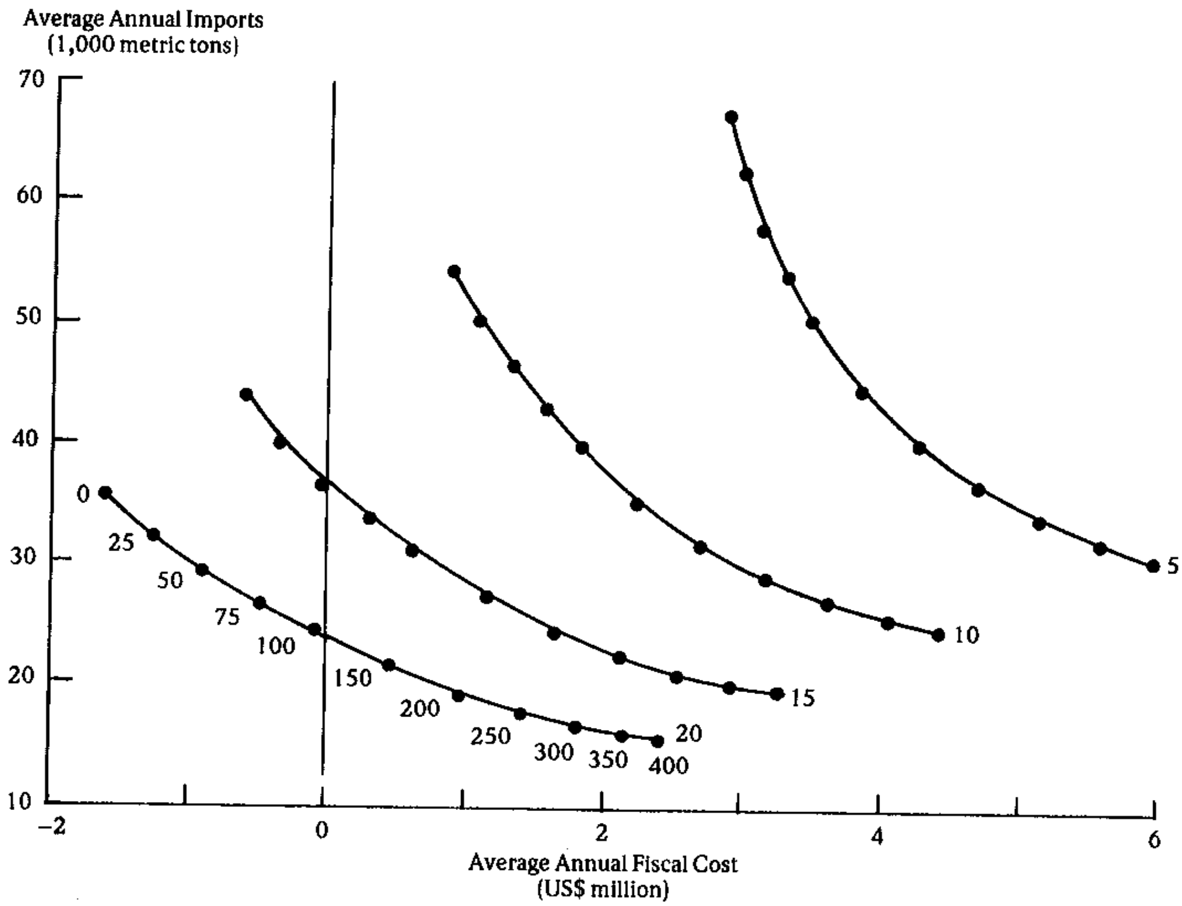
The horizontal axis is the average annual fiscal cost associated with each policy. The vertical axis represents average imports over the 10 years of the simulation. Note that this is different from the average import in importing years. If a price band policy led to total imports of 500,000 tons per 10-year cycle on average, then the figure appearing in the graph would be 500/10 = 50, whether there was an average of 5 years or only 1 year when imports took place per cycle.

There are several important points to notice about the graph before analyzing why the curves are shaped in this way. First, there are large differences in cost and import levels between the different constant price variability curves. Moving from 5 to 10 percent price variability and holding imports constant decreases the average annual cost by $2-3 million. While the degree of leverage that price commands over cost decreases as price variability increases, it remains large; even moving from 15 to 20 percent price variability, with constant imports the difference amounts to almost $2 million annually.

Second, buffer stocks are much more effective at lower levels of price variability than at higher levels. This is apparent from the relative shapes of the constant price variability curves. The 5 percent price variability curve is much steeper than the 20 percent variability curve, implying that increasing stock variability "buys" a large amount of decreased imports for relatively little additional fiscal cost at that price level. Increasing stock variability from zero to 100,000 tons at this price level costs about $30,000 annually per 1,000-ton decrease in average imports. On the other hand, increasing stock variability by the same amount when prices vary by 20 percent costs more than four times as much. Reasons for this are discussed in the next section.

The results are presented numerically in Table 11. The first two columns of the table list the percent price band and the stock variability. Column 3 lists the standard

Figure 4—Price band trade-off curves



Note: The number at the bottom of each line is the maximum allowable percentage deviation from the target price.

deviation of price that corresponds to the percent price variability.[31] Columns 4 and 5 are the coordinates on the vertical and horizontal axes in the figures, the average annual imports and the average annual cost. The standard deviation of the fiscal cost is presented in column 6, while the mean closing stock level at the end of each 10-year cycle is presented in column 7. Columns 8 through 11 list the four components of fiscal cost: returning the stock level to 100,000 tons at the end of each cycle, physical storage costs, losses from trade in the domestic market, and losses from trade in the international market. All monetary figures are in terms of average annual losses; that is, a negative number represents a profit.

The domestic and foreign trade accounts are simply revenues from sales minus expenditures on purchases in each market. The foreign trade account therefore shows the gains or losses in foreign exchange of the different policies. Since it is possible that

[31] Actually, the number in column (3) is the square root of $\Sigma(P_t - P^*)^2/(N - 1)$. This will differ from the standard deviation of price if the mean of price differs from P*. This number is called "standard deviation of price" throughout the text.

Table 11—Price band results

(1)	(2)	(3)	(4)	(5)	(6)	(7)	Components of Fiscal Cost (8)	(9)	(10)	(11)
Price Band	**Stock Variability**	**Standard Deviation of Price**	**Imports**	**Average Annual Fiscal Cost**	**Standard Deviation of Cost**	**Average Stock Level**	**Replace Stock Charges**	**Storage Costs**	**Domestic Trading Losses**	**Foreign Trading Losses**
(percent)	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
5	0	6.7	67.5	2.88	3.23	0	0.87	0.00	−0.17	2.18
5	25	6.7	62.5	2.98	3.24	13	0.76	0.34	−0.17	2.05
5	50	6.7	58.0	3.12	3.26	26	0.65	0.69	−0.17	1.96
5	75	6.7	54.0	3.29	3.31	38	0.53	1.03	−0.17	1.90
5	100	6.7	50.4	3.49	3.37	51	0.42	1.37	−0.17	1.87
5	150	6.7	44.6	3.85	3.51	77	0.20	1.99	−0.17	1.82
5	200	6.7	40.2	4.25	3.70	103	−0.02	2.59	−0.17	1.85
5	250	6.7	36.8	4.69	3.92	127	−0.24	3.16	−0.17	1.93
5	300	6.7	34.2	5.14	4.17	152	−0.45	3.69	−0.17	2.07
5	350	6.7	32.2	5.56	4.43	176	−0.66	4.17	−0.17	2.21
5	400	6.7	30.7	5.96	4.71	199	−0.86	4.60	−0.17	2.39
10	0	12.8	54.9	0.88	2.86	0	0.87	0.00	−1.01	1.02
10	25	12.8	50.4	1.07	2.88	13	0.76	0.35	−1.01	0.97
10	50	12.8	46.5	1.30	2.94	25	0.65	0.70	−1.01	0.96
10	75	12.8	43.0	1.55	3.01	38	0.54	1.05	−1.01	0.97
10	100	12.8	40.0	1.81	3.09	51	0.42	1.40	−1.01	1.00
10	150	12.8	35.3	2.24	3.27	77	0.20	2.00	−1.01	1.04
10	200	12.8	31.8	2.71	3.50	101	−0.01	2.58	−1.01	1.15
10	250	12.8	29.2	3.18	3.76	126	−0.22	3.12	−1.01	1.30
10	300	12.8	27.1	3.62	4.03	149	−0.43	3.60	−1.01	1.46
10	350	12.8	25.7	4.04	4.32	172	−0.63	4.03	−1.01	1.65
10	400	12.8	24.7	4.41	4.62	195	−0.83	4.41	−1.01	1.84
15	0	18.4	43.9	−0.61	2.58	0	0.87	0.00	−1.53	0.05
15	25	18.4	40.1	−0.34	2.63	13	0.76	0.36	−1.53	0.07
15	50	18.4	36.7	−0.03	2.71	26	0.65	0.72	−1.53	0.12
15	75	18.4	33.7	0.29	2.80	39	0.53	1.08	−1.53	0.20
15	100	18.4	31.2	0.62	2.93	51	0.43	1.44	−1.53	0.28
15	150	18.4	27.5	1.13	3.15	76	0.21	2.03	−1.53	0.41
15	200	18.4	24.7	1.63	3.41	100	0.00	2.57	−1.53	0.58
15	250	18.4	22.7	2.10	3.70	124	−0.20	3.06	−1.53	0.77
15	300	18.4	21.2	2.54	4.00	146	−0.40	3.49	−1.53	0.97
15	350	18.4	20.3	2.93	4.29	169	−0.60	3.87	−1.53	1.18
15	400	18.4	19.7	3.26	4.60	189	−0.77	4.18	−1.53	1.37
20	0	23.5	35.3	−1.63	2.38	0	0.86	0.01	−1.86	−0.64
20	25	23.5	32.0	−1.27	2.45	14	0.75	0.39	−1.86	−0.55
20	50	23.5	29.1	−0.89	2.55	27	0.64	0.77	−1.86	−0.44
20	75	23.5	26.5	−0.50	2.69	39	0.53	1.14	−1.86	−0.31
20	100	23.5	24.3	−0.10	2.85	51	0.42	1.51	−1.86	−0.17
20	150	23.5	21.4	0.44	3.09	75	0.21	2.07	−1.86	0.02
20	200	23.5	19.2	0.95	3.36	99	0.01	2.57	−1.86	0.23
20	250	23.5	17.8	1.41	3.65	121	−0.18	3.01	−1.86	0.45
20	300	23.5	16.8	1.81	3.94	142	−0.37	3.38	−1.86	0.66
20	350	23.5	16.2	2.15	4.25	161	−0.53	3.68	−1.86	0.86
20	400	23.5	15.9	2.43	4.53	179	−0.68	3.93	−1.86	1.04

more physical units could be bought than sold in a market, a profit (loss) alone does not imply that the average selling price is higher (lower) than the average buying price.

Components of Cost for Price Band Schemes

The components of fiscal cost given in Table 11 are useful for analyzing the reasons for the responsiveness of fiscal cost to price variability and stock variability. Replacement costs are straightforward, being related directly to the mean closing stock level. Storage costs are somewhat more complicated. Note that for stock variability levels above 200, storage costs decrease with increasing price flexibility, but for higher levels of stock variability the decrease is larger proportionately than the corresponding change in mean stock level. In addition, the storage costs for 150,000 tons and below increase slightly with increasing price variability.

Both of these outcomes are the result of the opening stock level of 100,000 tons. The storage costs are the sum of the average closing stock level in each year multiplied by the cost per ton. For the 200,000-ton level of stock variability, the opening stock level is quite close to the average stock level; thus the proportionate change in storage costs is close to the change in closing mean stock level. On the other hand, the 300,000- and 400,000-ton stock variabilities generally have lower than average stock levels for the first few years of the simulation, and the stock level will remain low for more years when price variability is higher (since the government intervenes less often). The corresponding effect on the other side causes storage costs for lower levels of stock variability to be higher when prices are more flexible. Thus the storage costs differ from a straightforward multiplication of closing stock times average cost because the mean stock level in early years of the cycles differs from the mean stock level at the end of the cycles.

Domestic trading gains are determined by the difference between buying price and selling price and the amount of government intervention. With higher levels of price flexibility, the government makes more money whenever it buys one year and sells the next.

The foreign exchange account is the most complex. Recall that this account is the cost of imports (including aid) minus the cost of exports. This account is particularly difficult to understand for two reasons: the volume of imports may differ considerably from the volume of exports, and small volumes of exports are sold at a premium.

There are several characteristics of the foreign exchange account to notice. First, with 20 percent price flexibility, foreign exchange losses increase with increased stock variability. This result holds true for the higher levels of stock variability at 5, 10, and 15 percent price flexibility, but in each case foreign exchange losses decrease for the lowest levels of stock variability. Nevertheless, in every case foreign exchange losses are larger for the *lowest* level of imports—that is, for the highest level of stock variability—than they are for the *highest* level of imports. Thus, at some point for each level of price variability, reducing imports implies *losing* foreign exchange.

This conundrum is best understood by examining the relationship between average closing stock levels, imports, and exports. For the price band regimes, the width of the price band alone determines the government purchases. Consequently, the same amount is bought and sold in the domestic market regardless of the stock triggers for imports and exports. So alternative policies that differ only in stock variability would have equal net domestic purchases over any time period; closing stock levels, therefore, can differ only because of differences in net imports. This implies that over the same sequence of production years, the total volume imported minus the total volume exported minus the closing stock level is the same for all policies with the same price variability. Since increasing stock variability increases closing stocks and decreases imports, it must decrease exports by the sum of those two amounts, thereby decreasing export volume by a larger amount than import volume. Since the marginal decline in imports that results from increasing stock variability decreases as stock variability becomes large, while the increase in stock level is close to uniform, the relative effect on net export volumes increases.

If the difference between export and import parity were slight, the foreign-trade account would always lose money when stock variability increases. Since import parity is in fact considerably higher than export parity, this account begins to lose money with increasing stock variability only when the ratio of the decrease in export volume to the decrease in import volume is greater than the ratio of import parity price to export parity price.[32] This does not occur until stock variability reaches about 150,000 tons when the price band is 5 percent, but occurs at all levels of stock variability when the price band is 15 or 20 percent.

So at this point the components of cost of the price band schemes have been analyzed. Trade-offs between government objectives as measured by the price band schemes are presented in the next chapter, after an examination of the results of the dynamic programming runs.

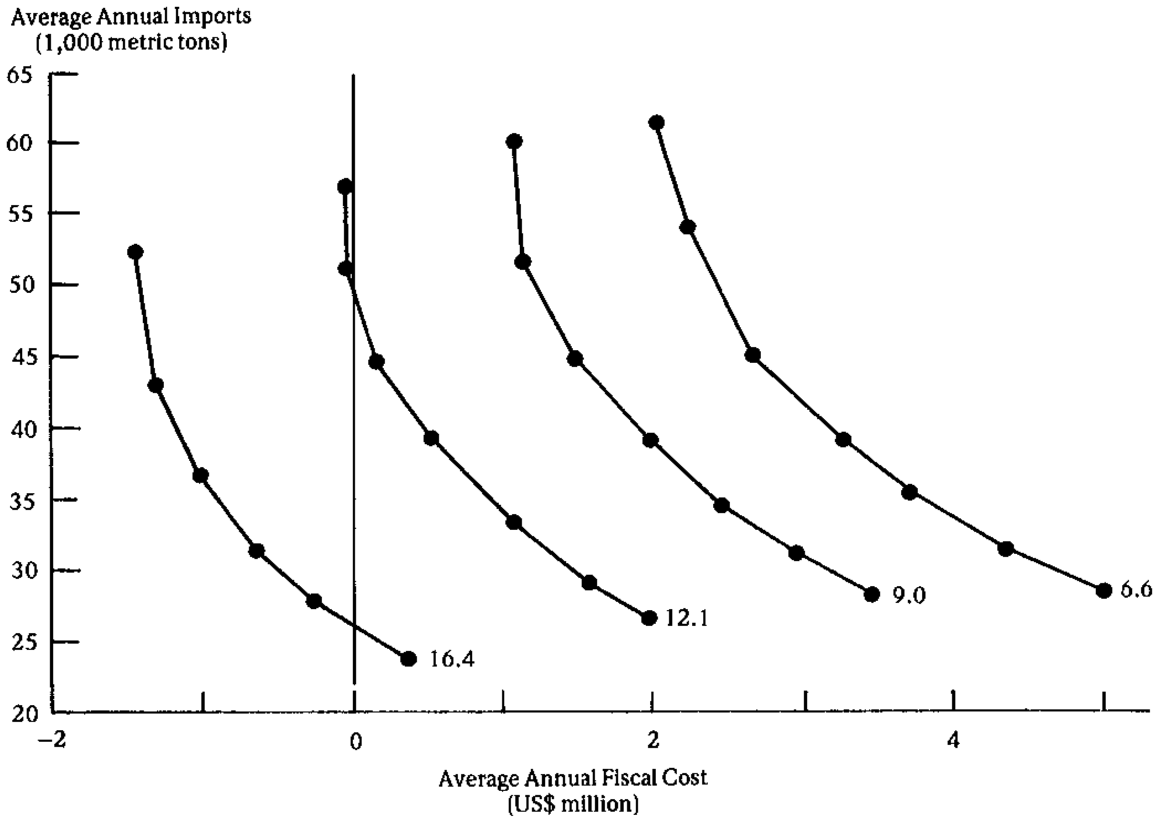
Optimization Results: Overview

Results of the dynamic programming policies are presented in Figure 5 and Table 12. For sensitivity analysis, similar tables for a demand elasticity of −0.2 and production instability of 12 percent are presented in Appendix 1, Tables 18 and 19. Each line of the tables displays the results of an optimization run with a different objective function. The producer/consumer surplus model appears at the bottom of Table 12. All other runs differ only in the weights applied in the objective function to the three different objectives. The weights have been chosen so that the standard deviation of price is constant for four sets of weight combinations. An attempt was made to make the average imports exhibit approximately the same range as occurs in the price band simulations.

As stated above, dynamic programming produces a set of optimal values of the policy variables for each possible combination of production, world price, and opening stock. These discrete policies are then interpolated to make them continuous, and the interpolated policies simulated in the same way as the price band policies are simulated. Thus the results for the optimal policies are directly comparable with those for the price band policies. Figure 5 differs from Figure 4 only in that the number at the base of each line in the price band figures is the maximum allowed percentage deviation in price; in the optimal policy figures, the number is the standard deviation of the price, which will be termed the level of price variability. The corresponding number for the price band schemes can be read from Table 11.

[32] This statement is exactly true if import and export parity prices are constant across different levels of stock variability. In actuality, the situation is slightly more complicated, since average export and import prices also vary with increasing stock variability, as higher stock levels lead to less food aid and a change in the proportion of exports that are sold at a premium. But these price changes are relatively small (5-7 percent between stock variabilities of 0 and 400,000 tons).

Figure 5—Optimal policy trade-off curves



Note: The number at the bottom of each line is the standard deviation of price in dollars per ton.

The price variability levels in Figures 4 and 5, however, are not identical. Consequently, Figure 6 presents price band trade-off curves for which the levels of price variability are the same as in Figure 5. Table 20 in Appendix 1 presents the results for these price band policies numerically. Figure 7 displays a price band and an optimal policy with the same standard deviation of price for direct comparison.

The first two columns differ between the tables for price band policies (Table 11 and appendix Tables 16, 17, and 20) and the tables for the optimal policies (Table 12 and appendix Tables 18 and 19). In the price band tables these are the percent price band and the maximum stock variability; for the optimal policies, these columns are the weights in the objective function on price stability and imports, respectively. Recall that fiscal cost, being the numeraire of the objective function, is not explicitly weighted; its weight results from changes in the combined level of the other two weighting parameters. For example, the weight on fiscal cost would be halved implicitly by moving from a weighting system of a = 10 and b = 40 to a = 20 and b = 80 (where "a" is the weight on price stability and "b" is the weight on imports).

The producer/consumer surplus maximization model describes the free market solution with no government intervention. With an open economy, average stock carry-out is virtually zero; trade is used rather than stocks to stabilize price. Average annual fiscal cost in this case is private sector "cost" (column 5 in the tables for price band and optional policies). Since the figure is negative, profits of about $3.7 million

Table 12—Optimal policy results

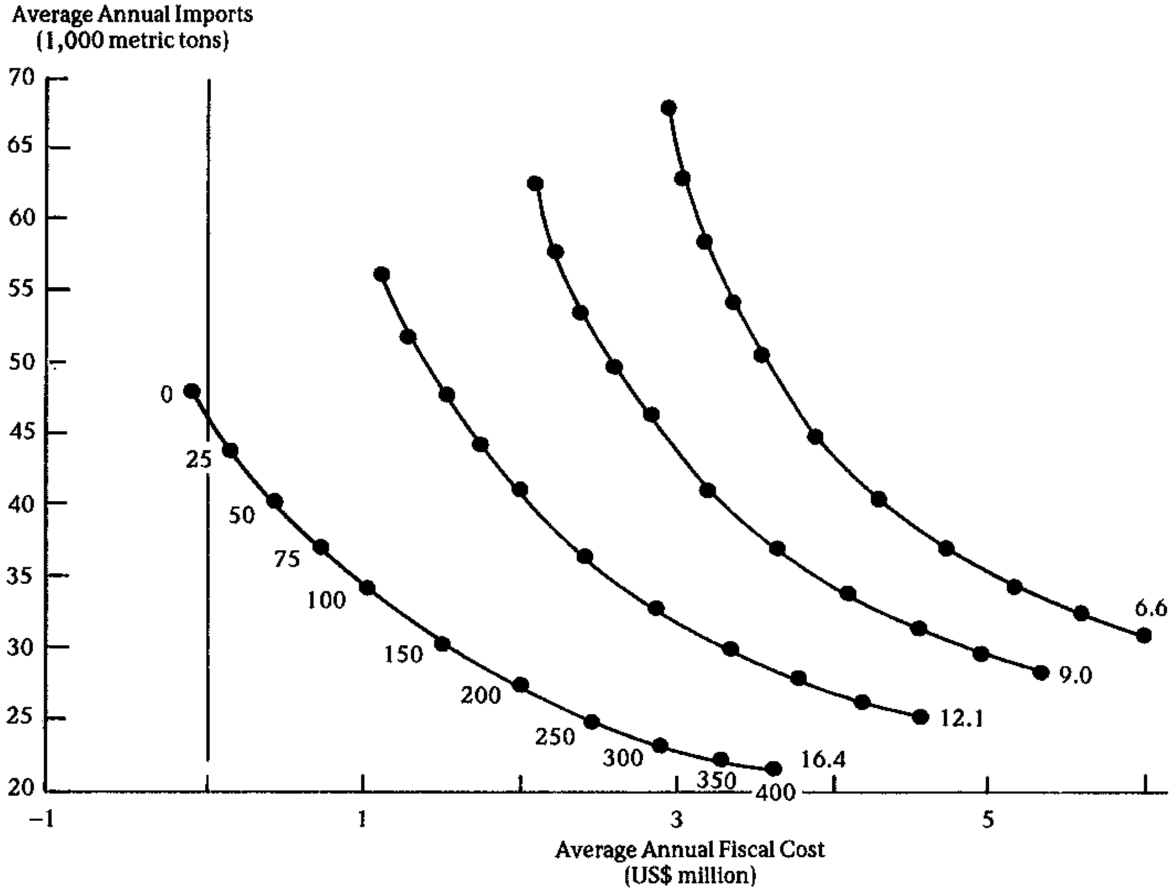
(1) Price Stability Weight	(2) Import Weight	(3) Standard Deviation of Price	(4) Imports	(5) Average Annual Fiscal Cost	(6) Standard Deviation of Cost	(7) Average Stock Level	Components of Fiscal Cost (8) Replace Stock Charges	(9) Storage Costs	(10) Domestic Trading Losses	(11) Foreign Trading Losses
		(US$/ metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
31.5	0	6.6	61.3	2.03	2.72	36	0.56	0.92	−1.26	1.82
37.3	50	6.6	54.2	2.24	3.08	60	0.35	1.44	−0.62	1.07
40.0	103	6.6	45.0	2.68	3.44	91	0.08	2.14	−0.00	0.48
44.6	149	6.6	39.2	3.27	3.73	117	−0.15	2.76	0.27	0.38
49.0	185	6.6	35.6	3.73	4.03	136	−0.32	3.21	0.55	0.28
53.5	241	6.6	31.7	4.38	4.31	163	−0.54	3.76	0.88	0.28
58.0	287	6.6	28.8	4.99	4.54	184	−0.73	4.24	1.13	0.35
22.0	0	9.0	59.9	1.09	2.39	31	0.60	0.81	−2.08	1.76
23.3	39	9.0	51.7	1.14	2.68	48	0.45	1.20	−1.25	0.75
26.5	80	9.0	45.3	1.48	3.04	67	0.28	1.69	−0.65	0.16
29.2	120	9.0	39.3	1.99	3.33	95	0.05	2.23	−0.15	−0.13
32.0	160	9.0	34.6	2.48	3.62	115	−0.13	2.71	0.27	−0.37
34.9	200	9.0	31.3	2.96	3.89	132	−0.28	3.13	0.52	−0.41
37.5	240	9.0	28.4	3.46	4.15	148	−0.42	3.52	0.85	−0.49
14.2	0	12.1	56.9	−0.04	2.06	24	0.66	0.68	−2.91	1.54
15.3	28	12.1	50.7	−0.03	2.29	36	0.56	0.93	−2.12	0.60
17.0	60	12.1	44.7	0.13	2.56	52	0.42	1.26	−1.48	−0.06
18.8	95	12.1	39.4	0.50	2.90	66	0.30	1.65	−0.99	−0.46
20.9	140	12.1	33.4	1.05	3.20	89	0.10	2.15	−0.29	−0.90
22.9	180	12.1	29.2	1.55	3.48	109	−0.08	2.60	0.08	−1.05
24.9	220	12.1	26.6	1.99	3.72	125	−0.22	2.95	0.53	−1.28
8.9	0	16.4	52.3	−1.46	1.91	16	0.73	0.49	−3.75	1.07
10.4	40	16.4	43.1	−1.33	2.18	31	0.60	0.84	−2.49	−0.27
11.7	80	16.4	36.6	−1.03	2.46	45	0.47	1.16	−1.69	−0.98
13.0	120	16.4	31.5	−0.65	2.80	62	0.33	1.54	−1.03	−1.49
14.3	155	16.4	27.8	−0.26	3.00	77	0.20	1.86	−0.47	−1.85
15.6	200	16.4	23.9	0.31	3.27	94	0.05	2.29	0.09	−2.11
Producer/consumer surplus model		29.0	50.0	−3.69	2.25	3	0.80	0.09	−5.26	0.64

annually are made. Larger domestic profits are offset to some extent by small losses in the other three accounts. The degree to which prices fluctuate, however, is much higher than the historical level, as the standard deviation of price is $29.00 per ton. With fluctuations in the international price and the large difference between import and export parity, trade alone is not able to stabilize price sufficiently. Nevertheless, virtually no storage takes place since the private sector cannot usually expect to profit from storage. Thus there is a clear rationale for some type of government intervention to stabilize price.

Relative Costs of Optimal and Price Band Policies

Tables 11 and 12 and Figure 7 show clearly that on average the optimal policies are less expensive to operate, holding price variability and average imports constant. The broken lines on the graph in Figure 7 show that when average imports are 40,000 tons, the optimal policy costs on average 1.6 million dollars annually less than the price band policy.

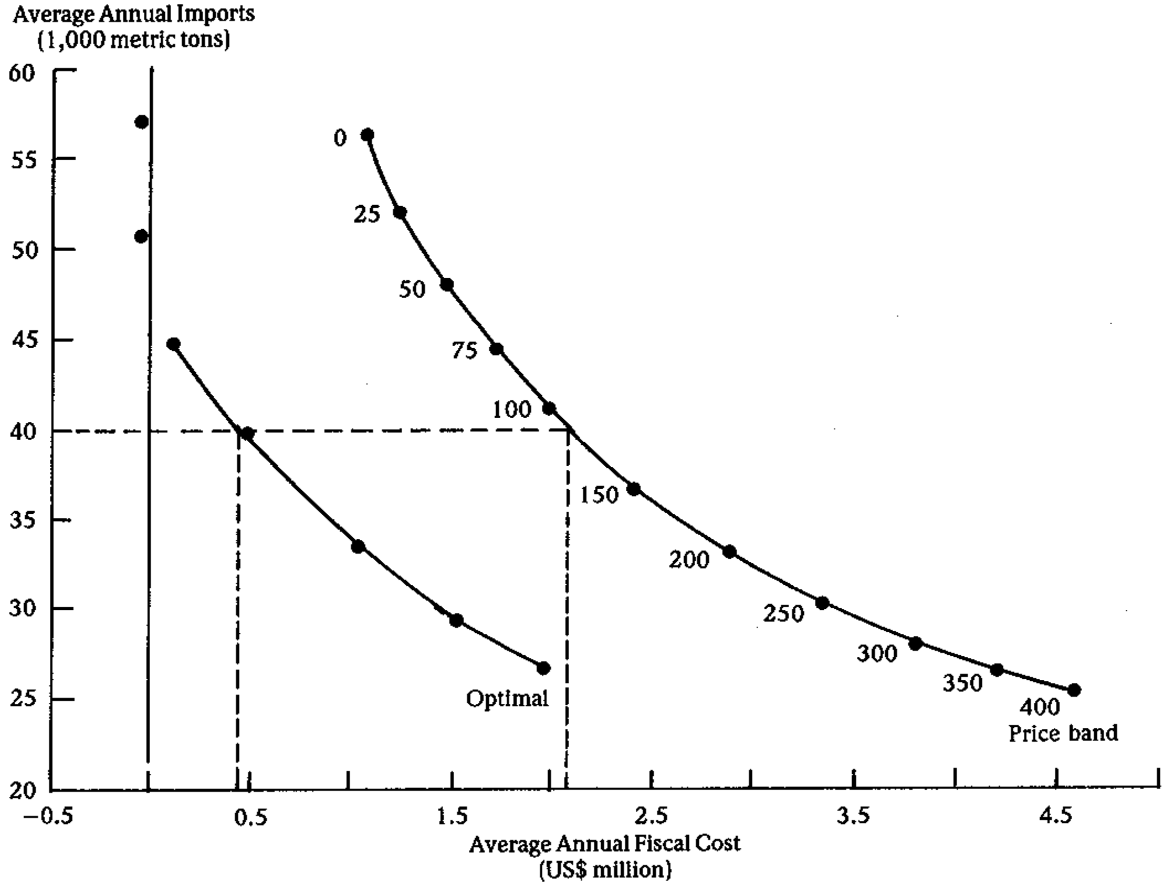
Figure 6—Price band trade-off curves for comparison with optimal



Note: The number at the bottom of each line is the standard deviation of price in dollars per ton.

Average cost differentials, however, may not be statistically significant if the standard deviation of the difference in cost is large. Consequently, costs for each of the 300 10-year cycles for one of the optimal policies were compared cycle by cycle with costs for one of the price band policies. The policies were chosen so that both price variability and imports are equal on average. The chosen optimal policy is the third point from the top on the optimal curve in Figure 7, with a price weight of 17 and an import weight of 60, resulting in average imports of 44,700 tons and a standard deviation of price of $12.10. The chosen price band scheme is the fourth point from the top in the figure (stock variability of 75). The average difference in cost is about $1.6 million annually, with a standard deviation of 1.1. The distribution of the price differential is skewed upward, however, as the median difference is $1.4 million. In the worst case of the 300 cycles for the price band scheme, the optimal policy costs $5.2 million less, which is 3.2 standard deviations from the mean. In the best case for the price band schemes, the optimal policy costs $40,000 more, which is only 1.4 standard deviations from the mean. The price band policy actually costs less than the optimal policy in 17 out of the 300 cycles, but in each of these cases the difference is small. Thus the difference in cost is significant.

Figure 7—Price band versus optimal policies for price variability of 12.1



The first step in gaining an understanding of these cost differences is to examine the differences in the components of cost. This is followed by a study of the differences in policy structure.

Optimization Results: Components of Cost

In examining the components of cost for the optimal policies, the replacement-of-stock component is directly related to closing stocks, as it is for the price band policies. Storage charges are actually simpler than in the price band schemes, being related almost directly to the mean closing stock level. Since the optimal policies produce the best level of each of the control variables for every possible stock level, the system is not in a state of disequilibrium at the start, as was the case for some of the price band policies.

Domestic trade looks considerably different than it does under the price band policies. This account actually loses money if the government has a relatively strong preference for reducing imports or stabilizing prices. This is not a case of the marketing board buying maize at a high price and selling it at a low price. Rather, the optimal policies adjust to government preferences by buying more than they sell domestically. This raises prices on average—which the government does not want—but also results in higher average stock levels, thereby improving the government's ability to cushion production fluctuations from stocks rather than from imports. This is advantageous given some patterns of relative preferences for the three objectives. For the price band schemes, average prices cannot be raised no matter what the preferences of the government are, since the policies are constrained to buy and sell approximately equal quantities domestically.

As with the price band schemes, the foreign exchange account is the most difficult to understand. One trend is clear: as the weight on price stability increases, the foreign exchange account loses more money. This is true across all levels of weights, elasticities, and production variabilities. As mentioned above, the government's preference for stable prices acts as a constraint that keeps the policy from responding flexibly to world price or stock level. The government must import more at unfavorable prices than previously, in addition to holding more stock and thus exporting less.

The foreign exchange consequences of increasing the desire of the government to minimize imports are less clear. The effect on domestic trade, noted above, is to exchange increased price stability in surplus years for decreased stability in deficit years, thus holding average price variability constant. This adjustment on the domestic side complicates the simple relationship between stocks, imports, and exports that explains the foreign exchange account of the price band schemes.

It is important to distinguish methods being used to decrease imports in the optimal and price band schemes. For the price bands, the mechanism is to use one tool, stock variability, which is subject to decreasing returns to scale and which actually decreases exports more than imports. For the optimal policies, the penalty on imports is direct, and thus in general the effect on imports is stronger than the effect on exports; the tables therefore show decreasing foreign exchange losses (or increasing profits) in the trade account as the weight on imports increases. It is not until the model is constrained by high weights on both price stability and imports that the mechanism described above for the price band schemes becomes dominant, with exports declining more than imports because of an increase in stockholding.

So the cost components of the optimal policies are quite different from those of the price band schemes. These result from differences in the way the two types of policies respond to production, world price, and opening stocks. An examination of these differences is conducted in the next section.

Differences Between Price Band and Optimal Policies

The best way to gain an intuitive understanding of the differences between price band and optimal policies is, first, to examine how the policies differ in a particular cycle of state variables; second, to examine the average relationships between state variables and control variables under the two policies. These will be discussed in turn.

Table 13 presents the results for a price band policy and an optimal policy that have similar values for imports and price variability on average. During the 300 10-year cycles of the simulation, both policies yield a standard deviation of price of $12.10 and average imports slightly greater than 44,000 tons. But as the table shows, in any one year the policies may produce very different results.

Since the random number generator for this cycle has produced high world prices, the optimal policy imports less than the price band policy (on average, with these two specific policies imports will be equal). The optimal policy virtually breaks even over these 10 years, while the price band policy loses about $1.4 million annually on average. The difference between the policies, however, is not spread out evenly over every

Table 13—Simulation of price band and optimal policies: one cycle

Year	Production	World Price	Net Purchases	Domestic Price	Net Imports	Closing Stocks	Annual Cost[a]	Sum of Costs
	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(1,000 metric tons)	(US$ million)	
Price band policy[b]								
0	...	...	...	...	...	100	...	...
1	2,047	133	−139	154	39	0	−13.83	−13.83
2	2,351	118	37	127	0	36	5.20	−8.63
3	2,306	125	0	129	0	36	0.79	−7.84
4	2,323	144	9	127	0	44	1.79	−6.06
5	2,622	161	308	127	−276	75	3.69	−2.37
6	2,836	154	522	127	−521	75	5.63	3.25
7	1,754	181	−432	154	357	0	−1.86	1.39
8	2,432	169	118	127	−42	75	6.06	7.45
9	2,349	114	35	127	−34	75	1.54	8.99
10	2,142	124	−44	154	0	31	−3.26	5.73
Replace stock adjustment	...	...	...	...	...	...	4.50	10.23
Average annual cost	...	...	...	...	...	...	...	1.36
Optimal policy[c]								
0	...	...	...	...	...	100	...	...
1	2,047	133	−140	154	40	1	−13.51	−13.51
2	2,351	118	79	136	−74	6	2.40	−11.16
3	2,306	125	43	137	−44	5	0.65	−10.46
4	2,323	144	61	138	−66	0	−0.76	−11.22
5	2,622	161	313	129	−182	132	14.91	3.69
6	2,836	154	500	124	−486	146	6.80	10.49
7	1,754	181	−384	166	238	0	−18.04	−7.55
8	2,432	169	160	136	−133	27	0.94	−6.61
9	2,349	114	73	135	−60	39	2.91	−3.70
10	2,142	124	−48	153	8	0	−3.18	−6.87
Replace stock adjustment	...	...	...	...	...	...	6.53	−0.35
Average annual cost	...	...	...	...	...	...	...	−0.05

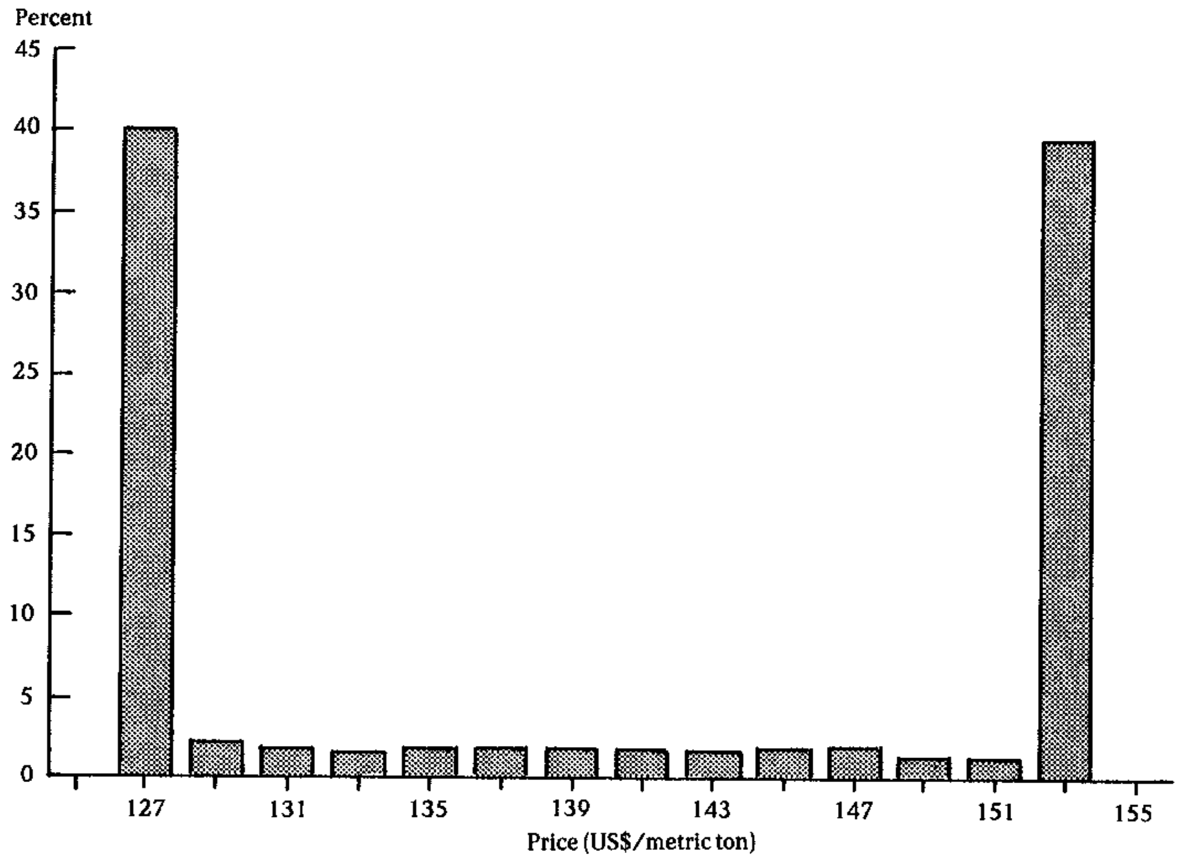
[a] Annual costs include a discount factor of 7 percent per year beginning in year 2.
[b] The price band policy has maximum price flexibility of 9.37 percent and stock variability of 75,000 tons.
[c] The optimal policy has a price weight of 17 and an import weight of 60.

year; for these 10 years, the optimal policy costs considerably less four times, the two are almost equal three times, and the price band policy costs less three times.[33] However, it is partly because the price band policy costs less in years 5 and 6 (because it exports more and stores less) that it is so far inferior to the optimal policy in year 7. The policies cannot be compared except in a dynamic context.

Although the price variability levels are equal on average for these two policies, the distribution of prices is strikingly different. For the 10 years in the table, the price band policy is at either the low or high extreme nine times, while the optimal policy prices are more spread out. Figures 8 and 9 present frequency histograms of price for all 3,000 simulated years (300 10-year cycles), using the same two policies as in Table 13. Note that the scale is different in the two histograms. The price band histogram shows that in 80 percent of the years the price is at either the maximum or minimum allowed value. The optimal policy is also bimodal, but much more dispersed. Although the price component of the objective function is equal for these two policies, if govern-

[33] Annual comparisons are obscured by the lack of any adjustment for differences in closing stock level. The adjustment is made at the end of the tenth year.

Figure 8—Price frequencies: price band policy



Note: Price variability = 12.1, demand elasticity = −0.3, production variability = 0.10.

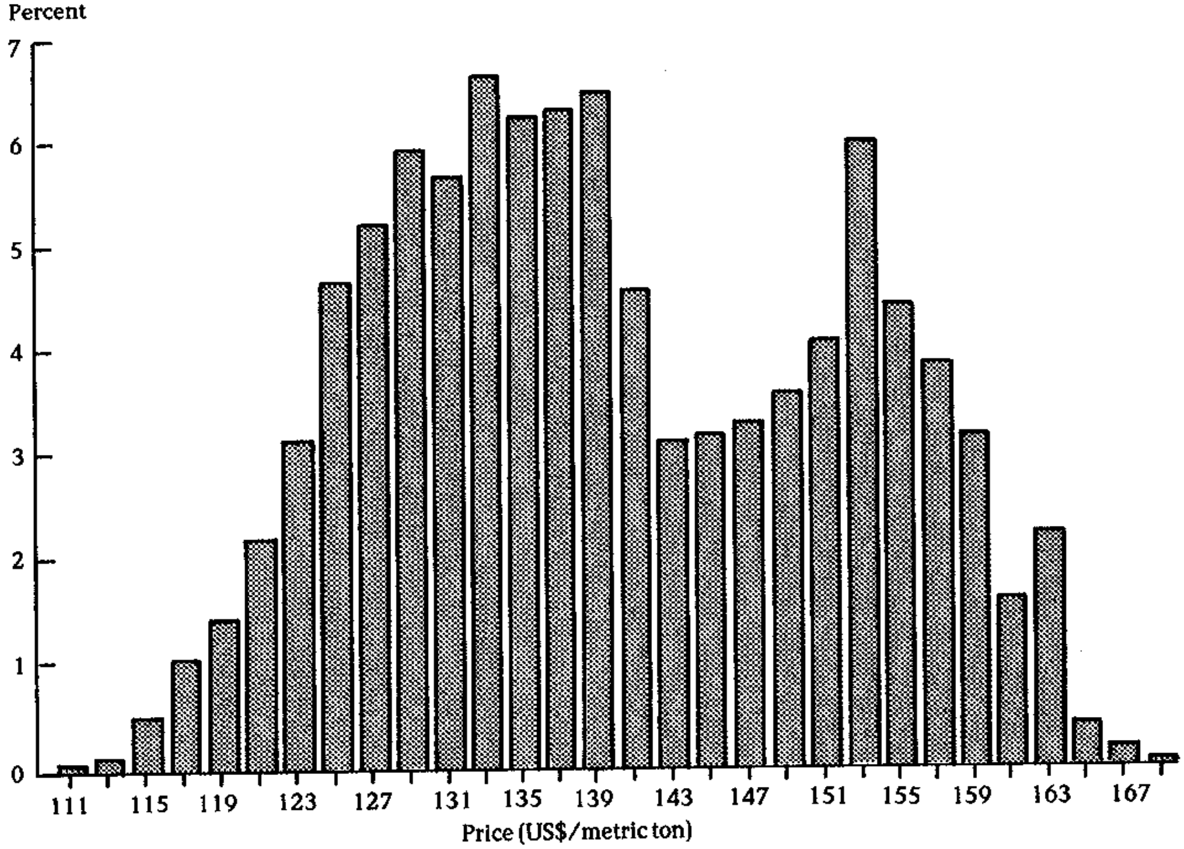
ment preferences have not been modeled accurately by the objective function, it is quite possible that one distribution of prices would be preferred over the other.

Government net purchases determine the domestic price. Net purchases and trade are the two control variables for the stockholding agency. For the price band policies the decisions are sequential, with the trade decision following the net purchases decision. The optimal policy decision will also be treated as sequential in order to facilitate the comparison with the price band policy, although in the optimization process the two are chosen simultaneously.

Figure 10 shows the relationship between production and net purchases for a price band rule that results in a price variability of $12.10 and an optimal policy with the same price variation. Unlike the price band schemes, the net purchases in the optimal policies are sensitive to opening stocks, world price, and the objective function weights; the optimal relationship shown is for opening stocks of zero and a world price of $100.00 per ton for the same objective function weights considered above (price weight of 17, import weight of 60). As mentioned in Chapter 3, the price band policy has three linear sections, with slopes of one, zero, and one. The optimal policy, on the other hand, is a smooth curve that is close to being linear.

The two curves are close together with the exception of the rare case of very high production. It would be surprising if differences of the magnitude shown on the graph

Figure 9—Price frequencies: optimal policy

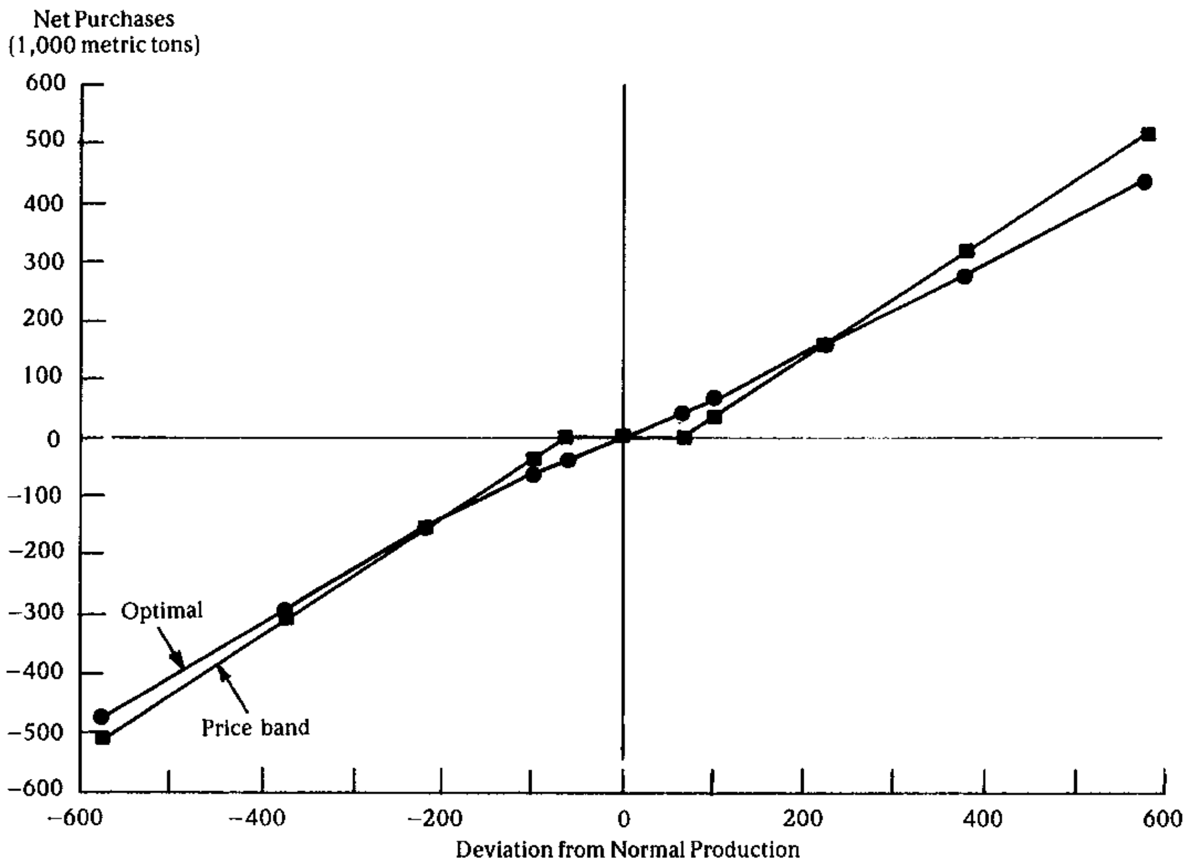


Note: Price variability = 12.1, demand elasticity = −0.3, production variability = 0.10.

produced such large differences in cost. But consider Figure 11, which displays the same case as Figure 10 except that opening stocks are 400,000 tons rather than zero. The price band curve does not change from one figure to the next since purchases are not sensitive to opening stocks in these schemes. But the optimal policy has changed considerably, leading to large differences between the curves in the frequent case of production being slightly below normal. This confirms that the major problem with price band schemes is the absence of flexibility to opening stocks and other state variables.

The way that the optimal policies respond to changes in government preferences is displayed in Figure 12. The curve displayed with diamonds and labeled "base" is the case considered above: a price weight of 17 and an import weight of 60, yielding price variability of $12.10 and average imports of 44,700 tons. This will be termed policy 1. The curve displayed with bullets and labeled "low imports" has a price weight of 24.9 and an import weight of 220. This policy, called policy 2, produces the same price variability as policy 1, but average imports of only 26,700 tons. The third curve, displayed with squares and labeled "low price variability" is called policy 3. It displays results for a price weight of 40 and an import weight of 103, yielding virtually the same level of imports as policy 1, but price variability of only $6.60 per ton. The displayed curves are all for a world price of $100.00 and opening stocks of 100,000 tons.

Figure 10—Net purchases: price band versus optimal for opening stock = 0

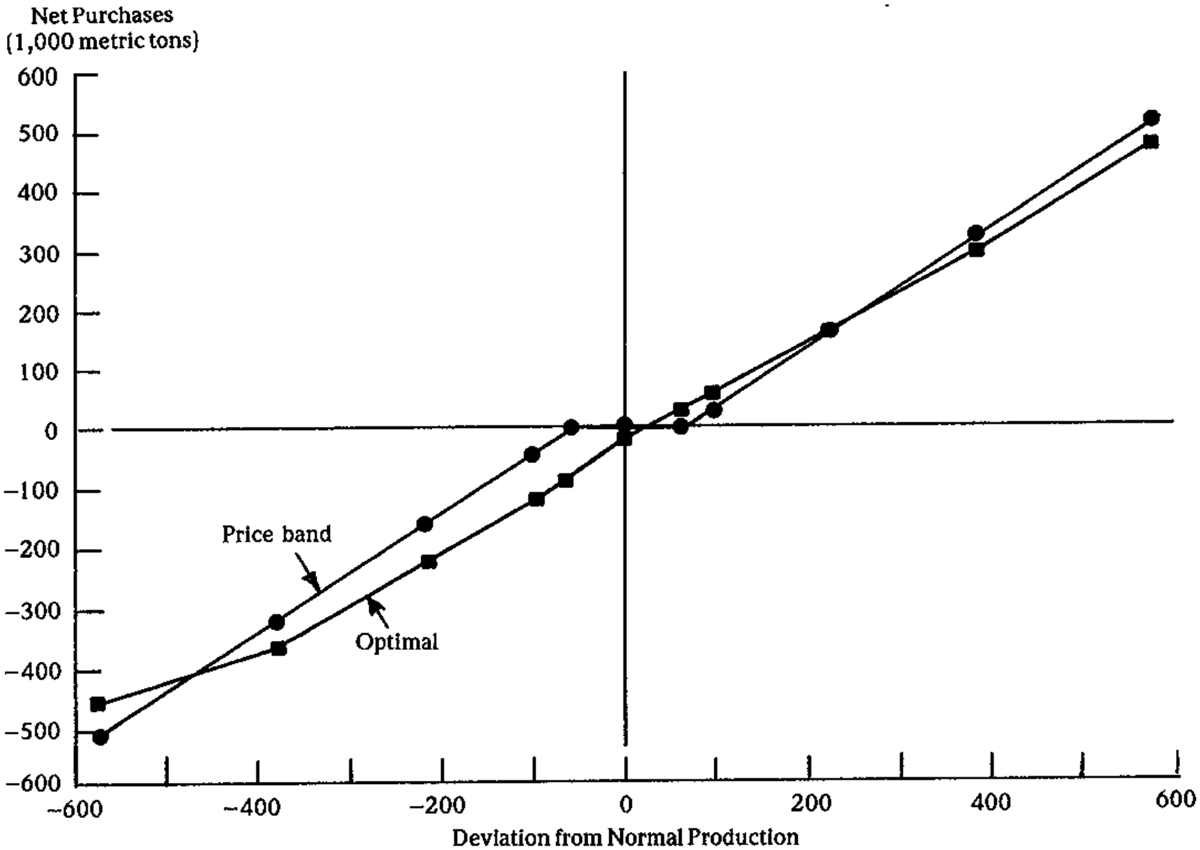


Note: Demand elasticity = −0.3, production variability = 0.10, and world price = US$100.

All of the policies have the same net purchases when production is between its mean value and 100,000 tons less than the mean, with each policy making up the entire difference between actual and normal production in such years. With these exceptions, however, the curve for policy 2 is always above the curve for policy 1, implying that more is bought in high production years and less is sold in low production years. Such a policy clearly leads to lower imports. The curve for policy 3, on the other hand, is below the policy 1 curve in low production years and above it in high production years. There are thus more purchases in high production years and more sales in low production years, leading to greater price stability. The larger stockholdings gained through higher purchases, however, do not reduce imports on average, because larger amounts of grain are required for sale in deficit production years.

Once net purchases are determined, the stockholding agency is left with a quantity equal to opening stocks plus net purchases, which will be termed "available supply." Imports and aid are brought in to make up the deficit exactly if the available supply is negative. Positive available supply can be either stored or exported. The relationships between available supply, closing stocks, and exports are displayed in Figure 13 for

Figure 11—Net purchases: price band versus optimal for opening stock = 400



Note: Demand elasticity = −0.3, production variability = 0.10, and world price = US$100.

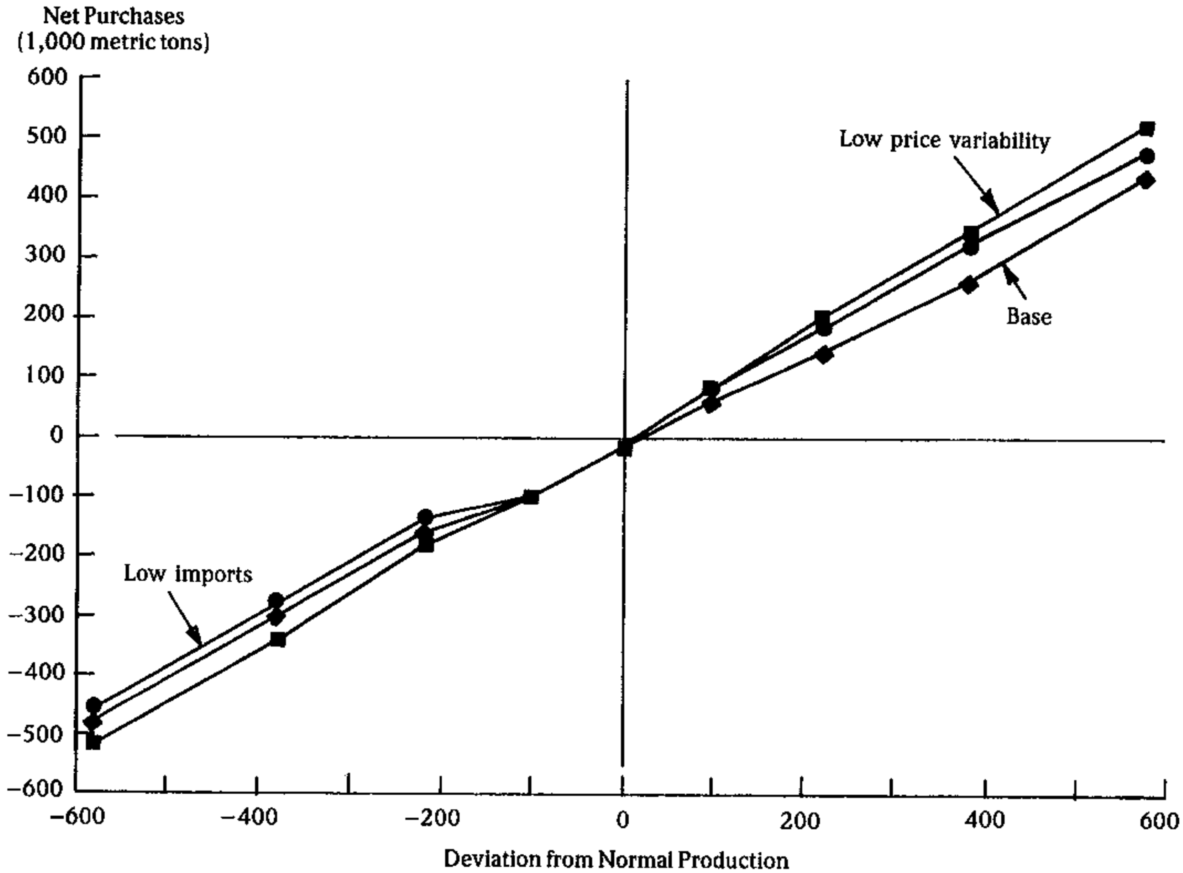
policy 1 from the net purchases analysis: world price equal to $100.00, price weight equal to 17, and import weight equal to 60.

Each curve has three segments that are almost linear. The stock curve rises with a slope of 0.5 until stocks reach 100, then rises with a slope of 1.0 until stocks reach 340, and then flattens out. Since whatever is not held as a stock is exported, the export curve also has three sections, with slopes of 1.0 minus the slope of the stock curve. It is clear that the value of holding stocks when available supply is low is approximately equal to the value of exporting at the prevailing premium price; when the export premium decreases at 100,000 tons of exports, stocks absorb all additional supply until the marginal value of holding additional stocks is smaller than the export price without the premium.

This stock curve for a world price of $100.00 is contrasted to the stock curve for a world price of $140.00 and the price band/buffer stock curve in Figure 14. Of course, additional curves could be included for price band policies with different levels of stock variability, but the shape would be the same.

The two optimal policy curves are similar in shape, with two important differences. First, the maximum stock level is much lower for a world price of $140.00 per ton

Figure 12—Optimal net purchases for different objective function weights



than it is for a world price of $100.00. This reflects the increased opportunity cost of stocks with higher world prices. Also, at higher world prices, 1 ton of exports is worth a larger fraction of a ton of future imports, since with higher world prices and a constant price differential the ratio of export parity to import parity increases. The second difference between the curves is that at the higher price, 80,000 tons of exports take place before any supply is placed in storage. Thus the marginal value of the export premium sales is higher than the marginal value of the first units of storage.

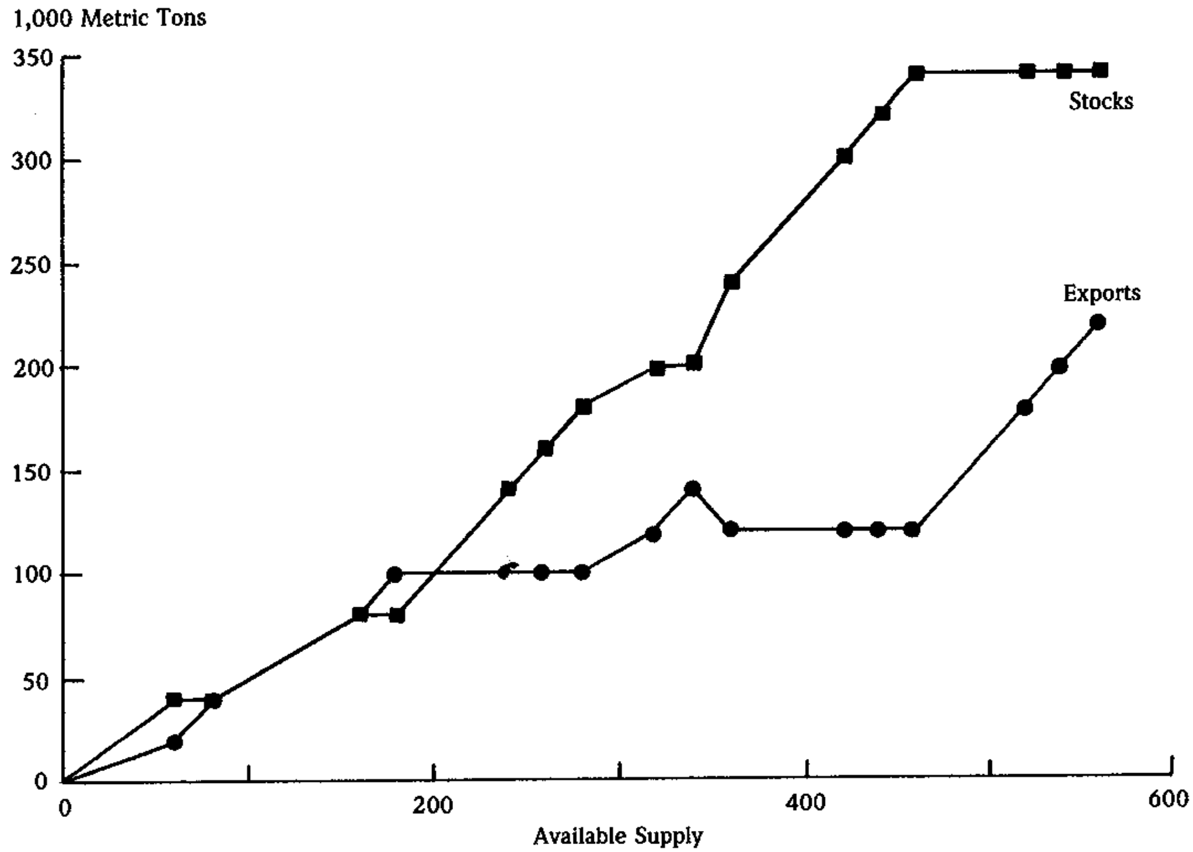
Both of these curves are in contrast to the price band curve, which simply places all supply into storage until the maximum stock is reached, and then exports the remainder. Two limitations of such a policy are clear: it ignores the presence of export premiums on small quantities of exports, and the maximum stock level is independent of world price.

Summary of Major Results

The major results from this chapter include the following:

1. The frequency distribution of price that results from a price band policy is quite different from the distribution under an optimal policy even when the standard deviation

Figure 13—Optimal closing stocks and exports



Note: Demand elasticity = −0.3, production variability = 0.10, and world price = US$100.

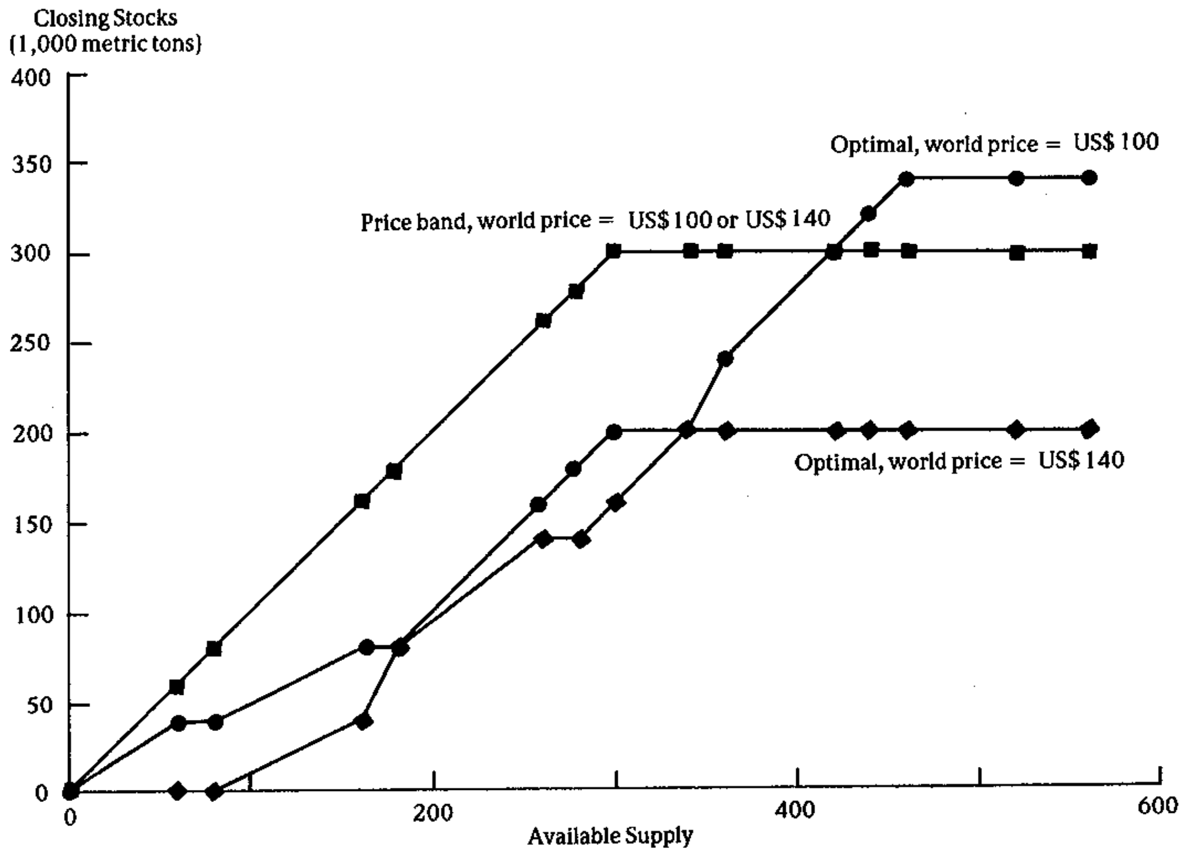
of price is held constant. For the price band policies, the distribution is strongly bimodal with a large majority of the prices at the extreme price limits. The optimal policies yield a relatively smooth distribution of prices.

2. The optimal policy net purchases (and thus domestic price) respond to world price and opening stock level, while net purchases for the price band schemes do not respond to those variables. By buying less (more) when world prices are high (low) and opening stock levels are high (low), the optimal policies save on fiscal cost.

3. The relationship between production and net purchases for the optimal policies is smooth, while it is kinked for the price band policies. The kinked relationship of the price band policies implies that the marginal cost of the next dollar price change at the limits is infinite; since this is not the case according to the objective function used here, the price band net purchases curve is inefficient.

4. The optimal export function is sensitive to world price in two ways: 100,000 tons of maize are exported before the maximum stock level is reached, and the maximum stock level itself is sensitive to the world price. The first 100,000-ton lot is exported to take advantage of the available export premiums. The maximum stock level adjusts, since the volume of future imports that can be bought with the cash gained from 1

Figure 14—Stocks: optimal versus price band policy at different world prices



Note: Demand elasticity = −0.3, production variability = 0.10.

ton of this year's exports increases with increasing world price. Thus the opportunity cost of holding stocks increases with higher world prices.

With these results in hand, the following chapter examines the trade-off between complexity of policy and cost. Based on the differences between the optimal and price band policies outlined above, changes are made in the price band policies to increase their efficiency. Chapter 7 presents policy recommendations and recommendations for policy analysts.

6

TRADE-OFFS BETWEEN GOVERNMENT OBJECTIVES

Trade-Offs Between Cost, Price Stability, and Imports

Figures 4 through 7 in Chapter 5 display the trade-off curves implied by the different policies. Since these can be slightly misleading for the purpose of measuring trade-offs, the results are presented numerically in Table 14. Trade-offs for price elasticity of −0.2 and production variability of 12 percent are presented in Appendix 1, Tables 21 and 22. As discussed above, buffer stocks are more effective at lower levels of price variability. The curves become steeper between corresponding levels of stock variability as price variability is decreased. This occurs because the slope of the line measures the relative effectiveness of only one instrument, increasing stock variability, which is subject to diminishing returns. With the optimal policies, on the other hand, all policy instruments can be adjusted simultaneously, and the least expensive adjustments are made. But with higher weights on price variability, the costs of making even minor adjustments in consumption are high, so the algorithm is constrained in the way it can adjust to a higher weight on imports. This leads to flatter curves for the low levels of price variability.

Such considerations can lead to the false conclusion that, for the price band schemes, the cost per unit decrease in imports declines with increasing price stability. This is not true, as Table 14 clearly shows, because as prices become more stable, higher

Table 14—Trade-offs between objectives: price band and optimal

Trade-off	Standard Deviation of Price			
	16.4	12.1	9.0	6.6
	(US$1,000/year)			
Cost per 1,000-metric-ton decrease in average annual imports				
As imports decline from 48,000 to 40,000 metric tons				
Price bands	69	76	75	82
Optimal policies	27	52	75	81
As imports decline from 40,000 to 31,000 metric tons				
Price bands	121	136	166	202
Optimal policies	73	110	134	167
Cost per US$ decrease in standard deviation of price				
With imports held constant at 48,000 metric tons				
Price bands	. . .	368	399	410
Optimal policies	. . .	335	417	501
With imports held constant at 31,000 metric tons				
Price bands	. . .	409	476	551
Optimal policies	. . .	451	540	630

levels of stock variability are required to maintain the same import level.[34] Although the line from 100,000 to 200,000 tons of stock variability is steeper with a smaller price band, the curve moving from imports of 40,000 to 31,000 is not.

The table confirms the impression of Figures 4 through 7 that for both the price band schemes and the optimal policies, price variability is the key determinant of cost. Each dollar decrease in price variability between $9.00 and $6.60 costs about $500,000 annually for the optimal policies with imports held constant at 48,000 tons; the figure is $630,000 when imports are held constant at 31,000 tons.

The cost of decreasing imports, while not as large in absolute terms as the cost of decreasing price variability, undergoes a larger percentage increase, rising from less than $30,000 annually to almost $170,000. The marginal cost increases as price stability increases, and also increases as imports decline.

With a few exceptions, the price band schemes overestimate the cost of decreasing imports. The price band estimates of the trade-off between lowering imports and lowering fiscal cost are particularly far off for high price variability. In this case, the optimal policies decrease imports by raising average prices. When the government preference for low imports is sufficiently high, this is preferred even though average prices are above the target price. On the other hand, with the width of the band held constant, the price band policies can reduce imports only by raising stock levels. This is very inefficient when prices are allowed to fluctuate widely.

In contrast to the fiscal cost/import trade-off, the trade-off between cost and price variability is almost always understated by the price band policies. The degree of underestimation increases as price variability declines. This appears to suggest that the price band schemes are more efficient at decreasing price variability than are the optimal policies.

But this is not the case. The optimal policies are the most efficient way to maximize the three objectives for any set of government preferences. Thus, the optimal policy measurements of the trade-offs are accurate. The reason for the relatively flat relationship between price variability and cost per unit of decrease in the price band schemes is that, as mentioned above, buffer stocks are more efficient policy instruments when prices are relatively stable. As price variability decreases, the price band curve gets closer to the optimal curve, biasing the measurement of the trade-off downward.

The Trade-Off Between Complexity and Cost

As shown above, the optimal policies achieve the government's objectives more efficiently than the price band policies. Despite these large differences in efficiency, several stockholding agencies in different parts of the world attempt to implement price band/buffer stock plans, while "in actual formulation of stockpiling strategy either at the national or at the international level . . . these [optimal stockpiling] models have barely been consulted" (Bigman and Yitzhaki 1983, 1). Cochrane (1980) suggests that risk considerations tend to make price band schemes with their floor and ceiling prices more intuitively appealing to both producers and consumers than the smooth intervention rules called for by optimal stockpiling analysis. Although the infinite marginal value attached to the next incremental price change in a price band scheme seems

[34] Trade-offs for demand elasticity of −0.2 and production variability of 12 percent are presented in Appendix 1, Tables 21 and 22.

irrational to an economist used to marginal analysis, the revealed preferences of governments around the world appear to be in favor of such schemes.

One compelling reason why optimal policies have never been implemented is the difficulty in communicating what they are. Indeed, the interpolated policies from the dynamic programming analysis are difficult to describe and implement. Savvy decisionmakers who have seen complex cure-all projects disintegrate into chaos are likely to agree with Chambers' (1978) dictum that "simple is optimal" in policy design as well as in project selection, and to be wary of a policy that is difficult to describe, even for its proponents. Furthermore, the process of formulating public policy is so complex that policies that are difficult to communicate are unlikely to be accepted at the many decisionmaking levels necessary for successful implementation. There is thus an additional trade-off that needs to be examined here: the trade-off between the complexity of a policy and its efficiency. Apparently, the efficiency gains from optimal policies have not been sufficient to outweigh the costs involved in attempting to gain approval for and implement a complex policy.

Thus, if optimal stockpiling analysis is to have an effect on policy, it is likely to be through the clues it provides for modification of price band policies, or through the formulation of a relatively simple policy that is close to the optimal policy in most circumstances.

Possible modifications to the price band policies are suggested by the differences between the optimal and price band policies discussed in Chapter 5. Four differences have been identified: the maximum stock level in the optimal policies is dependent on the world price, with lower maximum levels prevailing at higher world prices; 100,000 tons of grain are exported before the maximum stock level is reached in order to take advantage of export premiums; net purchases of the stocking agency are sensitive to opening stocks and the world price; and net purchases are almost linearly related to production for constant opening stock level and world price. These four elements account for the large difference in efficiency between the two curves.

Learning from the Optimal Policy

One approach to the formulation of a relatively simple and efficient policy is to introduce the components of the optimal policy into the price band policy one by one, and measure the gain in efficiency at each step. For example, the first step could be to make the maximum stock level dependent on the world price. To accomplish this, however, it is necessary to know how sensitive the maximum stock level should be to the world price. Once estimates are made of the degree of sensitivity, the price band policies can be adjusted so that they respond to changes in the state variables to the same extent as the optimal policies.

The first step in the analysis is to choose the specific policy for consideration. The policy with a price weight of 17 and import weight of 60, which yields a standard deviation of price of $12.10 and average imports of 44,700 tons, will be examined here.

Figures 10 through 12 suggest that the relationship between net purchases and the state variables (world price, opening stock level, and production) is close to linear. The following regression results confirm the suggestion:

$$NP_t = -1{,}826.8 + 0.5309 \cdot WP_t + 0.7847 \cdot Q_t - 0.09773 \cdot S_{t-1}; \qquad (25)$$
$$\quad (6.1) \quad (0.0194) \qquad (0.0024) \qquad (0.0036)$$

$N = 1{,}350,\ R^2 = 0.992,\ SEE = 15.98,$

where

NP_t = net purchases,
WP_t = world price,
Q_t = production, and
S_{t-1} = opening stock level.

Standard errors are in parentheses. The regression includes all states in the model except for the extreme world prices of $60 and $180, for which the optimal results are not deemed accurate, since world prices cannot go below or above these extremes. Since each state of the world is not equally likely, the observations are weighted by the product of two factors: first, the probability of the production occurring, which is known in the model; second, a linear weighting scheme that decreases with increasing stocks. The second term is not exact, but reflects decreasing likelihood of higher stock levels occurring.[35]

The second important relationship graphed in Chapter 5 is that between available supply and closing stocks (Figures 13 and 14). That relationship, however, appears to be piecewise linear in three segments and thus is not amenable to linear regression. The regression that can be run is maximum stock level on world price. Unfortunately, there are very few observations for this analysis, since the optimizing model considers only seven levels of world price and the two extreme values are somewhat suspect. With only five observations, the result is

$$MXST_t = 652 - 3.3 \cdot WP_t, \tag{26}$$

where $MXST_t$ is maximum stock level. This implies that when world prices are higher than $198, nothing will be stored.

With these results in hand, the step-by-step analysis of the price band policies can begin. The easiest policies to implement are those that are more or less invisible to the populace if imports are held constant: making the maximum stock level sensitive to the world price and exporting small quantities frequently. These will be discussed in turn.

Surprisingly, the results are only slightly better for the price band with a flexible maximum stock level (policy A) than for the normal schemes. Table 15 lists the components of cost for policy A and the price band scheme with 250,000 tons of stock variability, which has the same level of average imports. Figure 15 displays the result for policy A as the point labeled "A".

As expected, export revenues increase substantially by lowering stock levels when world prices are high. Average export prices increase over 20 percent, but the increased stock level leads to lower export volumes, since imports and domestic trade are constant. The higher stock level leads to higher storage charges that are tempered somewhat by increased "earnings" from the replace stock account. Also on the negative side, average

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[35] The unweighted equation is

$$-1{,}892.7 + 0.6007 \cdot WP_t + 0.8091 \cdot Q_t - 0.0760 \cdot S_{t-1},$$

with a slightly higher R^2. A weighting scheme in which weights were chosen based on how often each state of the world occurs in the simulation was tried also. Results differ only marginally.

Table 15—Adjusting the price band policy

Policy	Import Volume	Average Annual Fiscal Cost	Average Stock Level	Replace Stock Charges	Storage Charges	Domestic Trading Losses	Foreign Trading Losses
	(1,000 metric tons)	(US$ million)	(1,000 metric tons)	(US$ million)			
Price band	30.0	3.35	126	−0.23	3.13	−0.92	1.36
Policy A	30.0	3.27	149	−0.43	3.47	−0.92	1.14
Optimal (Policy A makes up 4 percent of the difference)	30.0	1.45	103	−0.05	2.51	0.01	−1.02
Price band	41.7	1.95	49	0.44	1.33	−0.92	1.09
Policy B	41.7	1.37	60	0.35	1.66	−0.92	0.28
Optimal (Policy B makes up 36 percent of the difference)	41.7	0.34	60	0.35	1.48	−1.20	−0.29
Price band	42.8	1.86	44	0.48	1.21	−0.92	1.08
Policy C	42.8	1.02	56	0.37	1.62	−0.92	−0.05
Optimal (Policy C makes up 53 percent of the difference)	42.8	0.26	57	0.38	1.40	−1.30	−0.20
Price band	41.3	1.98	50	0.43	1.37	−0.92	1.09
Policy D	41.3	1.04	57	0.37	1.64	−0.59	−0.39
Optimal (Policy D makes up 58 percent of the difference)	41.3	0.37	61	0.34	1.51	−1.17	−0.32
Price band	41.5	1.97	49	0.44	1.36	0.92	1.09
Policy F	41.5	0.48	54	0.40	1.54	−1.25	−0.21
Optimal (Policy F makes up 92 percent of the difference)	41.5	0.35	60	0.35	1.50	−1.18	−0.30

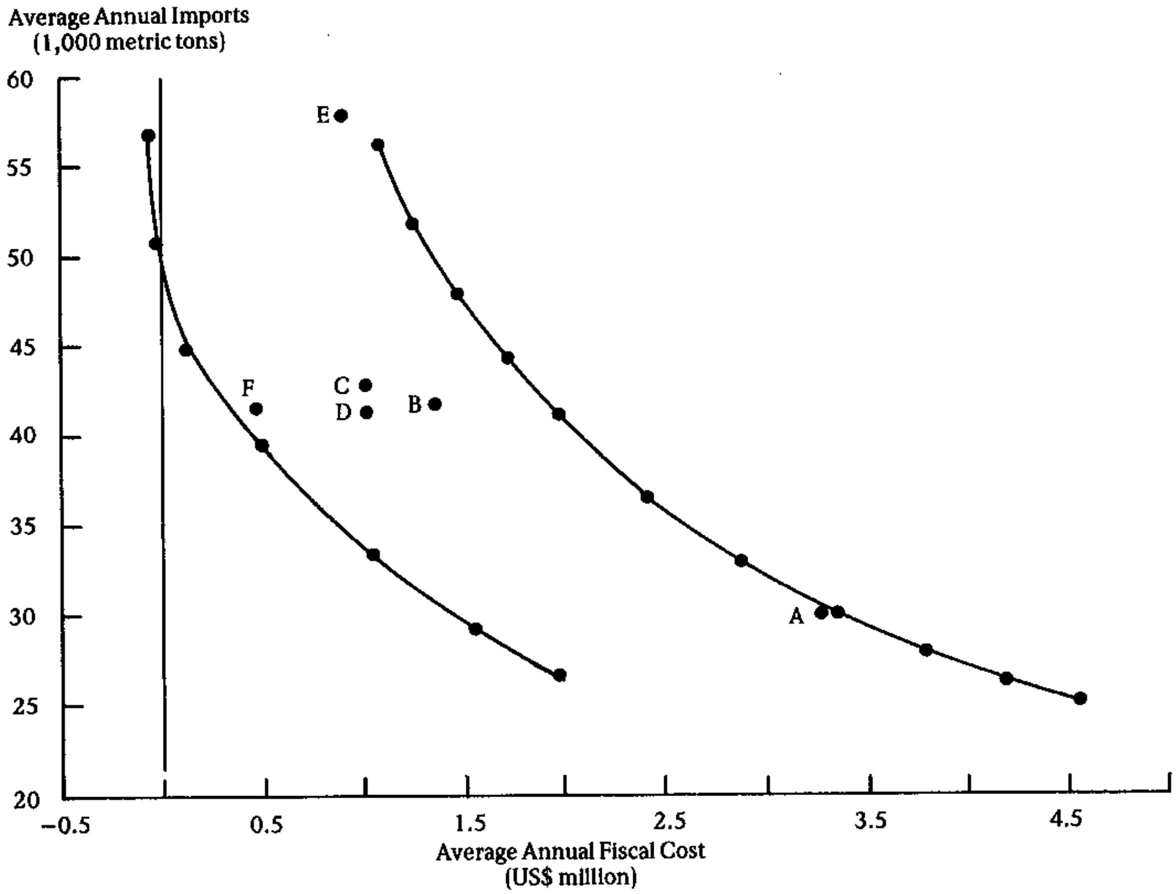
Notes: Policy A is a price band policy modified by the introduction of a flexible maximum stock level. Policy B is policy A modified by allowing half of the first 200,000 metric tons of available supply to be exported. Policy C is policy B modified by making net purchases sensitive to the world price. Policy D is policy C modified by making net purchases sensitive to opening stocks. Policy F is policy B modified by replacing the price band rule with a piecewise linear net purchases function.

import prices increase; this results from more of the imports taking place when world prices are high, since the maximum stock level is lower when world prices are high. The net result of these different factors is a gain of only about $80,000 annually. As the optimal policy achieves the same level of imports for $1.9 million less annually, this adjustment has made up only about 4 percent of the difference.

The next step on the exporting side is to allow the model to take advantage of the export premium that prevails when exports are small. The optimal policies examined in Chapter 5 suggest that a convenient rule of thumb might be to export one-half of the first 200,000 tons of available supply, then put the remainder in store until the maximum stock level is reached. This adjustment has a large payoff, as is evident in Table 15 and Figure 15 (the relevant point is labeled "B" in the figure).

This policy moves much closer to the optimal results, although a significant difference remains. The comparison with policy A is obscured somewhat by the large difference in import volumes, but one major change is that the additional exports in years

Figure 15—Moving toward the optimal: price band policy modifications



Notes: Policy A is a price band policy modified by the introduction of a flexible maximum stock level. Policy B is policy A modified by allowing half of the first 200,000 metric tons of available supply to be exported. Policy C is policy B modified by making net purchases sensitive to the world price. Policy D is policy C modified by making net purchases sensitive to opening stocks. Policy E is Policy D modified by making net purchases sensitive to production. Policy F is policy B modified by replacing the price band rule with a piecewise linear net purchases function.

of relatively low available supply keep export volumes from falling relative to the price band policy, as they did under policy A. Despite the gains made on the foreign trade side, however, a large difference remains between the foreign trade losses under policy B and the profits from trade under the optimal policies. Making the domestic market price sensitive to the world price is one way to close the gap.

Policy C attempts to accomplish that task. The domestic market continues to have a floor and ceiling price with a constant difference between them, but both maximum and minimum trigger prices move somewhat with world prices. This is accomplished in the model by taking the world price coefficient from the net purchases regression estimated above, multiplying it by the deviation of world price from $120.00 (the base world price), and adding the result to the production volume triggers (Q_{min} and Q_{max} as defined in equations (20) and (21) of Chapter 4). The resulting change in the price triggers is not particularly large; in policy C when world prices are at their base of

\$120.00, the lower price trigger is \$128.10, while the corresponding trigger for a world price of \$100.00 is \$126.20.[36]

Even these small changes, however, have significant results, with policy C more than 50 percent of the way from the price band scheme to the optimal policy. The major difference between policies B and C is in the price of imports and exports. Since lower volumes are sold domestically when world prices are high and domestic production is low, fewer imports are needed in those years, while relatively more is imported when world prices are low. A similar story can be told for the domestic purchases/export side. Thus, average import prices are about 5 percent lower and average export prices about 4 percent higher under policy C than under policy B.

Despite these gains, the optimal policy remains \$750,000 dollars cheaper on average. This results from a combination of higher domestic profits, lower storage charges, and a continued lead in foreign trade despite the substantial gains made. The last remaining way to make the policy more similar to the optimal policy while retaining maximum and minimum prices is to allow the triggers to vary with opening stock.

Policy D, then, makes this change. This is accomplished by multiplying the coefficient from the estimated regression by the deviation of the stock level from 100,000 tons, and adding the result to the volume triggers computed by policy C (Q_{min} and Q_{max}). As in the case of the world price adjustment, the changes in price are not large; an increase in the stock level from 100,000 to 200,000 tons increases the lower trigger from \$128.10 to \$129.90. Nevertheless, the results are significant if not dramatic, as shown in Table 15 and Figure 15.

Policy D is almost 60 percent of the way from the price band policy to the optimal policy. The change from policy C to D is somewhat different from the expected, however. Considerably lower profits are made domestically under policy D, while the cost of imports drops. The policy has adjusted by increasing domestic purchases when stocks are less than 100,000 tons. Since the greater number of years fall in this range, net domestic purchases have increased, displacing imports and raising the average domestic price slightly. Since domestic maize is cheaper on average than imported maize, this has resulted in some efficiency gains.[37]

Policy D is virtually identical to the optimal policy in the foreign trade account; the remaining differences between the policies are primarily in the domestic account. The next step in trying to approximate the optimal policy is to forgo the idea of minimum and maximum prices altogether. All elements of the regression estimated above have been entered into policy D except the smooth relation between net purchases and production. This is added in policy E.

The result is surprising, as the policy has a cost of \$920,000 and average imports of 57,700 tons.[38] As Figure 15 indicates, policy E is only marginally superior to the

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[36] Policies C and D must have a smaller maximum percentage deviation of price in order to achieve the same standard deviation of price. The standard price band scheme requires a percent limit of 9.37 percent to achieve a standard deviation of price of \$12.10; the percent limit for C is 8.86 percent, while the limit for D is 8.84 percent. The percent variability allowed must be adjusted because of the price flexibility that is added by the sensitivity of the triggers to opening stocks and world price.

[37] Policy D was also run using 80,000 rather than 100,000 tons in the computation of the trigger adjustment. The result was inferior to the one presented.

[38] The standard deviation of price that results from simulating the net purchases equation estimated above is \$13.00. In order to lower the price variability to \$21.10, an equation was estimated for an optimal policy with a lower price variability, and the coefficients were interpolated to yield the net purchases equation used for policy E. The interpolated equation is

$$NP_t = -1{,}855 + 0.49 \cdot WP_t + 0.80 \cdot Q_t - 0.091 \cdot S_t - 1.$$

price band policy. Despite the very high R^2 of the net purchases equation, the standard error of the estimate (16,000 tons) is large enough to cause the policy to be quite inefficient.

Figures 11 through 13 suggest that a more appropriate way to model the optimal net purchases function would be to use three linear segments: first, for production greater than or equal to normal; second, for production less than normal but with the shortfall less than the opening stock level; and third, for production plus opening stocks less than normal production. The following regressions, estimated from the standard optimal policy with price weight of 17 and import weight of 60, indicate that this is a fruitful way to proceed:

$$Q_t \geq 2250, \tag{27}$$

$$NP_t = \underset{(7.4)}{-1{,}937.3} + \underset{(0.0150)}{0.6121} \cdot WP_t + \underset{(0.0030)}{0.8219} \cdot Q_t - \underset{(0.0028)}{0.05317} \cdot S_{t-1};$$

$N = 750$, $R^2 = 0.994$, $SEE = 9.44$.

$$Q_t < 2250 \text{ and } Q_t + S_{t-1} \geq 2250, \tag{28}$$

$$NP_t = \underset{(16.3)}{-1{,}916.7} + \underset{(0.0194)}{0.5098} \cdot WP_t + \underset{(0.0074)}{0.8201} \cdot Q_t - \underset{(0.0047)}{0.07441} \cdot S_{t-1};$$

$N = 280$, $R^2 = 0.990$, $SEE = 7.25$.

$$Q_t + S_{t-1} < 2250, \tag{29}$$

$$NP_t = \underset{(17.8)}{-1{,}925.6} + \underset{(0.0345)}{0.3207} \cdot WP_t + \underset{(0.0084)}{0.8550} \cdot Q_t - \underset{(0.0118)}{0.08770} \cdot S_{t-1};$$

$N = 320$, $R^2 = 0.989$, $SEE = 12.92$.

Standard errors are in parentheses.

All of the coefficients are significantly different from the corresponding coefficients in the other two equations except the coefficients of production in equations (27) and (28). More important for the purposes at hand, all of the standard errors are considerably less than the standard error of 15.98 for the original equation (25). The standard error of 7.25 for equation (28) is about as small as could be expected when the original data are constrained to multiples of 20.

The results of simulating a policy with net purchases defined by a piecewise linear function are exceptionally close to the optimal policy, as shown in Table 15 and Figure 15.[39] The primary difference between policy D and the optimal policy is on the export

[39] As in the case of the linear net purchases equation, the standard deviation of price is higher than \$12.10 when the equations given in the text are simulated. Consequently, the same equations were estimated for an optimal policy with a lower level of price variability and the coefficients interpolated to yield the following three equations, which produce the results in Table 15:

$Q_t > 2{,}250$:	$-1{,}954.7 + 0.5796 \cdot WP_t + 0.8317 \cdot Q_t - 0.0506 \cdot S_t - 1$,
$2{,}250 - S_t - 1 < Q_t < 2{,}250$:	$-1{,}932.0 + 0.4844 \cdot WP_t + 0.8287 \cdot Q_t - 0.0714 \cdot S_t - 1$,
$Q_t < 2{,}250 - S_t - 1$:	$-1{,}940.3 + 0.3095 \cdot WP_t + 0.8618 \cdot Q_t - 0.0824 \cdot S_t - 1$.

side. This is most likely the result of always exporting 100,000 of the first 200,000 tons of available supply; Figures 13 and 14 indicate that the slope and placement of that first segment are somewhat sensitive to world price, as would be anticipated. Nevertheless, the modeled policy is very close. Since the standard deviation of cost is almost $3 million, policy F would be indistinguishable from the optimal policy in practice.

Summary of Major Results

The price band schemes generally underestimate the cost of decreasing price variability, since these schemes become relatively more efficient with decreasing price variability.

The cost of decreasing annual average imports by 1,000 tons ranges from $27,000 to almost $170,000 annually; the cost increases with decreases in price variability and average imports. The higher the weight on price variability, the less flexibility is allowed the optimizing algorithm in adjusting consumption to match production. Thus as price variability declines, the optimal policies are forced to hold more stocks in order to decrease imports, rather than allowing consumption to fall when production is low. This leads to a higher trade-off between imports and cost.

The cost of decreasing the standard deviation of price by $1.00 per ton ranges from $330,000 to $630,000 annually. This cost also increases with decreases in price variability and average imports.

It is possible to make up about 60 percent of the difference between the price band and optimal policies while retaining the maximum and minimum triggers of a price band scheme. The larger share of the remaining difference can be made up by making net purchases a piecewise linear function of production, world price, and opening stocks.

7

CONCLUSIONS AND POLICY IMPLICATIONS

At this point, the trade-offs between different government objectives have been measured, and the optimal policies have been compared and contrasted with the price band policies. The previous chapters show that there is considerable room for improvement upon the simple price band policies considered earlier by the Inter-Ministerial Working Group and that a relatively simple policy is virtually as efficient as the optimal policy. This chapter examines the implications, first, for policy analysis in general, and second, for policymakers in Kenya.

Implications for Policy Analysis

Four benefits of optimization are outlined in Chapter 3: the screening of many policy alternatives, the accurate measurement of trade-offs between objectives, the measurement of the degree of suboptimality of alternative policies, and the opportunity to learn from the optimal policy. The major methodological question addressed by this study is whether or not these benefits of optimization outweigh the considerable costs of the optimization process. Given the nature of the results, the answer is undoubtedly yes. The major objective of the study was to measure trade-offs; as shown in Chapter 6, the simulated price band policies do not measure accurately the trade-off between cost and price stability, or between cost and imports. So for that reason alone, the optimization process has been necessary and worthwhile.

The gains from optimization were not limited to the measurement of trade-offs, however. The optimization process screened out the infinitely many possible shapes of the net purchases function and suggested its formulation as a piecewise linear curve with three segments. The degree of suboptimality of the price band policies was seen to be large, and therefore these policies were modified based on insights provided by the optimal policy. Since policy F—the policy with a piecewise net purchases function, flexible maximum stock level, and exports of 100,000 tons of the first 200,000 tons of available supply—was only slightly suboptimal, no further modifications were made. Without having the goal of the optimal trade-off curve in mind, there would have been no way of knowing whether or not policies that are far superior to policy F exist.

The optimal policies themselves challenge some of the common assumptions about maize policy in Kenya. For example, most economists, including the author of this study, thought that carry-out stocks in 1982 and 1983 were too high and the government should have exported in those years. If the minimum stock level kept on hand as a cushion for the arrangement of imports is considered to be 300,000 tons, then carry-out (used in the sense of this study, total stock minus the import cushion) during 1982 and 1983 was about 350,000 tons. The model shows that these amounts were not excessive given some reasonable combinations of objective function weights and 1982/83 world prices and production levels, particularly with the 12 percent production variability assumption.

Thus optimization yields many insights into the problem and possible solutions, and was undoubtedly a profitable way to proceed given the objectives and constraints of the study. But this analysis was conducted in a research environment. The situation of a Third World government economist who needs to complete a report within a month if it is to affect the decisionmaking process is quite different; optimization may be impossible in such circumstances. The following lessons are proposed.

If the structure of the model used here is fairly similar to the structure of the market in the country of interest, it would be possible to accept a policy like policy F as a proxy for an optimal policy and simulate that policy across a large number of different parameters to approximate an optimal outcome. Trade-offs could be measured by this curve, and other policies compared to it for sub-"optimality".

On the other hand, there could be circumstances in which the basic structure of the policy has already been decided. In such circumstances, optimization may not be necessary. For example, if the price band policy studied by the Inter-Ministerial Working Group had been accepted as a strategy, the trade-offs measured by the price band curves would have been the relevant numbers for the government. Because there are only two parameters to vary with these policies, it is quite easy to find the best policy of this type without optimization. More complex policies that require several parameters for a complete definition will be less amenable to finding the best choice through simulation. For sufficiently complex policies, some optimization, perhaps of a subset of the problem, may be necessary.

Optimization was useful to this study even though the specific policies that were produced by the optimization process are not recommended. This point has been made elsewhere: "Formal and simplified optimization can provide a number of useful starting points for a process of policy design and dialogue. In no sense does it guarantee an optimal or even adequate policy" (Clark, Jones, and Holling 1979, 32). Utility functions of decisionmakers are always more complex than those that become the objective functions of optimization models; in addition, the process of reforming public policy always involves a set of compromises among officials with different utility functions. No optimization model can possibly deal completely with such complex situations. Nevertheless, as an aid to policy design, as a screening method across policy alternatives, as a reference point for other policies, and as a measuring device for trade-offs, the dynamic programming analysis has been invaluable.

Implications for Policy

For Kenyan decisionmakers, the key results that come out of this study are the high savings associated with increased price flexibility. At the lowest end of price stability measured here, each dollar increase in the standard deviation of price saves $400,000-$600,000 annually. This implies that a policy that has a standard deviation of price of 5 percent of the target price would be at least $3.5 million and probably closer to $6 million less in annual average cost than a policy that succeeded in holding prices constant.[40] These figures represent between one-tenth and one-fifth of the annual development budget of Kenya's Ministry of Agriculture. Given these high costs, it is not surprising that the NCPB has failed to implement the stated policy of keeping prices constant.

As demonstrated in Chapter 2, under present policies there is de facto price flexibility. This is the result of the large costs associated with implementing the stated

[40] Since the cost per unit decrease in price variability would continue to increase as price variability decreased, the numbers given in the text for average annual cost are slightly higher than the trade-offs found in the table.

policy of constant prices. If this existing price instability were acknowledged and built into the system, the price instability could be spread out over a larger population, causing less stress on any one group. In addition, an explicit decision could be made by senior officials about the trade-off between cost and price stability rather than forcing parastatal officials to make the decision based on their own fiscal constraints.

Both policy D and policy F described in Chapter 6 appear to be large improvements over the present policy and the type of price band schemes previously analyzed. The main elements of these policies are flexibility to world price, opening stocks, and production. Both policies make closing stocks sensitive to world price, and allow some exports if a white maize premium is available. In addition, both policies allow domestic net purchases—and thus the domestic price—to vary with the world price and opening stocks of the marketing board. The main difference between the two policies is that policy F allows the domestic price to vary somewhat with domestic production.[41]

This final adjustment saves a large amount of money, but would require more radical adjustments to present policy. Questions about implementation of these types of policies are addressed in the following section.

Considerations for Implementation

Implementation issues will be considered, first, for the foreign trade/domestic stock rules, which are the same for policies D and F; second, for a domestic price policy that is flexible with respect to opening stocks and world prices; and finally, for a domestic price policy that adjusts for unanticipated changes in domestic production.

Foreign Trade and Domestic Storage Policy

The export rules considered above—varying the maximum stock level inversely with the world price, and exporting one-half of the reserve stock if significant white maize premiums are available—would be easy to implement. The results in Chapter 5 clearly show that this type of export rule dominates rules in which exports are triggered by stocks alone. Since the policy can be set up so that on average the same amount of maize is imported as under any particular storage trigger policy, this aspect of the policy modification can be made invisible on average to consumers and producers.

The maximum stock level, however, should also be dependent on the government's relative preferences for low imports, low price variability, and low fiscal costs. If the government's desire to minimize imports were to decline, the correct maximum stock level would decline also. The relationship between maximum stock level and world price that was estimated in Chapter 6 was appropriate for a policy that allows price to vary plus or minus about 9 percent from the target price (price variability of $12.10) and that yields average imports of about 45,000 tons. A somewhat different relationship would hold with smaller or larger price bands, or with a different preference for imports. These different relationships could be estimated from the appropriate optimal policy.

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[41] The implied elasticity of domestic price for domestic production in policy F is about −0.6, implying that a 20 percent shortfall in production would lead to a 12 percent increase in the official price. This elasticity, however, is a function of the government's assumed preference for price stability. The elasticity would be lower if the preference for price stability were assumed to be higher.

Price Policy Responsive to Opening Stocks and World Price

At present, official producer prices for the harvest are announced before planting time, and official consumer prices are announced for the next 12 months about 1 month before the first maize is harvested. Clearly, any move toward flexible official prices would change this procedure considerably.

The type of modifications discussed here, however, could be implemented with relatively minor modifications to the present policy. It is shown in Chapter 5 that the degree to which domestic prices respond to world price and opening stocks in policy D is not large. Thus it would be possible to announce a floor price at planting time based on an optimistic prediction about end-year stocks and a pessimistic prediction of the world price at harvest time. These predictions should be sufficiently optimistic/pessimistic so that it is unlikely that actual stocks and world prices would be respectively higher or lower than the predicted value. Thus the announced floor price would be the lowest possible optimal domestic price.

At the time of announcement, the public could be informed that the government buying price is expected to be higher than the floor price. The government might find it in its interest to announce an expected price or a maximum price or both simultaneously with the floor price. The announcement could include indications of how sensitive the price would be to changes in the world price and government stocks. The expected buying price—based on the expected values of the two key variables—could be published in the local press regularly. A similar procedure could be followed for the government selling price.

Before the buying season begins, the government would make a final announcement; all maize bought during that marketing year would be at the set price. During the year, farmers would have the option of selling to the NCPB at the floor price or selling to traders; millers would have the option of buying from the board at the government selling price or buying directly from farmers or traders.

For the farmer the most significant change resulting from such a policy would be the possibility of adjustments in official prices after the crop has been planted. But given the fairly small sensitivity of domestic price to world price and opening stocks measured in the previous chapters, the required adjustments would not be large. There would have to be large, unanticipated movements in world prices and domestic stocks for the required price change to be as large as 10 percent. The possibility of such a price change is much less than many farmers experience under the present system with the possibility of waiting many months to receive payment, or not being able to sell to the board at all.

For the urban consumer, the presence of a price band would imply that there would be some change in price during the year, with lower prices at harvest time and higher prices before harvest in most years.[42] The extent of these changes would be determined by the width of the price band.

Price Policy Responsive to Domestic Production

The domestic price could be made sensitive to domestic production in a similar fashion. Theoretically, the policy adjustment is simple: before planting time, calculate

[42] The price rise would result not from changes in official prices, but from storage costs incurred by the private sector. Such price rises would occur only in years during which the price is between the NCPB floor and ceiling during some months. There would be no seasonal price rise during a poor crop year in which the NCPB's ceiling price was effective at harvest time and remained effective throughout the year.

the floor price after taking into account an optimistic estimate of production. The final price would be determined by the actual production level.

Production estimates, however, are subjective, unreliable (as discussed in Chapter 4), and unavailable until after most of the crop has been purchased. In addition, the buying season in Kenya is spread out over about six months, with purchases in the west beginning long before the large purchases from the Rift Valley. A price policy that depends on subjective estimates of production several months before the major harvest would be subject to large errors. Given these problems, implementation of a policy such as this one probably could be done most efficiently by a series of tender offers.[43]

A tender procedure for implementing such a policy might look like the following. Suppose it is August. The harvest is beginning in the west, and total annual production is predicted to be about 200,000 tons above trend. Given this production estimate and the present stock level and world price, suppose that the chosen strategy calls for a price of $125 per ton and net purchases of 100,000 tons for the year. The NCPB could advertise a tender offer to buy, say, a total of 10,000 tons for delivery in September in appropriately sized lots, and ask for bids. The bidding process would give the board additional feedback on prices and production, and this information would be used when deciding how much to offer to buy in October. Similar offers could be made in each of the months of the buying season.

Such a procedure may be workable, but the mechanism would be considerably more complicated and management-intensive than setting floor and ceiling prices. The cost savings that result from making the domestic price sensitive to production are about $600,000 in average annual cost. Whether or not the benefits of cost savings outweigh the increased complexity of implementation and administration is a political judgment.

Conclusions

This study has measured trade-offs between government objectives and has given indications of how the efficient policies that result from the model might be implemented. The three major trade-offs are between cost and price stability, between cost and imports, and between cost and complexity. The next step in policy reform is political; deciding how important each of the goals—price stability, low imports, low fiscal cost, low complexity of policy—is relative to the others.

A general strategy for pricing, stockholding, and foreign trading would be determined through the political choice of a strategy that yields a feasible combination of the objectives. Before the strategy is implemented, however, it would be desirable to study the tactical decisions of how the policy would be implemented within the seasonal and regional framework of the real world. For deciding on the broad approach the country wishes to pursue, a model that includes regions of the country and seasons of the year would have obscured rather than clarified the issues. For choosing the exact specification of the policy once a broad approach has been decided upon, however, a quarterly or monthly management model that includes four or five regions could be quite helpful. The purpose of the management model would be to determine the best way to achieve the annual values of the variables recommended by the accepted strategy. Thus, the model would only need to be 12 or 18 months long. Although the paucity of data would mean that heroic assumptions would have to be made about some of

[43] An alternative might be to base the decision on an objective measure, such as rainfall at particular stations.

the parameters, considerable insight could be gained into the best methods for implementing the chosen policy in the real world.

The study, then, has outlined the economic costs and benefits of some major choices available to the Kenyan government and has sketched the analytical steps that follow from acceptance of a specific strategy. Much can be gained in terms of lower cost and lower imports by allowing prices to reflect domestic production, world price, and domestic stock levels. The types of policies outlined here would be considerably more efficient at increasing price flexibility than the simple price band/buffer stock policy that was simulated by the Inter-Ministerial Working Group.

APPENDIX 1: SUPPLEMENTARY TABLES

Table 16—Price band results for demand elasticity equal −0.2

(1)	(2)	(3)	(4)	(5)	(6)	(7)	Components of Fiscal Cost (8)	(9)	(10)	(11)
Price Band	Stock Varia-bility	Standard Deviation of Price	Imports	Average Annual Fiscal Cost	Standard Deviation of Cost	Average Stock Level	Replace Stock Charges	Storage Costs	Domestic Trading Losses	Foreign Trading Losses
(percent)	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
4.75	0	6.5	72.5	3.41	3.35	0	0.86	0.00	−0.08	2.62
4.75	100	6.5	54.5	3.90	3.49	51	0.43	1.36	−0.08	2.21
4.75	200	6.5	43.6	4.60	3.78	103	−0.03	2.59	−0.08	2.12
4.75	300	6.5	37.1	5.47	4.24	153	−0.47	3.71	−0.08	2.29
4.75	400	6.5	33.1	6.28	4.76	201	−0.88	4.67	−0.08	2.58
6.75	0	9.1	68.7	2.65	3.25	0	0.86	0.00	−0.48	2.26
6.75	100	9.1	51.4	3.23	3.39	51	0.43	1.37	−0.48	1.92
6.75	200	9.1	41.0	3.98	3.71	103	−0.03	2.59	−0.48	1.89
6.75	300	9.1	34.9	4.87	4.18	153	−0.45	3.71	−0.48	2.09
6.75	400	9.1	31.2	5.70	4.72	200	−0.86	4.63	−0.48	2.41
9.20	0	12.2	64.3	1.78	3.13	0	0.86	0.00	−0.92	1.84
9.20	100	12.2	47.7	2.47	3.30	51	0.43	1.38	−0.92	1.60
9.20	200	12.2	38.0	3.27	3.65	103	−0.03	2.59	−0.92	1.62
9.20	300	12.2	32.3	4.18	4.14	152	−0.45	3.69	−0.92	1.86
9.20	400	12.2	29.0	5.00	4.68	199	−0.86	4.58	−0.92	2.21
13.10	0	17.0	57.8	0.57	2.94	0	0.86	0.00	−1.54	1.25
13.10	100	17.0	42.3	1.44	3.17	51	0.43	1.40	−1.54	1.16
13.10	200	17.0	33.7	2.30	3.55	102	−0.01	2.59	−1.54	1.26
13.10	300	17.0	28.7	3.21	4.09	151	−0.44	3.63	−1.54	1.57
13.10	400	17.0	25.9	4.02	4.66	197	−0.84	4.47	−1.54	1.93

Table 17—Price band results for production variability equal 12 percent

							Components of Fiscal Cost			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Price Band	Stock Varia-bility	Standard Deviation of Price	Imports	Average Annual Fiscal Cost	Standard Deviation of Cost	Average Stock Level	Replace Stock Charges	Storage Costs	Domestic Trading Losses	Foreign Trading Losses
(percent)	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
5.10	0	6.9	84.0	3.71	4.05	0	0.86	0.00	−0.23	3.06
5.10	100	6.9	66.0	4.23	4.16	51	0.43	1.36	−0.23	2.67
5.10	200	6.9	54.3	4.91	4.46	103	−0.03	2.58	−0.23	2.57
5.10	300	6.9	46.7	5.72	4.86	153	−0.47	3.74	−0.23	2.67
5.10	400	6.9	41.8	6.56	5.36	202	−0.89	4.75	−0.23	2.93
5.10	450	6.9	40.1	6.95	5.62	226	−1.09	5.19	−0.23	3.07
5.10	500	6.9	38.8	7.33	5.88	249	−1.29	5.60	−0.23	3.25
6.80	0	9.1	79.5	2.86	3.90	0	0.86	0.00	−0.67	2.65
6.80	100	9.1	62.1	3.47	4.06	51	0.43	1.36	−0.67	2.36
6.80	200	9.1	51.0	4.20	4.36	103	−0.03	2.58	−0.67	2.30
6.80	300	9.1	44.0	5.04	4.79	152	−0.45	3.71	−0.67	2.45
6.80	400	9.1	39.5	5.87	5.30	201	−0.88	4.70	−0.67	2.73
9.55	0	12.5	72.4	1.62	3.71	0	0.86	0.00	−1.24	2.00
9.55	100	12.5	56.1	2.41	3.90	51	0.43	1.37	−1.24	1.84
9.55	200	12.5	46.0	3.19	4.24	102	−0.03	2.58	−1.24	1.86
9.55	300	12.5	39.7	4.07	4.70	151	−0.45	3.69	−1.24	2.08
9.55	400	12.5	35.7	4.90	5.23	199	−0.86	4.60	−1.24	2.38
12.82	0	16.4	64.7	0.36	3.50	0	0.86	0.00	−1.80	1.28
12.82	100	16.4	49.6	1.30	3.75	51	0.43	1.40	−1.80	1.28
12.82	200	16.4	40.6	2.17	4.14	101	−0.01	2.57	−1.80	1.40
12.82	300	16.4	35.1	3.09	4.64	150	−0.44	3.63	−1.80	1.68
12.82	400	16.4	31.7	3.90	5.19	196	−0.84	4.51	−1.80	2.02

Table 18—Optimal policy results for demand elasticity equal −0.2

(1) Price Stability Weight	(2) Import Weight	(3) Standard Deviation of Price	(4) Imports	(5) Average Annual Fiscal Cost	(6) Standard Deviation of Cost	(7) Average Stock Level	Components of Fiscal Cost: (8) Replace Stock Charges	(9) Storage Costs	(10) Domestic Trading Losses	(11) Foreign Trading Losses
		(US$/metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
33.0	92	6.5	49.6	3.14	3.58	94	0.05	2.20	−0.32	1.21
35.9	138	6.5	43.5	3.73	3.90	121	−0.18	2.89	−0.03	1.05
39.4	184	6.5	39.1	4.28	4.15	146	−0.40	3.42	0.18	1.08
43.1	230	6.5	36.0	4.78	4.36	170	−0.60	3.85	0.40	1.13
47.2	276	6.5	33.6	5.31	4.68	188	−0.76	4.29	0.55	1.23
21.7	69	9.1	50.5	2.07	3.21	74	0.23	1.74	−0.86	0.96
22.8	115	9.1	43.7	2.57	3.54	103	−0.03	2.45	−0.61	0.76
24.9	161	9.1	38.2	3.21	3.89	129	−0.25	3.10	−0.36	0.72
27.1	207	9.1	35.7	3.59	4.12	146	−0.40	3.43	−0.12	0.68
29.3	253	9.1	32.6	4.14	4.34	170	−0.61	3.89	0.20	0.67
14.1	46	12.2	52.7	0.84	2.79	52	0.42	1.28	−1.77	0.91
15.6	92	12.2	45.4	1.24	3.14	78	0.19	1.86	−1.28	0.45
16.9	138	12.2	39.0	1.80	3.47	104	−0.04	2.48	−0.84	0.19
18.2	184	12.2	34.3	2.41	3.82	129	−0.25	3.08	−0.56	0.15
19.6	230	12.2	31.1	2.95	4.07	149	−0.43	3.50	−0.25	0.13
8.8	33	17.0	51.4	−0.64	2.41	39	0.53	0.96	−2.94	0.81
9.8	79	17.0	42.8	−0.24	2.82	61	0.33	1.51	−2.08	−0.02
10.7	126	17.0	36.9	0.25	3.11	86	0.12	2.06	−1.58	−0.35
11.8	172	17.0	31.8	0.86	3.46	110	−0.08	2.61	−1.07	−0.58
12.6	219	17.0	28.6	1.37	3.76	128	−0.24	3.04	−0.77	−0.65

Table 19—Optimal policy results for production instability equal 12 percent

(1) Price Stability Weight	(2) Import Weight	(3) Standard Deviation of Price	(4) Imports	(5) Average Annual Fiscal Cost	(6) Standard Deviation of Cost	(7) Average Stock Level	Components of Fiscal Cost: (8) Replace Stock Charges	(9) Storage Costs	(10) Domestic Trading Losses	(11) Foreign Trading Losses
		(US$/metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
42.5	99	6.9	57.3	3.34	4.26	106	−0.05	2.46	−0.31	1.24
47.2	146	6.9	51.0	3.90	4.62	133	−0.29	3.10	0.05	1.04
52.3	193	6.9	45.8	4.54	4.94	158	−0.50	3.70	0.41	0.93
56.9	240	6.9	42.5	5.04	5.19	180	−0.69	4.14	0.73	0.88
62.0	287	6.9	39.5	5.68	5.42	200	−0.86	4.62	1.00	0.93
30.2	92	9.1	56.0	2.24	4.01	92	0.07	2.18	−0.74	0.73
33.2	138	9.1	48.8	2.87	4.35	123	−0.20	2.87	−0.32	0.51
36.5	184	9.1	43.6	3.49	4.68	145	−0.40	3.43	0.07	0.37
40.0	230	9.1	40.3	4.01	4.98	164	−0.55	3.85	0.49	0.23
43.6	276	9.1	37.3	4.52	5.23	182	−0.71	4.26	0.80	0.17
18.9	69	12.5	55.2	0.63	3.47	72	0.24	1.72	−1.93	0.59
21.4	115	12.5	48.5	1.10	3.83	92	0.07	2.22	−1.20	0.00
23.9	161	12.5	42.6	1.71	4.21	119	0.07	2.77	−0.48	−0.41
25.8	207	12.5	38.2	2.28	4.54	139	−0.34	3.27	−0.02	−0.62
28.2	253	12.5	34.8	2.82	4.84	156	−0.48	3.67	0.42	−0.80
12.0	40	16.4	56.8	−1.09	2.82	45	0.48	1.13	−3.37	0.67
13.4	80	16.4	49.5	−0.77	3.23	63	0.32	1.53	−2.44	−0.19
15.1	120	16.4	43.7	−0.37	3.62	80	0.17	1.94	−1.60	−0.87
16.5	160	16.4	38.9	0.16	3.91	100	0.00	2.37	−0.96	−1.25
17.8	200	16.4	34.4	0.71	4.17	116	−0.14	2.80	−0.51	−1.43

Table 20—Price band results for comparison with optimal

(1)	(2)	(3)	(4)	(5)	(6)	(7)	Components of Fiscal Cost			
							(8)	(9)	(10)	(11)
Price Band	Stock Variability	Standard Deviation of Price	Imports	Average Annual Fiscal Cost	Standard Deviation of Cost	Average Stock Level	Replace Stock Charges	Storage Costs	Domestic Trading Losses	Foreign Trading Losses
(percent)	(1,000 metric tons)	(US$/ metric ton)	(1,000 metric tons)	(US$ million)		(1,000 metric tons)	(US$ million)			
4.88	0	6.6	67.9	2.94	3.24	0	0.87	0.00	−0.15	2.22
4.88	25	6.6	62.9	3.04	3.24	13	0.76	0.34	−0.15	2.09
4.88	50	6.6	58.4	3.17	3.27	26	0.65	0.68	−0.15	2.00
4.88	75	6.6	54.3	3.34	3.31	38	0.53	1.03	−0.15	1.94
4.88	100	6.6	50.7	3.54	3.38	51	0.42	1.37	−0.15	1.90
4.88	150	6.6	44.9	3.89	3.51	77	0.20	1.99	−0.15	1.86
4.88	200	6.6	40.5	4.30	3.70	103	−0.02	2.59	−0.15	1.88
4.88	250	6.6	37.1	4.73	3.92	127	−0.24	3.16	−0.15	1.96
4.88	300	6.6	34.5	5.18	4.17	152	−0.45	3.69	−0.15	2.09
4.88	350	6.6	32.5	5.60	4.43	176	−0.66	4.17	−0.15	2.24
4.88	400	6.6	30.9	6.00	4.71	199	−0.86	4.60	−0.15	2.41
6.80	0	9.0	62.7	2.09	3.09	0	0.87	0.00	−0.51	1.73
6.80	25	9.0	57.9	2.23	3.10	13	0.76	0.34	−0.51	1.63
6.80	50	9.0	53.6	2.40	3.13	26	0.65	0.69	−0.51	1.57
6.80	75	9.0	49.8	2.60	3.19	38	0.54	1.04	−0.51	1.54
6.80	100	9.0	46.4	2.83	3.26	51	0.42	1.38	−0.51	1.53
6.80	150	9.0	41.1	3.21	3.41	77	0.20	1.99	−0.51	1.52
6.80	200	9.0	37.0	3.64	3.61	102	−0.02	2.59	−0.51	1.58
6.80	250	9.0	33.9	4.09	3.85	127	−0.23	3.15	−0.51	1.68
6.80	300	9.0	31.5	4.54	4.11	151	−0.44	3.66	−0.51	1.83
6.80	350	9.0	29.7	4.95	4.38	175	−0.65	4.12	−0.51	1.99
6.80	400	9.0	28.4	5.35	4.66	198	−0.85	4.54	−0.51	2.18
9.37	0	12.1	56.3	1.10	2.90	0	0.87	0.00	−0.92	1.14
9.37	25	12.1	51.8	1.28	2.93	13	0.76	0.35	−0.92	1.08
9.37	50	12.1	47.8	1.50	2.97	25	0.65	0.70	−0.92	1.06
9.37	75	12.1	44.3	1.74	3.04	38	0.54	1.05	−0.92	1.07
9.37	100	12.1	44.1	2.00	3.12	51	0.42	1.40	−0.92	1.09
9.37	150	12.1	36.4	2.41	3.29	77	0.20	2.00	−0.92	1.13
9.37	200	12.1	32.8	2.87	3.52	101	−0.01	2.58	−0.92	1.22
9.37	250	12.1	30.0	3.35	3.77	126	−0.23	3.13	−0.92	1.36
9.37	300	12.1	27.9	3.79	4.04	150	−0.43	3.61	−0.92	1.53
9.37	350	12.1	26.4	4.20	4.33	173	−0.63	4.04	−0.92	1.71
9.37	400	12.1	25.3	4.58	4.63	196	−0.83	4.44	−0.92	1.90
13.10	0	16.4	48.0	−0.10	2.67	0	0.87	0.00	−1.38	0.42
13.10	25	16.4	44.0	0.14	2.71	13	0.76	0.36	−1.38	0.41
13.10	50	16.4	40.4	0.42	2.78	26	0.65	0.71	−1.38	0.44
13.10	75	16.4	37.2	0.71	2.87	38	0.53	1.07	−1.38	0.49
13.10	100	16.4	34.4	1.02	2.97	51	0.42	1.42	−1.38	0.56
13.10	150	16.4	30.4	1.49	3.18	76	0.21	2.01	−1.38	0.65
13.10	200	16.4	27.4	1.99	3.43	100	−0.00	2.58	−1.38	0.80
13.10	250	16.4	25.1	2.46	3.71	124	−0.21	3.08	−1.38	0.98
13.10	300	16.4	23.5	2.90	4.00	147	−0.41	3.53	−1.38	1.16
13.10	350	16.4	22.3	3.30	4.29	170	−0.61	3.93	−1.38	1.36
13.10	400	16.4	21.6	3.65	4.60	191	−0.79	4.27	−1.38	1.56

Table 21—Trade-offs with price elasticity equal −0.2

Trade-off	Standard Deviation of Price 17.0	12.2	9.1	6.5
	(US$1,000/year)			
Cost per 1,000-metric-ton decrease in average annual imports				
As imports decline from 44,000 to 34,000 metric tons				
Price bands	93	100	130	152
Optimal policies	90	110	134	153
Cost per US$ decrease in standard deviation of price				
When average annual imports equal 44,000 metric tons				
Price bands	...	299	317	314
Optimal policies	...	345	385	435
When average annual imports equal 34,000 metric tons				
Price bands	...	341	375	395
Optimal policies	...	387	463	506

Table 22—Trade-offs with production variability equal 12 percent

Trade-off	Standard Deviation of Price 16.4	12.5	9.1	6.9
	(US$1,000/year)			
Cost per 1,000-metric-ton decrease in average annual imports				
As imports decline from 50,000 to 40,000 metric tons				
Price bands	98	116	146	161
Optimal policies	84	105	129	142
Cost per US$ decrease in standard deviation of price				
When average annual imports equal 50,000 metric tons				
Price bands	...	409	424	478
Optimal policies	...	459	522	571
When average annual imports equal 40,000 metric tons				
Price bands	...	451	515	544
Optimal policies	...	514	593	687

APPENDIX 2: PSEUDOCODES FOR PRICE BAND AND OPTIMIZATION PROGRAMS

Pseudocode for price band simulation program

```
Compute Q_max and Q_min
Loop for number of cycles
t = 0, S_0 = 100
Loop for number of years in cycle
    Random selection of WP_t and Q_t
    If Q_t < Q_min then
        NP_t = Q_t - Q_min
    Else
        If Q_t > Q_max then
            NP_t = Q_t - Q_max
        Else
            NP_t = 0
        Endif
    Endif
    S_t = S_t-1 + NP_t
    If S_t < 0 then
        M_t = -S_t
        S_t = 0
    Else
        If S_t > S_max then
            X_t = S_t - S_max
            S_t = 0
        Else
            X_t = 0
            M_t = 0
        Endif
    Endif
    Compute all costs
    If t = 10 then
        Add replace stock charges
        Add all costs to summary variables
    Endif
Next year in cycle
Next cycle
Produce printout
```

Pseudocode for optimization program

```
*First section computes cost-to-go in final year
Loop for each possible state of the world (WP, Q, S)
GC_min = a very large number
Loop for each possible combination of control variables (NP, X, M)
    If this is realistic control combination for this state, then
        Compute GC for this state and control
        If GC < GC_min then
            GC_min = GC
        Endif
    Endif
Next control
Next state
*Next section does the backward recursion
Loop for each year, beginning with final year
Compute E(GC_t+1 | S_t); that is, the expected costs in future years of carrying out
    S_t in the present year

    This equals the sum of GC_min for each particular stock level, the GC_min's being
    weighted by the probability of that production level and world price occurring.

Loop for each possible state of the world
    GC_min = a very large number
    Loop for each possible combination of control variables
        If this is a realistic control for this state, then
            Compute GC for this state and control
            If GC + E(GC_t+1 | S_t) < GC_min then
                GC_min = GC + E(GC_t+1 | S_t)
            Endif
        Endif
    Next control
Next state
Next year
*Next section does simulation of optimal policy
Loop for number of cycles
t = 0, S_0 = 100
Loop for number of years in cycle
    Random selection of WP_t and Q_t
    Interpolation of optimal policy to compute proper values of
        NP_t, X_t, and M_t given WP_t, Q_t, and S_t-1
    Compute all costs
```

```
    If t = 10 then
        Add replace stock charges
        Add all costs to summary variables
    Endif
Next year in cycle
Next cycle
Produce printout
```

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